final report

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Design, measurement and verification of abattoir wastewater emissions reduction and biogas capture to offset Natural Gas/Coal consumption

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Executive Summary

On 1 July 2012, a carbon pricing scheme (CPM) was introduced in Australia under which large carbon emitters were penalised on Scope 1 emissions above a threshold of 25,000 tonnes CO_2e per year. At the same time, carbon emitters were able to access capital grants to invest in clean technologies under the Federal Government's Clean Technology Investment Program (CTIP).

A number of large meat processing facilities in Australia exceeded the 25,000 tonnes CO_2e per year emissions threshold. This project investigated the suitability of Covered Anaerobic Lagoons (CALs) for use in abattoirs and the challenges and benefits of using the biogas generated by the CALs for steam/heat generation. Use of the biogas displaced fossil fuels such as coal and natural gas (NG) and dramatically reduced CO_2e emissions associated with waste water treatment and steam/heat generation. Meat & Livestock Australia (MLA) and the Australian Meat Processor Corporation (AMPC) partnered with Teys Australia (Teys) to investigate two Teys beef processing facilities. Both facilities are located in Queensland (Beenleigh and Rockhampton) and process around 90,000 tonnes HSCW per year.

Johns Environmental (JEPL) was contracted to characterise wastewater quality and flows at both sites, followed by design of the CALs with third party design of the biogas system. The WWTP at both sites were constructed and commissioned during 2013 - 2015. The year preceding construction of the WWTP was termed the 'baseline year' and the year following the commissioning was termed the 'verification year'. Numerous quantities such as fuel consumption, wastewater flows and quality, biogas flow and methane content were measured. This allowed calculation and comparison between sites of the improvements in energy and carbon intensity due to the investment in the WWTP and biogas use assets.

During the verification year, the CALs performed well, removing 96% and 87% of the incoming biological oxygen demand (BOD) at each of the sites. A total of 2,180,000m^3 and 1,390,000m^3 of biogas was produced at average methane content of 70% and 67% respectively. Natural gas (NG) usage at Beenleigh was reduced by approximately 30%. Rockhampton reduced coal usage by 18%. Total carbon abatement over the 20 year operational lifetime is estimated to be 603,000 tCO_2e and 655,000 tCO_2e respectively. Wastewater carbon emissions were largely eliminated (98.7%), with total Scope 1 emissions (liable under the now discontinued CPM system) being reduced by 83% at both sites. Total scope 1 emissions at both facilities were reduced under the original CPM threshold of 25,000 tonne CO_2-e.

The NG-burning Beenleigh facility saved approximately $1.66/head and the coal-fuelled Rockhampton facility $0.42/head in reduced fuel bills. With the CTIP funding, the investment at Beenleigh had a payback period within 5 years. At Rockhampton, the investment failed to offer payback within the timeframe required. This result is due mainly to the low cost of coal relative to natural gas. Without government funding or a price on CO_2e emissions, investment in CAL technology at Teys Rockhampton would not be financially viable.

A cost benefit analysis (CBA) was performed which revealed the addition of a price on CO_2e emissions at $23/tonne CO_2e shortened the financial payback considerably. The imposition of an Annual Contract Quantity (ACQ) in existing NG supplier contracts resulted in financial penalties where displacement of NG by biogas triggered the penalty. This created a financial disincentive to invest in biogas usage over the term of the existing NG supply contract. In contrast, coal supply contracts do not have similar penalties.

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Abbreviations

ACQ	=	Annual Contract Quantity
AEMO	=	Australian Energy Market Operator
BFP	=	Belt Filter Press
BNR	=	Biological Nutrient Removal
BOD_5	=	Biochemical Oxygen Demand (measured in 5 days at 20°C) (mg/L).
CAL	=	Covered Anaerobic Lagoon
CAPEX	=	Capital Expenditure
CBA	=	Cost Benefit Analysis
CH_4	=	Methane
CO	=	Carbon Monoxide
CO_2	=	Carbon Dioxide
CO_2e	=	Carbon Dioxide Equivalent
COD	=	Chemical Oxygen Demand (mg/L)
CODf	=	Filtered Chemical Oxygen Demand (mg/L)
Conc	=	concentration
CPI	=	Consumer Price Index
CPM	=	Carbon Pricing Mechanism
CTIP	=	Clean Technology Investment Program
CTFFIP	=	Clean Technology Food and Foundries Investment Program
DAF	=	dissolved air flotation
EBITDA	=	Earnings before Interest, Tax, Depreciation and Amortisation
EC	=	Electrical conductivity (µS/cm)
FTE	=	Full Time Equivalent
GHG	=	Greenhouse Gas
Hd	=	head of cattle
HDPE	=	High-density Polyethylene
H_2S	=	Hydrogen Sulphide
HRT	=	Hydraulic Retention Time
HSCW	=	Hot Standard Carcass Weight
KO	=	Knock Out (Pot)
L/W	=	length:width ratio of lagoon
NATA	=	National Association of Testing Authorities
NG	=	Natural Gas
NGER	=	National Greenhouse and Energy Reporting
NH_3-N	=	ammonia-nitrogen concentration (mg/L)
NO_2	=	nitrogen dioxide
NO_2-N	=	nitrite-nitrogen concentration (mg/L)
NO_3-N	=	nitrate-nitrogen concentration (mg/L)
NPV	=	Net Present Value
O&G	=	Oil and Grease (mg/L)
OPEX	=	Operating Expenditure
PFD	=	Process Flow Diagram
RAS	=	Recycled Activated Sludge
Rem	=	removal
SCADA	=	Supervisory Control and Data Acquisition
SCOD	=	Soluble Chemical Oxygen Demand (mg/L)

TA	=	Total Alkalinity (mg/L)
TCOD	=	Total Chemical Oxygen Demand (mg/L)
TDS	=	Total Dissolved Solids (mg/L)
TKN	=	Total Kjeldahl nitrogen (mg/L)
TN	=	Total Nitrogen concentration (mg/L)
TP	=	Total Phosphorus concentration (mg/L)
TSS	=	Total Suspended Solids (mg/L)
TWL	=	Top Water Level
VFA	=	volatile fatty acids (mg/L as acetic acid)
WAS	=	Waste Activated Sludge
WWTP	=	Wastewater Treatment Plant

LIST of UNITS

GJ	=	gigajoule
$kgCO_2$-e	=	kilograms carbon dioxide equivalent (1 $kgCO_2$ = 1 $kgCO_2$-e; 1 $kgCH_4$ = 21 $kgCO_2$-e)
tCO_2-e/yr	=	tonne carbon dioxide equivalent per year
kL/d	=	kilolitres (cubic metres – m^3) per day
kWh	=	kilowatt hours
L	=	litre
mg/L	=	milligrams per litre = ppm.
MJ	=	megajoule
ML	=	Megalitres (1,000 kL)
MW	=	Megawatt (1,000 kW)
m	=	metre
t	=	tonne
tHSCW	=	tonne Hot Standard Carcass Weight
w:h	=	width:height ratio of pond wall slope (horizontal:vertical)
90%ile	=	90^{th} percentile

1 Background

1.1 Project Context

1.1.1 Carbon Pricing Mechanism

A primary driver of this project was the introduction of the Carbon Pricing Mechanism (CPM) in Australia, which introduced a price on CO_2-e emissions. The CPM came into effect on 1 July 2012 and targeted large carbon emitters generating Scope 1 CO_2-e emissions (boiler, transport and wastewater emissions) above a site threshold of 25,000 tonnes CO_2-e per year. For annual emissions above this threshold, the facility was required to remit payment to the government at the rate of $23/tonne CO_2-e on all Scope 1 emissions.

The operation of naturally crusted anaerobic ponds as part of the wastewater treatment process at large Australian abattoirs released methane-rich biogas into the atmosphere. This contributed significantly to the Scope 1 emissions from Australian abattoirs. The wastewater emissions from the Beenleigh and Rockhampton facilities comprised 66% and 44% of total Scope 1 emissions respectively. This translated into a liability of $580,000 and $890,000, respectively in the first year of the CPM. Future liability also remained and would be determined by the effectiveness of the biogas capture and reuse as well as the carbon price. Consequently there was a strong incentive to consider investment in biogas capture and reuse technology, such as Covered Anaerobic Lagoons (CALs). This approach would in most instances reduce Scope 1 emissions from meat processing facilities below the CPM threshold and preclude liability under the CPM.

The Abbott Government repealed the CPM on 1 July 2014 which removed one of the financial drivers for the projects at Teys Rockhampton and Beenleigh. The impact of this is discussed later in the cost benefit analysis (CBA). Despite repealing the CPM, the Abbott Government honoured committed CTIP funding arrangements which included the biogas capture and reuse projects at Teys Rockhampton and Beenleigh.

1.1.2 Energy Costs

In addition to the impact of the introduction of the CPM, the red meat processing industry was affected by ongoing increases in the cost of boiler fuels and electricity, which are a major cost to operations. Australia has been a low cost energy nation for many years, but increasingly this competitive advantage has been eroded compared to competitor nations. One strong benefit of CAL technology is the ability to recover the energy-rich biogas generated by anaerobic wastewater treatment and use it to displace fossil fuels. Not only does this reduce annual fuel costs, it has a multiplying benefit in that the biogas boiler emissions are accounted (under greenhouse accounting methodology) at near zero compared to those from fossil fuel-powered boilers. This provides a double benefit in using biogas as a fuel.

The benefit in using biogas is relatively complex since it varies with fuel type. Most meat processing plants south of northern NSW use natural gas for boilers. Meat plants in Queensland, however tend to have access to cheap coal and use this fuel for boilers. Although the number of plants using coal is less than natural gas, their share of total Australian production is significant.

Natural gas fuel generates less carbon emissions per MJ compared to coal, but is more expensive to purchase. In addition, most coal-fired meat processing sites are located relatively near coal mines with which there are rarely long term supply contracts with required minimum deliveries. In contrast, natural gas supply by pipeline comes with complex long term supply contracts that include Annual Contract Quantity (ACQ) requirements which can impose financial penalties on substitution of the natural gas with biogas use.

Consequently the opportunity to compare the impact of installing CAL technology coupled with biogas usage in boilers at the Teys Beenleigh site (natural gas) and the Teys Rockhampton site (coal) was a unique one with potential to offer industry-wide insights.

1.2 Covered Anaerobic Lagoons & Biogas Use

At the time of the project start, CALs were becoming increasingly recognised within the red meat processing industry as a feasible solution to capture biogas emitted from the anaerobic breakdown of waste water. Two of Teys Australia's beef processing facilities, located in Tamworth and Wagga Wagga NSW, had already implemented CALs and were successfully capturing the biogas and flaring it.

Johns Environmental has a long history of designing and commissioning anaerobic systems for the red meat industry and designed the CALs at both Wagga Wagga and Tamworth which were commissioned in 2011 and 2012 respectively. JEPL designed the small CAL at King Island for JBS and conducted the P.PIP.0290 project studying its operation during 2011/12 [1]. The twin 20 ML CALs installed at TFI Murray Bridge, SA in 2012 were also a JEPL design. The start-up performance and benefits of sludge recirculation were studied in two PIP projects conducted by JEPL in 2012 – 2015 [2,3]. However, the operation of CALs at large meat processing plants was still in its infancy in early 2013 and the installation of new CALs at Beenleigh and Rockhampton offered the opportunity to investigate their performance at large processing facilities operating in Queensland, where the bulk of the larger facilities operate.

Most CALs installed up until 2012 flared the biogas generated. This was in part due to uncertainty about the reliability and quantity of biogas production, its methane content and the concentration of impurities, especially hydrogen sulphide gas (H_2S), which is toxic and highly corrosive. An early CAL installation at Young NSW had experienced biogas H_2S levels of up to 8%v/v [4].

This project aimed to de-risk the application of biogas for boiler fuel by investigating the composition and quantity of the biogas available and how these parameters impact on the successful use of the gas for boiler combustion, especially in regard to continuity of supply, corrosion matters and the degree of biogas conditioning required. Biogas represents a significant value add to users of CAL technology in terms of reduced fossil fuel costs, carbon abatement and energy efficiency.

1.3 Industry Significance

This project contributes to a competitive, low-carbon, Australian red meat processing industry in the following ways:

1.3.1 Broader environmental benefits

The technology and processes deployed as part of this project could be applied within meat processing facilities across Australia of similar scale and operation, of which there are around ten facilities. Teys Australia estimated that these facilities are responsible for over 200,000 tonne CO_2-e emissions p.a, of which at least half is derived from wastewater treatment. Based on the preliminary estimates for this project, it is feasible to assume that an annual reduction in excess of 100,000 tonne CO_2-e emissions could be achieved across the red meat processing industry alone through the use of CALs with biogas use. Although only 0.01% of Australia's annual 600 million tonne CO_2-e emissions, this contribution assists in Australia's aspirations to reduce its contribution to global emissions.

1.3.2 Impact on the economy and employment

The technology on trial in this project reduces the operating costs of running large meat processing plants, especially through boiler fuel costs and carbon liabilities. Although the CPM was subsequently discontinued under the Abbott Government, the opportunity for reduced fossil fuel costs remains pertinent.

This avoided expenditure comes at a time when toughening export market conditions and Australia's high exchange rate was impacting greatly on export oriented meat processing businesses. Avoided expenditure on energy and permits assists in maintaining the Industry's competitive position in the global market place.

2 Projective Objectives

At both the Beenleigh and Rockhampton sites, the aims of the project were:

- Wastewater characterisation to confirm feed design specifications for the CAL;
- The engineering design and configuration of a CAL(s) waste water treatment system (concept design);
- The design of appropriate biogas transfer and biogas flaring equipment and boiler modifications;
- Measurement and verification of the reduction in CO_2-e emissions achievable from the wastewater treatment system upgrade. This includes an analysis of the quality and quantity of biogas captured by the CAL and the resulting emissions reductions using proven methods of determination;
- Sampling and testing of the CAL and biogas to address issues concerning biogas use such as production and quality, corrosion of the boiler and design of biogas conditioning before transfer to the boiler;
- A detailed report on the issues concerning biogas capture and its use in a boiler to offset fossil fuel consumption including an assessment of CO_2-e emissions abated from the project.
- Comparison of results from the two sites to identify learning's of value to the broader industry so that the outcomes of the project will be applicable to any facility that uses natural gas or coal for boiler fuel within the Australian red meat processing industry.

3 Site Descriptions

3.1 Teys Beenleigh

3.1.1 Abattoir

The Teys Beenleigh meat processing facility is an integrated modern beef export plant performing a full range of activities including slaughtering, boning, inedible by-products rendering, edible offal processing and packaging and blood processing. It is situated on Logan River Road, Beenleigh on the south side of Brisbane, Queensland. The site is urban encroached but with room for a new WWTP upgrade on the western part of the site.

The facility processes of the order of 1,375 head/day at full production and uses natural gas for combustion in boilers for steam generation.

3.1.2 Pre upgrade WWTP

Prior to the WWTP upgrade at the Teys Beenleigh site, the wastewater generated by the facility was treated through a simple pond system (see Figure 3).

The red stream is fed through a rotating screen and into a DAF (Figure 1). The green stream is treated using a rotating screen and screw press (Figure 2). Paunch solids are removed off-site.

Figure 1. Red stream DAF

Figure 2. Green stream Rotating Screen

Both red and green streams then enter a mix tank. This combined stream of approximately 3.4 ML/day was pumped to a large 19 ML uncovered anaerobic pond (Pond 1) which was about 12 years old. Following anaerobic treatment the wastewater flowed by gravity through a series of aerobic ponds (ponds 2 & 3) to receive additional polishing treatment. Finally the treated effluent flowed into the Irrigation Dam. From the Irrigation Dam, the wastewater was pumped to either the wet weather storage dam or directly to sewer for treatment and disposal by the Logan City Council.

Among the challenges of the existing WWTP were:

- Odour emissions from the pond system;
- Uncaptured greenhouse emissions from the uncovered anaerobic pond and loss of valuable energy-rich biogas to atmosphere;

- Sludge accumulation in the ponds necessitating labour-intensive desludging activities;
- Significant remaining nutrient levels.

The upgrade of the WWTP sought to eliminate as many of these issues as possible.

3.2 Teys Rockhampton

3.2.1 Abattoir

The Teys Rockhampton meat processing facility, like the Beenleigh plant, is an integrated modern beef export plant performing a full range of activities including slaughtering, carcass boning, inedible by-products rendering, edible offal processing and packaging and blood processing. It is situated on the northern bank of the Fitzroy River at Lakes Creek near Rockhampton, Queensland. The facility processes of the order of 1,731 head/day at full production and generates steam for hot water production and rendering operations using two 11 MW coal-fired boilers prior to the project activities.

The main part of the Rockhampton site occupies a thin slice of land bounded on the west by the estuarine Fitzroy River and on the east by the Rockhampton Emu Park Road and a railway. Across the road is a large area of cattle-yards and land leading up into the Beserker Ranges. Small settlements occupy the northern and southern boundaries of this block of land.

3.2.2 Pre upgrade WWTP

The wastewater at the Teys Rockhampton site was treated via initial primary treatment after which it was pumped 7 km distant to the Nerimbera pond system prior to the WWTP upgrade (Figure 4). The two uncovered anaerobic ponds operated in parallel and discharged by gravity into a large and shallow aerobic pond (pond 2) and then into aerobic pond 3A. From pond 3A, a small fraction of the treated effluent could be sent to a nearby turf farm for disposal by irrigation, whereas the majority flowed through aerobic pond 3B before release into the adjacent Black Creek. Approximately 2.5 ML was discharged daily compared to the 4.2 ML/day of potable water brought into the site.

In 2011 and prior to the start of this project, Teys invested $2.2 million into a major upgrade of the primary treatment system by separating different waste streams and installing two chemical-free third generation FRC plate pack DAFs with respective balance tanks and solids handling systems. These were designed to recover suspended and dissolved fats from the red and render waste streams for recovery as product and as pre-treatment for future CALs.

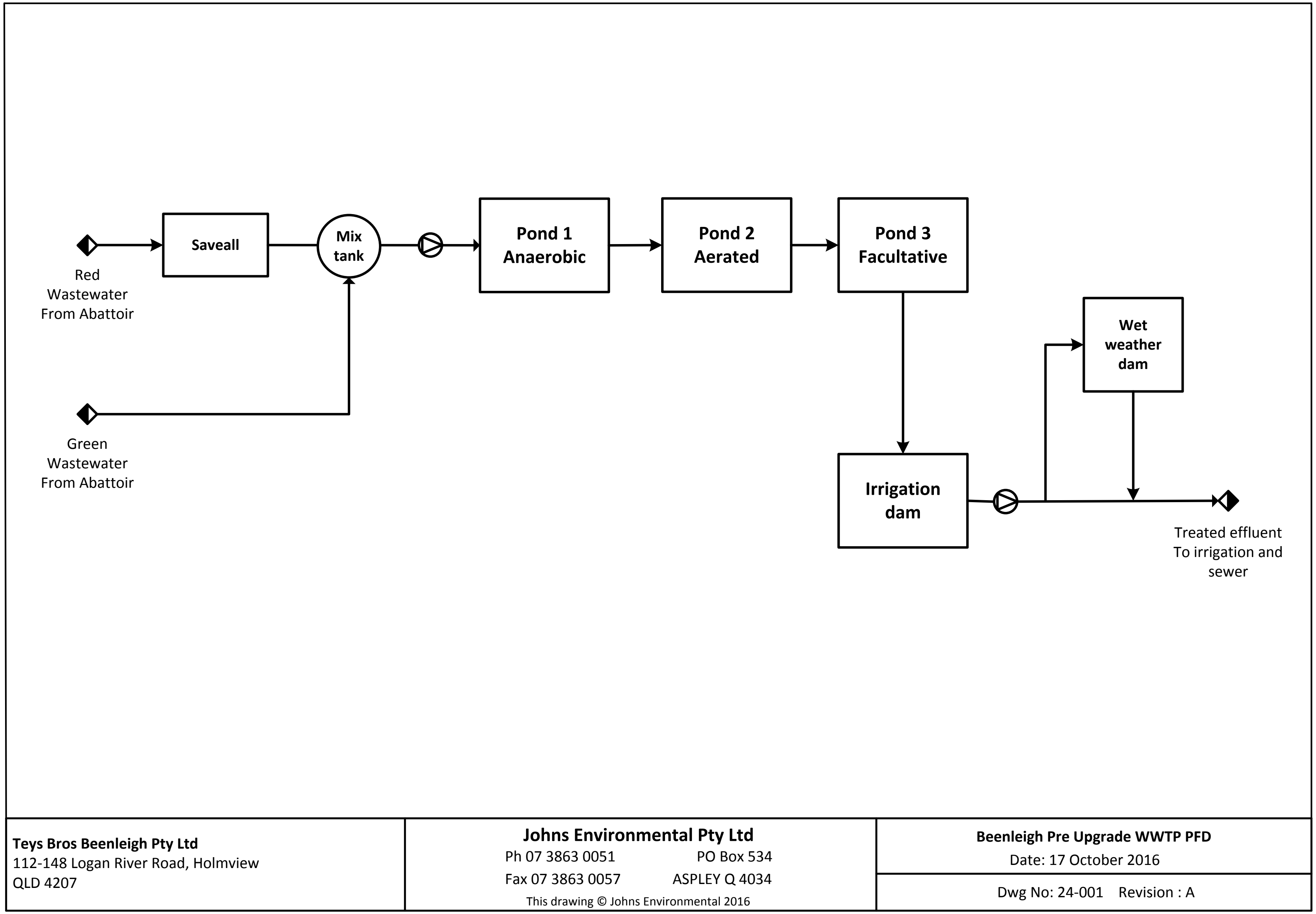

Figure 3. Teys Beenleigh Pre Upgrade WWTP

The aims of the WWTP upgrade described in this project were:

- Recovery of biogas fuel from the new CALs and decommissioning of the old uncovered anaerobic ponds to abate Scope 1 emissions;
- Ensure negligible odour emissions from the new WWTP;
- Decommission the 7 km pipeline and Nerimbera ponds from routine use (it was retained for contingency purposes);
- Upgrade treated effluent water quality to permit direct discharge into the Fitzroy River at the Lakes Creek site.

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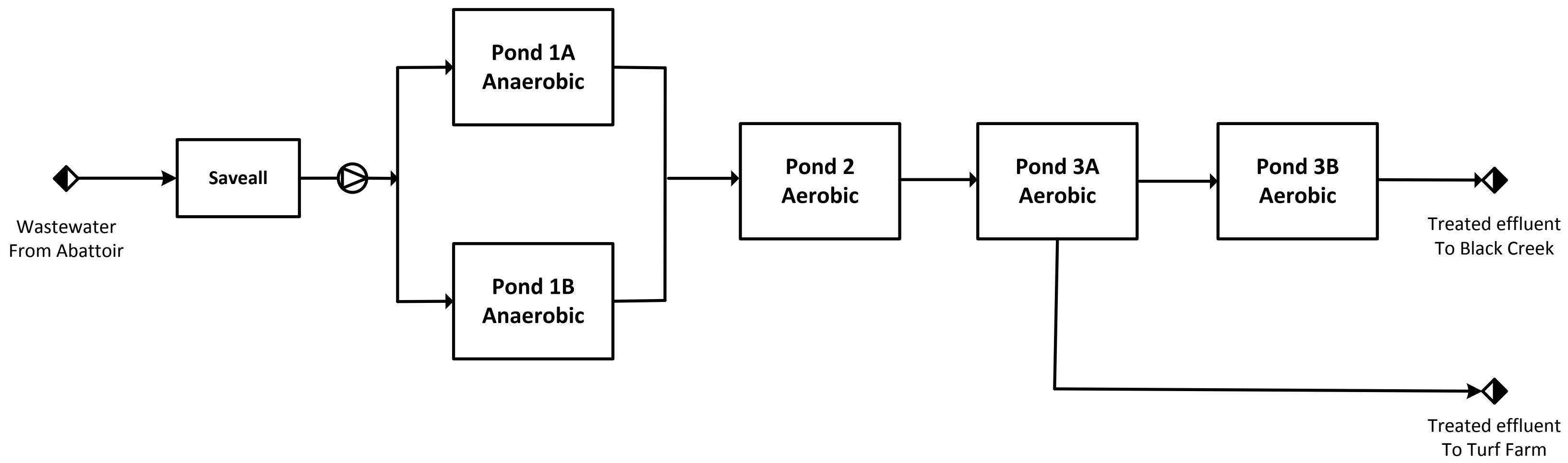


Teys Bros Pty Ltd 112-148 Logan River Road, Holmview QLD 4207	**Johns Environmental Pty Ltd** Ph 07 3863 0051 PO Box 534 Fax 07 3863 0057 ASPLEY Q 4034 This drawing © Johns Environmental 2016	**Rockhampton Pre-Upgrade WWTP PFD** Date: 17 October 2016 Dwg No: 24-002 Revision : A

Figure 4. Teys Rockhampton Pre Upgrade WWTP

3.3 Site Comparison

Table 1 compares the main characteristics of both Teys facilities in terms of factors that might influence biogas production. Both are located in the eastern sub-tropical climate zone as defined by the modified Koeppen climate classification system used by the Australian Bureau of Meteorology. However, Beenleigh lies at the southern extent of the sub-tropical region compared to Rockhampton which is centrally located.

Production throughput is approximately the same for both sites with a slight majority of grass-fed beef animals processed compared to grain-fed. The average hot standard carcass weight per head is similar.

Due to the recent investment in DAF technology at Rockhampton, there is extensive pre-treatment of wastewater prior to the biological system, which typically reduces the organic load for biogas production. However, the extent of pre-treatment should offer a longer CAL life by minimising risks associated with crust and scum build-up under the HDPE covers and rapid sludging of the lagoons with settleable solids. In contrast, the pre-treatment system at Beenleigh remains relatively rudimentary.

A significant difference between the two facilities was the choice to build two CALs at 28 ML working volume at Rockhampton compared to a single 28 ML unit at Beenleigh. This decision reflects the design scope for Rockhampton which required the ability for higher future throughput. The Beenleigh CAL was suitable for current throughput. The long residence times given in Table 1 reflect the lower than design flows during the verification year.

From a carbon emissions study viewpoint the difference in the fuel used for steam generation was a significant factor in the selection of the two sites for the comparative study as is emphasised throughout the report. Beenleigh is unusual for a Queensland facility in using natural gas as fuel - most Queensland plants use coal due to its ready availability and low cost.

Table 1. Site comparison (Verification Year)

Parameter	Units	Beenleigh	Rockhampton
Climate		sub-tropical	sub-tropical
Production throughput	tHSCW	85,000	80,000
Grass vs. grain-fed cattle	% grass-fed	60	>50
Average HSCW per animal	kg	300	280
Primary treatment	N/A	moderate	extensive
No. of CALs	#	1	2
Anaerobic Volume	ML	28	56
Residence times (CALs)	days	19	18
Fuel being offset	N/A	Natural gas	Coal

3.4 Teys Australia Biogas Use Goals

3.4.1 Teys Beenleigh

Prior to the WWTP upgrade, Teys Beenleigh had a 4MW General Electric Boiler which was burning natural gas for steam generation. It was decided that the biogas that was produced as a result of the WWTP upgrade would be used to displace a portion of this natural gas.

For this reason, it was decided that the 4MW GE boiler would be repurposed at minimal cost for co-combustion of biogas with natural gas. This repurposing involved:

- upgrades to the boiler house,
- additional pipework, and
- upgrades to the burner and vent system.

An approximately 350 metre long underground stainless steel pipeline was constructed to transport the biogas from the flare pad at the WWTP to the boiler house.

3.4.2 Teys Rockhampton

Teys Rockhampton was using coal for steam generation in two existing Fluidised Bed Boilers which were unsuitable for biogas combustion. Accordingly, a new, purpose-built package plant biogas boiler was purchased to allow the biogas to displace some of the coal usage.

A new structure to house the boiler was constructed, with appropriate electrical and plumbing works also completed. Additionally, an approximately 700 metre long underground stainless steel biogas pipeline was constructed between the WWTP flare pad and the biogas boiler house.

4 Methodology

4.1 Wastewater Characterisation for CAL Design

4.1.1 Teys Beenleigh

At the start of the project, the JEPL process design team was of the view that a wastewater characterisation exercise was not required for the following reasons:

- The production throughput and processing facilities had remained largely unchanged over the previous 2 years.
- The wastewater treatment system, especially the primary system, had also remained unchanged so that historical composition data for the feed to the anaerobic pond were considered valid for the CAL design.
- There was no intention to significantly alter the primary treatment to the new CAL.
- The historical data regarding composition had been obtained from samples collected by external, trained personnel and were analysed by a NATA-accredited laboratory (ALS Environmental, Brisbane) and therefore had a good degree of integrity.

However, on inspection of the wastewater composition data, there seemed to be a step change from values reported since mid-2012 and previous years. JEPL decided to conduct a sampling campaign to investigate the wastewater composition further.

JEPL collected daily composite samples of the raw wastewater discharged to the anaerobic ponds from the 14th May to the 17th May 2013 during a normal production week. An ISCO autosampler with a single large composite collecting bottle was used to collect the daily composite sample. Equi-volume samples were collected each half hour during production hours and each hour during cleaning hours. The timing was paced to achieve a flow proportional composite sample. The resultant composite sample formed a representative sample of the entire day's wastewater flow.

The composite sample was analysed both onsite and with laboratory analysis. Conductivity and pH analysis of the composite sample was measured onsite using a HACH HQ40d. The composite sample was then dispensed into bottles and sent to ALS for laboratory analysis.

4.1.2 Teys Rockhampton

In contrast to Beenleigh, there had been substantial investment in the pre-treatment system at the Rockhampton facility in the year preceding the project and significant in-house improvements aimed at reduced wastewater loads. Consequently an intensive 1 week wastewater characterisation program was conducted by JEPL and Teys personnel during a normal production week (Figure 5).

Sampling included field and laboratory analysis and collection of SCADA flow data. Four operating periods were identified during the production day and samples were collected within each. Each sample was measured immediately to determine pH, temperature and conductivity using a portable Hach HQ40d or TPS WP81 instrument, previously calibrated according to the manufacturer's instructions using certified standard solutions (Figure 6). The visual appearance and odour of the effluent was also noted. The sample was then thoroughly mixed and distributed into bottles supplied by the laboratory and held in chilled ice water until sent to the laboratory overnight.

Analytical testing of samples was performed by ALS Environmental (Brisbane) with samples couriered overnight for testing. ALS Environmental is NATA accredited for the tests conducted and has long experience with complex meat processing samples.

Results over the four sampling days were moderately reproducible. Flows and the best estimate of the typical composition of the pre-treated wastewater were determined and provided a basis to derive the appropriate design values.

Figure 5. Sampling of waste streams at Teys Rockhampton

Figure 6. Field measurements of parameters at Teys Rockhampton

4.2 CAL Design

4.2.1 Teys Beenleigh

The single 28 ML CAL for Beenleigh was designed by Johns Environmental on the basis of the design composition determined from historical wastewater analysis over the previous two years (Table 2). Subsequent characterisation performed in 2013 suggested lower organic loads than the design values, but it was decided to retain the original design due to hydraulic constraints. The design flow was 3.4 ML/day and developed from historical production levels.

The nominal CAL dimensioning for construction are provided in Table 3 in addition to the minimum hydraulic retention time (HRT) at design flow. Note that some variations in dimensioning can occur during construction. The CAL was designed as a positive pressure CAL at 6 m working depth and 1 m freeboard. The CAL is HDPE lined for groundwater protection and covered with 2 mm HDPE cover using the compacted anchor trench approach.

Table 2. Design values for Beenleigh CAL

Item	Units	Design
Flows		
Median flow	kL/day	3,400
Max flow	kL/day	4,500
Composition		
TCOD	mg/L	9,000
BOD	mg/L	4,000
TSS	mg/L	2,800
O&G	mg/L	1,000
Temp	ºC	35
pH	-	6.7 - 7.4

Table 3. Nominal dimensioning for Beenleigh CAL

Item	Units	Value
Pond area TWL	m^2	6,950
L/W ratio		1.50
Pond width TWL	m	68.0
Pond length TWL	m	102
Pond water depth TWL	m	6.0
Wall batter	w:h	2.5
Pond Volume (TWL)	m^3	28,000
Design HRT	days	9.2
Freeboard	m	1.0

At a raw wastewater bypass ratio of 10 – 20% to the downstream BNR system, the CAL can be expected to obtain at least 85% BOD and 80% COD removal under design load conditions to give a typical:

- Effluent BOD_5 concentration: 600 mg/l
- Effluent COD concentration: 1,800 mg/l.

For the lower organic load (COD median 6,000 mg/l) from the 2013 characterisation, the design CAL effluent values are:

- Effluent BOD_5 concentration: 170 - 230 mg/l
- Effluent COD concentration: 1,200 – 1,500 mg/l.

The lower range is for 10 – 20% bypass to the BNR, the higher values for no bypass.

4.2.2 Teys Rockhampton

Johns Environmental performed the overall process design of the WWTP upgrade at Rockhampton for Teys Australia. The full final process flow diagram is provided as Figure 26. The system was designed to provide for full discharge to the Fitzroy River with provision for reuse of some of the treated effluent for example for cattleyard washing.

The design basis for the system is provided in Table 4. The WWTP upgrade was designed for a daily average flow of 6.0 ML/day, 5 days/week to allow for future production increases and for more intensive water use per head. The CALs can accommodate the full design flow but are more likely to operate at smaller flows due to the need for bypass of some wastewater to the downstream BNR plant.

The design composition was derived from the wastewater characterisation performed in 2012 (See Section 4.1.2). Teys facilities typically generate weaker wastewater than many meat processing plants in Australia.

Table 4. Design basis for Teys Rockhampton CALs

Item	Units	2013	Design feed for CAL	Design ex CAL
Flows				
Average flow	kL/day	4.5	6.0	4.8/6.0
Max flow	kL/day	5.4	7.5	7.0
Composition				
TCOD	mg/L	7,500	7,500	1,500
SCOD	mg/L	830	830	300
BOD	mg/L	2,850	2,850	500
TSS	mg/L	3,300	3,300	800
O&G	mg/L	900	900	10
TKN	mg/L	150	150	180
NH_3-N	mg/L	15	15	162
TP	mg/L	30	36	36
Temp	°C	43	43	< 40
pH	-	7.4	7.4	6.8 – 7.2
EC	µS/cm	1,400	1,400	1,400

The typical composition of the CAL-treated wastewater is also provided in Table 4. The design removal of COD is 80%, although over time this is expected to be exceeded as the microbial biomass increases. BOD removal is usually higher.

Nutrient concentrations (TN, TP) are assumed to be unaffected by the CAL as is the usual observation by JEPL for meat processing CALs. The increase in TKN level in the CAL-treated effluent is entirely an artefact of the design process – this represented the design level for the downstream BNR system and was deliberately uplifted to ensure that excess nitrogen removal capacity is assured. The actual impacts of the anaerobic biology in the CAL on the nutrients in the wastewater are to change their chemical form:

- Organic nitrogen is almost completely converted to inorganic ammonia nitrogen;
- Organic phosphorus is completely solubilised as reactive phosphorus.

For Rockhampton, twin CALs were designed for the total installed nominal volume of 56 ML. JEPL's preference is for large volumes to be split into two parallel CALs rather than one large CAL. This provides some degree of operational redundancy in the event of problems although this comes at some additional capital cost. Note that this is simply a JEPL preference - large single CALs have been successfully used overseas (Cargill, pers. comm.). In the event, the decision to construct two CALs proved to be a wise one for the facility.

The dimensioning and process design values for each CAL are given in Table 5 and Table 6, respectively. The CALs were HDPE-lined and designed to operate as positive pressure systems.

Table 5. Nominal dimensioning of CALs at Rockhampton

Item	Units	Value
Pond area TWL	m^2	6,930
L/W ratio		1.50
Pond width TWL	m	68.0
Pond length TWL	m	102
Pond depth TWL	m	6.0
Wall batter	w:h	2.5
Pond Volume (TWL)	m^3	28,000
Freeboard	m	1.0

Table 6. Process design values

Item	Units	At 4.8 ML/d	At 6 ML/d
Design HRT	days	11.7	9.3
BOD_5 volumetric loading	kg/m^3.d	0.24	0.31
COD volumetric loading	kg/m^3.d	0.64	0.80

4.3 Biogas System Design

The biogas flare and ancillaries at Teys Beenleigh were designed and constructed by Eneraque. The design peak biogas generation was estimated by JEPL as 615 m^3/hr at 70% methane at the design load. ABM Combustion supplied additional sensors and flowmeters in the biogas system to the boiler.

The Teys Rockhampton biogas flare and ancillaries was designed and constructed solely by ABM Combustion for a design peak biogas generation of 1,300 m^3/hr at 70% methane. ABM Combustion have performed a number of these installations in the meat industry.

4.4 Site Data Collection

The site data used in this report was collected from a number of sources by Teys personnel and supplied to JEPL in Microsoft Excel format.

- Wastewater flows. This was collected by in-line mag flowmeters that link back to the on-site SCADA system.
- Wastewater composition. Samples collected by Teys staff were analysed in independent NATA-accredited laboratories.
- Biogas Quantity and composition. Biogas flows were measured using in-line biogas flowmeters linked to the site SCADA system. To confirm on-site measurements of biogas quality, additional testing by JEPL and Airlabs was performed at both sites (See sections 4.5 and 4.6).
- Production data was measured daily.
- Electricity and fuel consumption for the baseline and verification years was gathered from receipts provided by suppliers to Teys. This was supplied to JEPL in a combination of scanned PDF receipts and Microsoft Excel form.
- Capital (CAPEX) and operating (OPEX) cost data was recorded by the sites. Operating costs were determined for the verification year.

4.5 JEPL Biogas Sampling and Analysis

To gain an understanding of the composition of the raw, un-combusted biogas being produced by the CALs, JEPL went to both sites to collect data over a period of a number of days. From 29th Nov – 1st Dec and 7th – 9th Dec, JEPL went to Teys Beenleigh and Rockhampton, respectively. Biogas at a number of locations was measured including before and after the knockout pot, as well as after the biogas chiller, to determine whether these units had any impact on the composition. A GEM5000 gas analyser was used to measure the following parameters continuously for a few hours each day over 3 days:

- Methane (CH_4)
- Carbon dioxide (CO_2)
- Oxygen (O_2)
- Carbon monoxide (CO)
- Hydrogen sulphide (H_2S)

4.6 Stack Testing

In addition to the sampling and analysis of the raw biogas, Airlabs Environmental were engaged by JEPL to conduct stack testing on all of the release points at both sites. All points were measured for a number of parameters including gas velocity and volume flow rate, temperature and moisture content. The boiler stacks were measured for nitrogen oxides as NO_2 and hydrogen sulphide (H_2S) to determine the influence of impurities in the biogas on boiler exhaust relative to normal fuels. All stacks were checked for whether they met ‘ideal sampling positions’ requirement per AS 4323.1-1995. Where required, additional samples were collected to ensure that this requirement was met.

4.7 Assessment of Greenhouse Gas Abatement

For both sites, greenhouse gas emissions during the baseline and verification years were calculated using the National Greenhouse and Energy Reporting (NGER) Technical Guidelines [5] and the relevant factors in the NGER Determinations. The most recent NGER Determinations were released in 2015 and therefore, these factors were used to calculate the greenhouse gas emissions.

The NGER methodology for fuel consumption involves multiplying the quantity of fuel combusted (tonnes, kL, m^3 etc.) by the energy content factor (GJ/t, GJ/kL, GJ/m^3 etc.) and then multiplying by the various emissions factors (kg CO_2e/GJ) to determine the total greenhouse gas emissions in carbon dioxide equivalents.

Electricity related greenhouse gas emissions are calculated by multiplying the quantity of electricity consumed (kWh) with the emissions intensity factor (kg CO_2e/kWh) for the Australian State in which it was consumed – Queensland for both sites.

Greenhouse gas emissions associated with the uncovered anaerobic lagoons used in the baseline year were calculated using NGERs Method 1 for industrial wastewater. This involves multiplying the throughput of the abattoir (tonnes HSCW) with relevant factors that assume a flow of wastewater and a COD concentration in the wastewater. This method also makes assumptions for the quantity of COD that is converted into biogas, and the methane content of that biogas. This biogas volume has a certain CO_2 equivalent emission potential based on the methane content. This factor is known as the global warming potential for methane (when uncombusted).

Greenhouse gas emissions associated with covered anaerobic lagoons (CALs) used in the verification years were calculated using the actual recorded biogas flow combined with the actual recorded methane content of the biogas to determine the methane volume in the produced biogas. This methane volume was multiplied by the energy content factor (GJ/m^3) and the various emissions factors for combusted methane (kg CO_2e/GJ) to determine the total greenhouse gas emissions for the combusted methane in carbon dioxide equivalents.

4.8 Cost Benefit Analysis

4.8.1 Scenarios examined

The cost benefit analysis (CBA) for this project was completed by JEPL with assistance from Thixo Pty Ltd. The CBA has been prepared in Microsoft Excel, in accordance with the MLA CBA Guidelines [6], which dictate the format of the Excel file, relevant assumptions that must be made and the outputs that are required.

The CBA for this particular project examined a number of potential scenarios, to provide information on both the actual works that were undertaken at Teys Beenleigh and Rockhampton, as well as provide information to other processors in the industry that may be considering implementing this technology at their own facility. The scenarios that were investigated are summarised in Table 7.

Scenarios 1, 1a, 2 and 2a are fixed in the CBA as these results are discussed in this report. Scenarios 3 to 6 are adjustable within the Excel file to suit an individual processor.

Scenarios 3 and 4 look at the CBA associated with a generic meat industry situation where all the infrastructure (CAL, flare, biogas train & boiler) must be purchased and installed for sites using coal or natural gas, respectively.

Scenarios 5 and 6 consider the generic meat industry situation where the CAL and associated biogas flare already exist and only biogas conditioning and connection to a biogas boiler is needed for sites using coal or natural gas, respectively.

Table 7. CBA scenario descriptions

#	Scenario	Fuel	Comment
1	Actual Teys Beenleigh scenario with the portion of funding contributed by CTIP subtracted	NG	
1a	Teys Beenleigh scenario with carbon tax at $23/tonne	NG	
1b	Teys Beenleigh self-funded scenario	NG	
2	Actual Teys Rockhampton scenario with the portion of funding contributed by CTIP subtracted	Coal	
2a	Teys Rockhampton scenario with carbon tax at $23/tonne	Coal	
2b	Teys Rockhampton self-funded scenario	Coal	
3	CAL & flare, biogas boiler, biogas pipeline required	Coal	Greenfield/existing anaerobic ponds on site
4	CAL & flare, biogas boiler upgrade, biogas pipeline required	NG	Greenfield/existing anaerobic ponds on site
5	Biogas boiler and biogas pipeline required	Coal	CAL and flare already exist, only flaring biogas
6	Biogas boiler upgrade and biogas pipeline required	NG	CAL and flare already exist, only flaring biogas

4.8.2 CBA methodology

All scenarios were prepared using standard cost benefit methodology with annual time-steps out to 20 years of operation (the project life defined under CTFFIP rules). Capital expenditure (CAPEX) for each scenario was spent over two years (the construction phase), before operation of the WWTP commences, resulting in positive revenue in the form of fuel savings and carbon tax reduced liability as well as operational expenditure (OPEX) in the form of labour and maintenance. The savings and OPEX combine to form the Earnings Before Interest, Tax, Depreciation and Amortisation (EBITDA). Taxation, interest, depreciation and amortisation are not considered as part of this CBA. Strictly speaking, there are no actual ‘earnings’ associated with this project, but rather savings due to reduced fuel expenditure or reduced carbon tax liability. Nevertheless, the term ‘EBITDA’ will be used in this CBA.

Capital costs for scenarios 1 to 2a were based on information provided by Teys staff. This data included a capital cost breakdown for each major unit. Capital costs for scenarios 3 to 6 were calculated by using the cost breakdown for each of the Teys sites and selectively adding the costs for the process units that were relevant to that scenario.

Operational costs for scenarios 1 to 2a were based on actual financial information provided by Teys staff. These costs were averaged between both Teys sites to generate the OPEX for scenarios 3 to 6.

A discount rate of 7% was used as per the MLA CBA Guidelines to account for the time value of money and opportunity cost of the investment. A project lifetime of 20 years of WWTP operation was used.

To account for changes in electricity, coal and natural gas prices over the 20 year project lifetime, energy price forecasts published for the Australian Energy Market Operator (AEMO) were embedded in the CBA. These forecasts have a significant degree of uncertainty, but are the best available figures (Appendix 1).

Customisable options have been embedded in the CBA for scenarios 3 to 6 to allow individual processors to tweak the calculations to more accurately calculate the true EBITDA for their facility if they were to implement this technology. Table 8 outlines the options that can be adjusted.

Table 8. Customisable options in CBA (scenarios 3 to 6)

Parameter	Units	Comment/effect on scenario
HSCW throughput	tonnes/year	Affects the CAPEX as per scaling factor and maintenance component of OPEX. This aims to account for economies of scale benefit for larger plants. It is a very rough estimate only.
Head throughput	head/year	Affects the $/hd output factors of the CBA.
Carbon tax in action	Y/N	Turns the carbon tax on/off. Only turn on if the processor is liable under the original carbon tax (>25,000 tCO_2e/year).
Carbon price	$/tonne CO_2e	Sets the price of carbon. Default is $23/tonne.
Natural gas price in 2016	$/GJ	The price of natural gas paid by site in 2016. Do not include fixed costs such as network charges etc. that will not change. Leave at zero if not relevant.
Coal price in 2016	$/tonne	The price of coal paid by site in 2016. Do not include fixed costs that will not change. Leave at zero if not relevant.
Discount cash rate	%	Set at 7% as a default as per MLA guidelines [6].
Consumer Price Index, CPI	%	Set at 2.5% as a default as per RBA target.
Biogas pipeline length	metres	Affects the cost of the biogas pipeline based on the distance from the WWTP to the boilers.

It is important to note that intangible assets have not been considered as part of this project. These include additional benefits that construction of the WWTP may bring which are difficult to quantify, such as:

- More robust, reliable treatment of wastewater.
- Meeting EPA discharge licence limits.
- Reduced odour emissions.
- Improved reputation and branding.
- Social licence to operate.

Finally, a number of assumptions have been made when performing this CBA. These are detailed in the CBA file and companion document.

5 Results

5.1 Wastewater Characterisation Outcomes - Beenleigh

The results of the characterisation of wastewater at the Teys Beenleigh plant are presented in this section and informed the design flow and composition used to design the WWTP upgrade.

5.1.1 Wastewater flows to WWTP

Figure 7 presents the wastewater flows derived from daily records for full production days. The median wastewater flow was 3,420 kL per day. The design "average" flowrate was selected as 3,400 kL/day. Note that this includes captured stormwater flows and is not the average dry weather flow usually used for municipal plants. Some flow also occurred on weekends and other non-production flows, but this was relatively minor in the context of a 5-day production week.

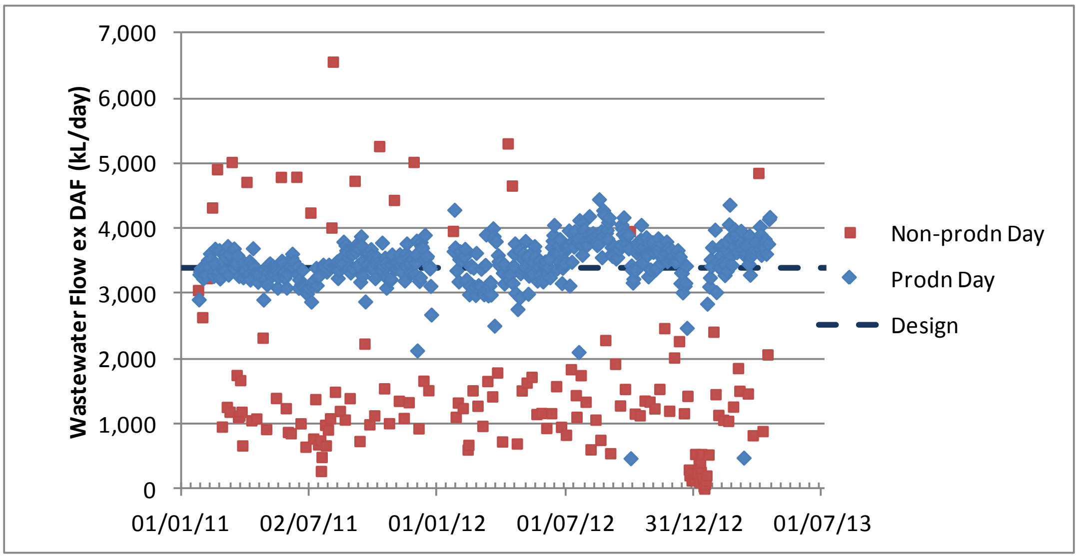


Figure 7. Daily wastewater generation at Teys Beenleigh

5.1.2 Wastewater Feed composition to CAL

The results of the characterisation campaign performed in May 2013 for the Beenleigh facility is presented in Table 9. The composite results indicate a lower organic composition than that used to develop the original CAL design values, although other parameters were similar. The BOD value of 1,200 mg/L was considered erroneous compared to the COD value and was not used in any design assessment.

Examination of COD concentrations in the primary-treated wastewater over the 2 year period showed that levels had reduced consistently since mid-2012 and that COD values in the 12 month period since that time correlated reasonably well with the median result from the composite samples from the May 2013 campaign (Figure 8). BOD and oil & grease showed the same trend.

Table 9. Results of characterisation in May 2013

Item	Units	Original Design values	Composite Median concentration
TCOD	mg/L	9,000	6,000
BOD	mg/L	4,000	1,200
TSS	mg/L	2,800	3,300
O&G	mg/L	1,000	550
Temp	ºC	35	39.5
pH	-	6.7 - 7.4	7.4

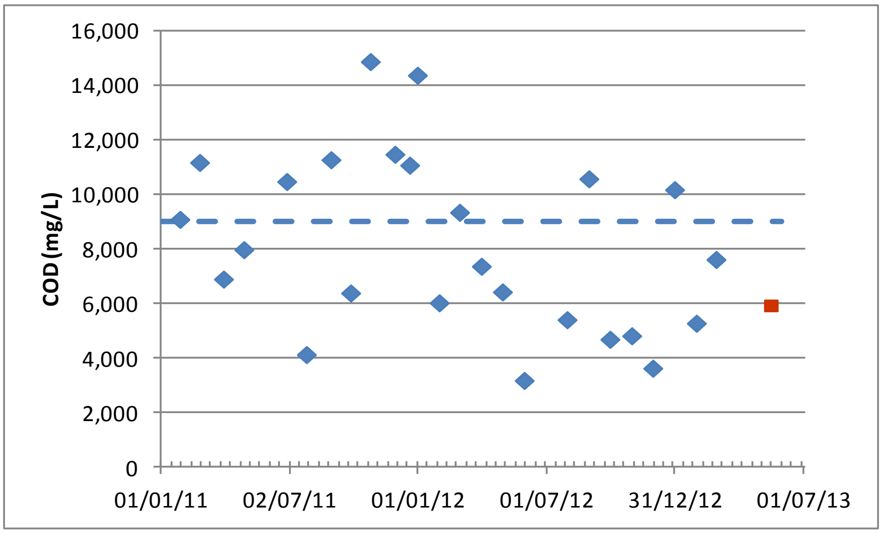


Figure 8. COD results (Red square = May 2013 composite median result)

5.2 Teys Beenleigh Post Upgrade WWTP and its Performance

5.2.1 Overall Description of WWTP

The upgrade of the WWTP at Teys Beenleigh resulted in the replacement of the existing pond system with CAL anaerobic treatment system with biogas collection followed by Biological Nutrient Removal (BNR) in a Biolac unit (see Figure 9).

Following the upgrade, the primary treatment of the wastewater at the Teys Beenleigh site remained unchanged. The primary-treated red and green streams combine in the mix tank, from which they are pumped to the Covered Anaerobic Lagoon (CAL) inlet pit entering the CAL by gravity (Figure 10). The CAL has a volume of 28ML, giving an average residence time of 19 days (at current flows). The CAL generates biogas from bacterial activity, which can be used in one of three different ways. Once the biogas under the CAL cover reaches a certain pressure set-point (as measured by a pressure transmitter) the blower at the boiler or biogas flare switches on. This depends on the boiler demand for biogas at the time.

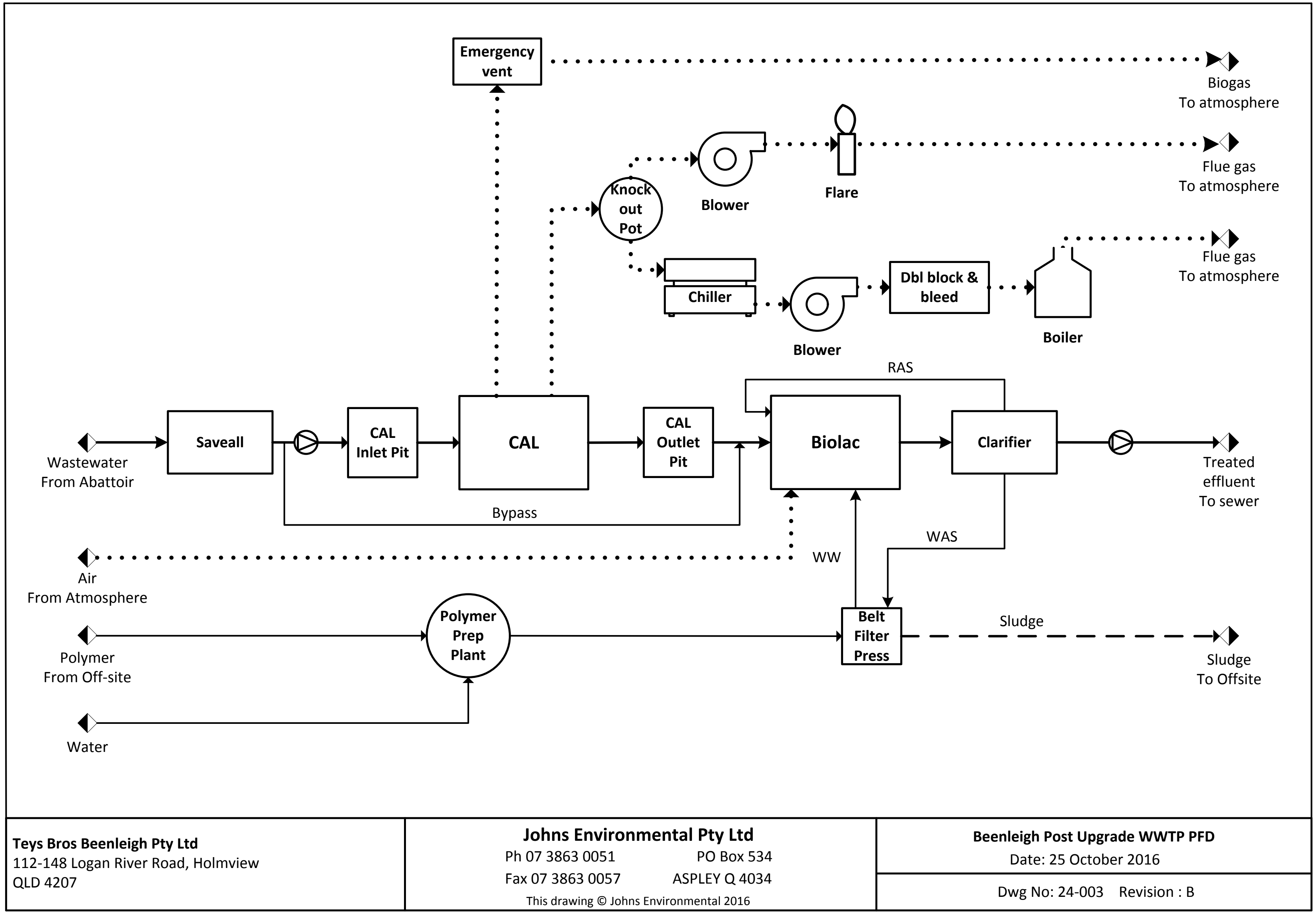


Figure 9. Teys Beenleigh Post Upgrade WWTP

Figure 10. New CAL at the Teys Aust. Beenleigh WWTP

If the boiler blower switches on, the biogas under the CAL cover is drawn through the biogas offtake line and into a knockout pot. This unit acts as the first line of defence against free water in the biogas which would harm the downstream blower by separating the biogas from any condensed water or foam. This condensate forms as the biogas cools as it travels from the CAL to the knockout pot. After the knockout pot, the gas is chilled using a glycol refrigeration system to further dry the biogas for use in the boiler, removing additional moisture as condensate. The various gas conditioning process units are shown in Figure 11 to Figure 14.

The biogas then passes through the blower and a double block and bleed isolation manifold before entering a 4MW General Electric boiler for combustion (Figure 15). This boiler can alternately use either natural gas or biogas fuel but it must be started on natural gas to reach the right combustion temperature. It is also shutdown on natural gas to prevent corrosion of the boiler internals from H_2S present in the CAL biogas.

If the biogas pressure under the CAL cover exceeds the pressure set-point when there is no demand for biogas (ie. the boiler is being serviced or otherwise experiencing downtime), another blower at the biogas flare skid will draw biogas through the knockout pot, the blower and then to the biogas flare for combustion (Figure 16).

If the pressure under the CAL cover exceeds the pressure set-point but the biogas blower and the flare blower fail to start, the biogas can be vented directly from the CAL cover via an emergency vent (Figure 17). This vent operates with a water seal on the biogas vent pipeline. If the pressure exceeds the hydrostatic pressure of the water seal, the biogas can be safely vented, but without combustion.

Figure 11. Knockout pot

Figure 12. Glycol storage tank

Figure 13. Biogas chiller

Figure 14. Chiller refrigeration unit

Figure 15. Biogas Boiler (General Electric 4MW)

Figure 16. Biogas Flare

Figure 17. CAL Emergency Vent

Biogas flow and quality (methane content) are measured on-line using an Endress & Hauser flowmeter (Figure 18) and Draeger methane analyser (Figure 19).

Figure 18. Biogas Flowmeter

Figure 19. Biogas Methane Analyser

After anaerobic treatment, the wastewater flows by gravity from the CAL into the adjacent Biolac activated sludge treatment plant (Figure 20). The Biolac is a biological nitrogen removal (BNR) system that has a number of different bacterially-catalysed processes occurring that are spatially separate. Essentially, it provides further removal of organic material and nitrogen. The air required for nitrification and organic removal reactions is compressed and then injected into the Biolac by a number of blowers situated in a blower building nearby. The air travels to the Biolac in a large diameter stainless steel header pipe and is injected at pressure into the Biolac from bottom of the lagoon via a number of floating header pipes fitted with suspended fine bubble air diffusers. The Biolac receives approximately 20% of the raw wastewater as a bypass feed that does not go through the CAL.

Figure 20. Biolac BNR lagoon showing air header pipe (foreground) and floating headers

Effluent flows from the Biolac basin into an internal clarifier (Figure 21), where the biological sludge settles to the base of the unit. Waste activated sludge (WAS) is periodically pumped out of the base of the clarifiers and dewatered in a Belt Filter Press (BFP) unit with polymer added. The dewatered WAS is disposed of off-site. Return activated sludge (RAS) is pumped back to the Biolac to maintain the bacterial population at the desired set-point. Treated effluent from the clarifier is pumped directly to the sewer off-take point for further treatment and disposal by Logan City Council.

Figure 21. Biolac clarifier for activated sludge settling

5.2.2 CAL Performance – Organic removal

The Beenleigh CAL was commissioned in March 2015 with anaerobic sludge added from the existing anaerobic pond. Table 10 shows its wastewater treatment performance with respect to COD and BOD removal during the verification year.

The CAL achieved excellent COD and BOD removals relative to the expected performance (see Section 4.2.1) within 3 months of commissioning. This is an excellent result and was aided by the sludge seeding and careful adoption of the commissioning plan worked out between JEPL and Teys Beenleigh personnel. Based on median results, the CAL was able to remove

92% of the incoming COD load and 96% of the incoming BOD load during the verification year and produced effluent of consistent composition despite significant variations in feed strength.

After 1 year of operation, the CAL does not appear to be showing any signs of crusting under the cover or having any other major issues.

Table 10. Teys Beenleigh CAL Wastewater Treatment Performance (Verification Year)

	CAL in (mg/L)		CAL out (mg/L)	
Date	**COD**	**BOD**	**COD**	**BOD**
17-Jul-15	6,110	2,120	840	211
13-Aug-15	7,480	1,740	1,000	154
20-Aug-15	7,270	1,150	700	187
8-Sep-15	6,120	2,860	606	74
17-Sep-15	1,500	387	492	96
10-Dec-15	6,080	3,120	484	77
23-Dec-15	3,520	1,600	334	80
12-Jan-16	3,760	1,960	430	41
15-Feb-16	3,920	2,150	604	61
22-Mar-16	8,000	4,620	322	40
10-May-16	8,560	3,860	476	78
Median	**6,110**	**2,120**	**492**	**78**

5.2.3 CAL Performance – Biogas production & quality

The Beenleigh CAL produced 2,180,000m^3 of biogas in the verification year at an average methane content of 70% - the expected design quality. Figure 22 to Figure 24 represent the biogas composition as sampled and analysed by JEPL at Teys Beenleigh during the verification year. In these figures the red data refers to the methane concentration in %v/v and the blue data refers to the biogas H_2S concentration in ppm. The sampling was performed over three days both pre-knockout pot and post biogas refrigeration and immediately prior to combustion in the boiler. Table 11 summarises the composition data for the period.

Table 11. Teys Beenleigh Raw Biogas Composition Data

Parameter	**29-Nov-16**	**30-Nov-16**	**1-Dec-16**
Sampling location	Post Chiller	Post Chiller	Post Chiller
Methane, CH_4 (%v/v)	69.9	70.0	70.0
Carbon dioxide, CO_2 (%v/v)	26.3	27.0	27.0
Oxygen, O_2 (%v/v)	0.6	0.3	0.4
Carbon monoxide, CO (ppm)	4	5	4
Hydrogen sulphide, H_2S (ppm)	1,490	1,730	1,730

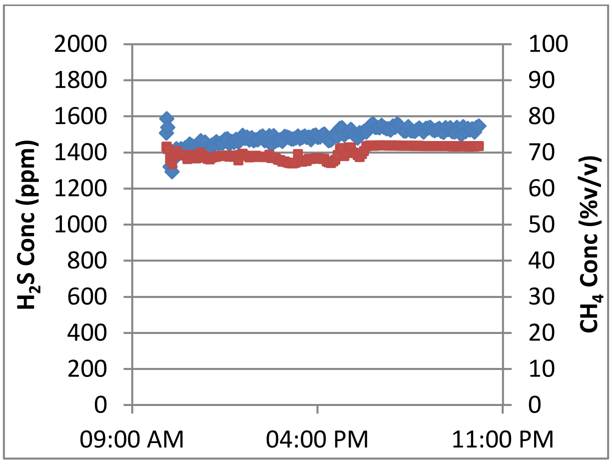


Figure 22. Biogas quality 29 Nov 16

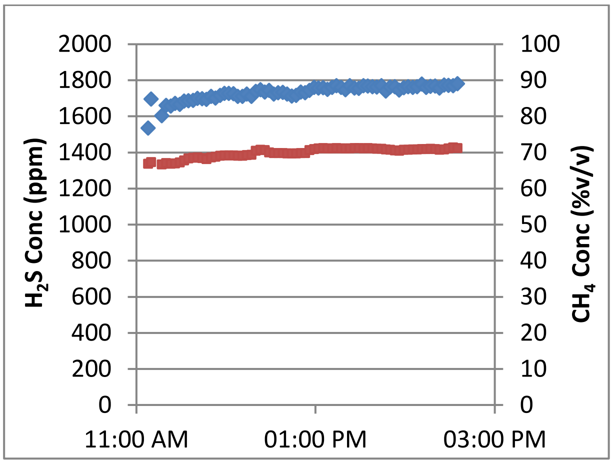


Figure 23. Biogas quality 30 Nov 16

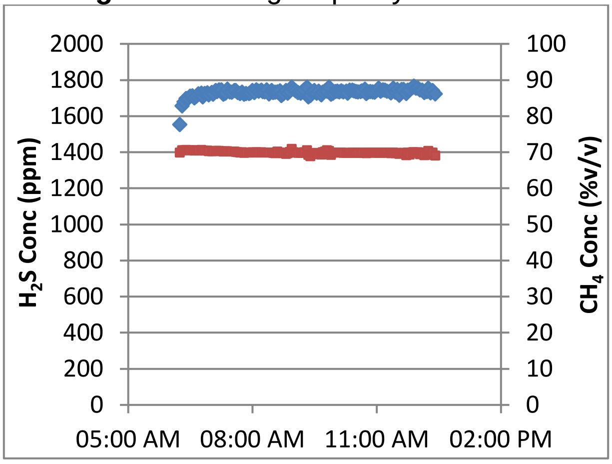


Figure 24. Biogas quality 1 Dec 16

The data presented was generated by sampling the biogas every 3-5 minutes for a number of hours each day. The results reveal that the biogas composition does not change greatly throughout the day, and is in fact consistent day to day. This was expected, as the volume of biogas under the CAL cover is quite large, and this probably acts to equalise the biogas composition that is being generated.

H_2S concentrations were also constant at approximately 1,500 – 1,750 ppm. This is in the range typically observed for beef processing facilities in Australia.

Airlabs Environmental of Brisbane collected ‘grab’ samples of the raw, un-combusted biogas for analysis off site in December 2016. Their results are provided in Table 12. These results largely agreed with those from the JEPL measurements, although the methane content was surprisingly high at 78%. Some deviation is to be expected when analysing a grab sample.

Table 12. Airlabs Environmental biogas composition data

Biogas composition	Teys Beenleigh
Date	14-Dec-16
Temperature (ºC)	32
Moisture content (%v/v)	1.4
Methane, CH_4 (%v/v)	78.3
Carbon dioxide, CO_2 (%v/v)	21.5
Oxygen, O_2 (%v/v)	0.1
Hydrogen sulphide, H_2S (ppm)	1,500
Nitrogen, N_2 (%v/v)	<0.1
Hydrogen, H_2 (%v/v)	<0.01

5.2.4 Biogas System Performance

A high level of reliability was achieved for the biogas system during the verification year. Approximately 86% of the total biogas generated in the CAL at Beenleigh was combusted in the biogas boiler with only 14% being sent to flare.

In addition to the raw biogas sampling, Airlabs Environmental also performed stack testing on the biogas boiler to determine the concentrations of key pollutants in the exhaust gas. The combustion of biogas rather than natural gas in the boiler might be expected to generate higher levels of pollutants due to the less pure nature of biogas. The results from the boilers combusting biogas and natural gas (NG) are contrasted in Table 13.

Table 13. Impact of biogas on stack emissions at Teys Beenleigh

Parameter	Biogas boiler	NG boiler
Date	*14-Dec-16*	*14-Dec-16*
Temperature (ºC)	251	203
Velocity (m/s)	27.0	5.7
Flow rate (Am^3/min)	114	228
Moisture content (%v/v)	11.0	14.0
Oxygen dry, O_2 (%v/v)	5.4	2.1
Carbon dioxide dry, CO_2 (%v/v)	10.5	11.8
Nitrogen Oxides, NO_2 (mg/Nm^3)	85	208
Hydrogen Sulphide (H_2S) (mg/Nm^3)	36	4.6

These results fall within Teys Beenleigh's stack emission limits, but hydrogen sulphide concentration in the combusted exhaust is much higher than for natural gas. On the whole, the Teys Beenleigh biogas system has performed very well in its first year of operation.

5.3 Wastewater Characterisation Outcomes - Rockhampton

The results of the characterisation of wastewater at the Teys Rockhampton plant are presented in this section and informed the design flow and composition used to design the WWTP upgrade.

5.3.1 Wastewater flows to WWTP

Figure 25 shows the daily wastewater generation over the design year at the Teys Rockhampton facility. During this time, most weeks comprised 5-day kills with a median throughput of 1,603 head/day.

Some statistics on wastewater flow are given in Table 14. The overall 7-day weekly wastewater production on a typical five day operating week had a median of 23.2 ML per week over the past operating year with a median production day flow of 4,450 kL. These data informed the WWTP system design.

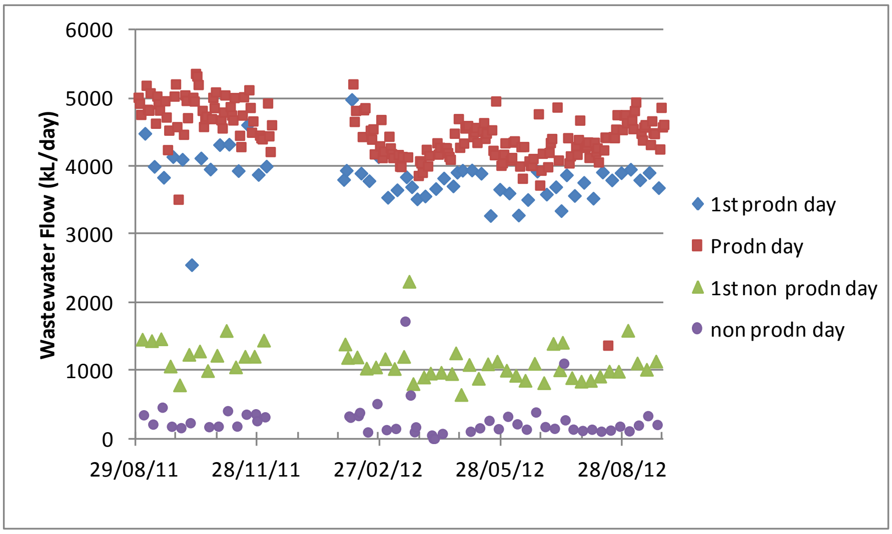


Figure 25. Daily wastewater generation over the previous year at Teys Rockhampton

Table 14. Summary of wastewater generation at Teys Rockhampton

	Mon flow (kL/d)	Tues to Fri flow (kL/d)	Sat flow (kL/d)	Sun flow (kL/d)	Weekly flow (ML/wk)
Median	3,850	4,450	1,050	180	23.2
90 %ile	4,150	4,950	1,450	400	25.2
Maximum	4,983	5,365	2,310	1,724	

5.3.2 Wastewater feed composition to CAL

An extensive week-long characterisation campaign was undertaken at the Rockhampton facility. This involved intensive sampling of various major waste streams prior to their combination in the final balance tank. The largest sampling was conducted during normal processing since this comprised the majority of the volume.

The best estimate of the typical composition of the combined pre-treated wastewater discharged to the future CAL is presented in Table 15. These values are within the usual range observed at Australian meat processing facilities, although the nutrient levels are at the low end of the range.

Table 15. Best estimate of combined wastewater composition at Rockhampton facility

Parameter	Unit	Best estimate
pH	-	7.4
EC	µS/cm	1,400
Temperature	°C	43
COD	mg/L	7,500
BOD_5	mg/L	2,850
COD filtered	mg/L	830
O&G	mg/L	900
TSS	mg/L	3,300
TKN	mg/L	150
NH_3 as N	mg/L	15
TP	mg/L	30

In Table 16 the organic composition and daily load are given for the various waste streams segregated at the facility by time of production. The "kill floor processing" stream comprises the aggregate of all the various waste streams (red, green, render and boning) during the processing day. The concentrations represent averages of the measured data (n = 15). The "render, boning room" stream represents the concentration of mainly the aggregated high temperature render processing waste streams since the boning flow is small. Cleaning compositions are relatively high, especially from the boning room.

Table 16. Organic composition and load by waste stream

	Flow (kL)	BOD (mg/L)	COD (mg/L)	CODf (mg/L)	O&G (mg/L)	TSS (mg/L)
Kill Floor processing	2,850	2,010	6,680	920	660	3,380
Kill Floor clean	840	2,050	2,975	420	475	1,520
Render, boning room only	260	11,700	27,300	1,870	3,410	8,420
Boning room clean	500	4,280	8,780	445	1,630	2,780
Total production day load (kg/d) (average)		12,635	33,000	3,685	4,000	14,500
Weighted concentration (mg/L)		2,850	7,500	830	900	3,300

At the current wastewater flow (4.45 ML/day), Rockhampton discharged a COD load of 33 tonne daily with an additional 14.5 tonne TSS and 4 tonne oil & grease, despite sophisticated, best practice, primary treatment.

The nutrient composition of the discharged wastewater is presented in Table 17. These are of little impact on the CAL, but were relevant to the design of the Biolac BNR system. Table 18 provides useful information on the physical characteristics of the Rockhampton facility waste streams. The waste streams are generally hot (average combined temperature of 43°C), neutral pH and low salinity. Sodium, chloride and bicarbonate alkalinity made up the bulk of the ionic salts.

Table 17. Waste stream nutrient composition and loads discharged from Rockhampton facility

	TKN as N (mg/L)	NH_3 as N (mg/L)	TP as P (mg/L)
Kill Floor processing	177	17	41.4
Kill Floor clean	64	8	8.3
Render, boning room only	232	7	15
Boning room clean	53	4	5.2
Daily Load (kg/d**)**	**645**	**60**	**132**
Weighted Conc. (mg/L)	**150**	**15**	**30**

Table 18. Physical wastewater data

	pH	pH range	Conductivity (µS/cm)		Temperature (°C)	
			Fat DAF	No Fat DAF	median	range
Kill Floor processing	7.4	7.1 – 7.7	1,210	4,310	43	36.7 - 49
Kill Floor clean	7.3	7.3 – 7.4	800	2,990	46	30 - 54
Render, boning room only	7.6	-	2,760		46	33 - 50
Boning room clean	7.5	-	2,370		40	30 - 49
Flow weighted median value	**7.4**		**1,400**		**43**	

5.4 Teys Rockhampton Post Upgrade WWTP & Performance

5.4.1 Overall Description of WWTP

The WWTP upgrade at Teys Rockhampton was quite similar to the upgrade at Beenleigh (Figure 26). The combined, primary treated wastewater is pumped to the CAL inlet pit, which splits the stream and allows it to flow by gravity into each of two 28 ML volume positive pressure CALs operating in parallel. Each of these CALs operates in the same manner as the Beenleigh CAL. Biogas is continually produced by the bacterial breakdown of organic material in the wastewater, which accumulates under the cover before being used (Figure 27). Biogas can be released through an emergency vent if necessary.

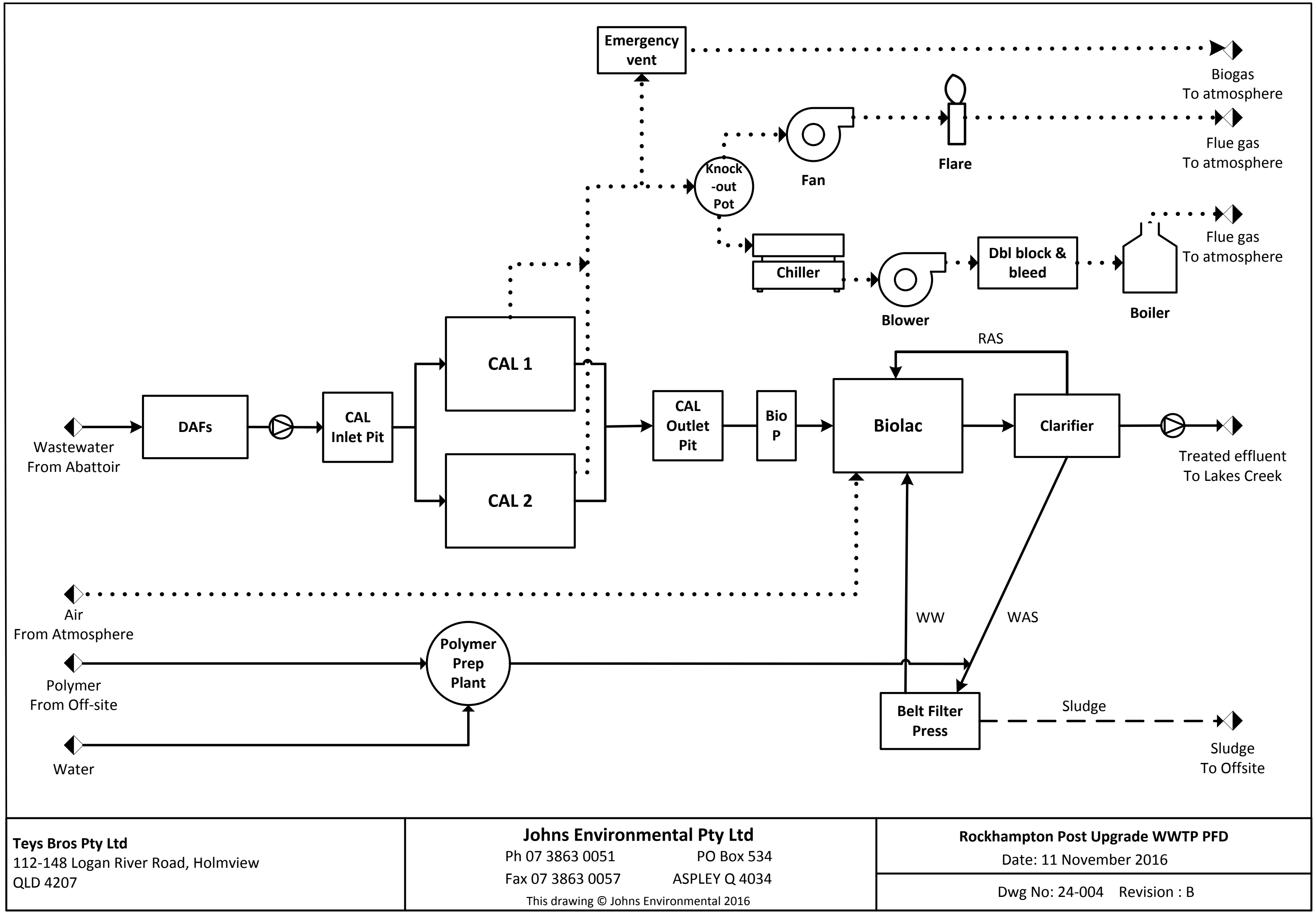


Figure 26. Teys Rockhampton Post Upgrade WWTP

Figure 27. Biogas under the CAL1 cover at the Teys. Rockhampton WWTP

During normal operation, biogas from both CALs combines and passes through a single knockout pot, which removes condensate from the biogas. If there is demand from the plant for heat from the biogas boiler, the biogas blower switches on, forcing the biogas from the knockout pot through a glycol refrigeration system (Figure 28 to Figure 30). The chiller cools the biogas, further removing condensate. The blower then compresses the biogas to 35-50 kPa.g and delivers it to the biogas boiler in the plant (Figure 31).

Alternatively, if the biogas under the CAL cover has reached a pressure set point but there is no demand from the biogas boiler, the flare blower will force the biogas directly to the fully enclosed flare for combustion (Figure 32).

In the event that both the boiler and flare were non-operational and the pressure under the CAL cover was excessive, then biogas automatically released through the same style of water seal emergency vent as Beenleigh (Figure 17).

From the two CALs, the anaerobically treated wastewater combines and flows by gravity into the Biolac BNR plant (Figure 33). The Rockhampton Biolac was constructed with additional basins in which biological phosphorus removal can be performed, in addition to biological nitrogen removal. There were no data to suggest that Bio P was in fact occurring and the issue is outside the scope of this project.

Effluent from the Biolac flows into the internal clarifier to settle the sludge which is either recycle it back into the Biolac (RAS) or pump it to the BFP for dewatering (WAS). Dewatered sludge is disposed of off-site. Clarified effluent is pumped from the WWTP to the Lakes Creek discharge point where it flows into the Fitzroy River.

Figure 28. Glycol storage tank

Figure 29. Chiller

Figure 30. Chiller refrigeration unit

Figure 31. Biogas boiler

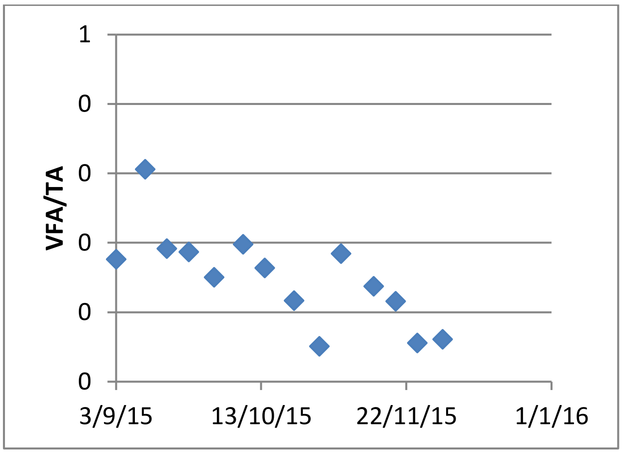
Figure 32. Fully enclosed flare

Figure 33. Biolac biological nutrient removal plant

5.4.2 CAL performance – Organic removal

The Rockhampton CAL was commissioned in April 2015. Table 19 shows its wastewater treatment performance with respect to COD and BOD removal during the verification year. The CALs required a substantial time to settle down to steady performance with high VFA/TA ratio (> 0.5) experienced for 4 months (April – July). Design removals of COD and BOD began to be achieved from August, although consistent performance was not achieved until October. This correlated with low VFA/TA values (Figure 34).

Figure 34. CAL performance - VFA/TA ratio for months 6 - 9



Based on the median results, the CALs were able to remove 78% of the incoming COD load and 87% of the incoming BOD load during the verification year.

In early November 2015, a severe thunderstorm damaged CAL2 and it had to be taken off-line and the wastewater diverted into CAL1, which remained undamaged. Fortunately, the Rockhampton facility was operating at the 4.5 ML/day wastewater rate with processing consistently limited to 3-4 days/week due to high cattle prices. Furthermore, CAL1 had become operationally stable and appeared to be able to handle the organic load by itself.

Table 19 - Teys Rockhampton CAL performance (verification year)

	CAL in COD (mg/L)	**CAL in** BOD (mg/L)	**CAL out** COD (mg/L)	**CAL out** BOD (mg/L)
03-Sep-15	7,760	3,970	2,150	1,040
11-Sep-15	5,200	1,890	1,990	738
17-Sep-15	2,400	1,770	2,130	642
23-Sep-15	6,280	2,900	1,880	690
30-Sep-15	6,900	2,920	1,700	557
08-Oct-15	7,520	3,890	1,720	498
14-Oct-15	4,640	2,100	1,960	537
22-Oct-15	8,080	2,660	1,600	328
29-Oct-15	2,740	1,060	376	133
04-Nov-15	10,100	8,140	1,840	491
13-Nov-15	176	1,180	1,620	420
19-Nov-15	2,450	1,720	1,380	352
25-Nov-15	8,040	3,420	488	194
02-Dec-15	6,580	3,640	1,150	278
26-Feb-16	5,330	2,440	1,280	198
04-Mar-16	7,640	3,630	880	199
11-Mar-16	9,840	4,210	856	353
16-Mar-16	6,640	988	1,160	390
23-Mar-16	3,890	3,090	625	409
30-Mar-16	8,440	3,540	1,120	282
06-Apr-16	4,180	2,150	1,150	278
13-Apr-16	5,500	2,210	1,290	325
20-Apr-16	28,900	11,100	1,470	344
27-Apr-16	4,880	1,880	980	168
04-May-16	5,640	2,440	1,230	247
11-May-16	6,240	2,520	1,330	364
18-May-16	7,540	3,160	964	246
25-May-16	4,120	1,470	1,220	108
01-Jun-16	4,620	1,770	1,140	215
08-Jun-16	6,240	2,440	1,250	287
15-Jun-16	6,820	2,540	1,030	192
22-Jun-16	4,310	1,770	654	103
29-Jun-16	4,340	1,650	722	93
06-Jul-16	5,980	2,990	943	224
13-Jul-16	1,080	572	1,270	265
20-Jul-16	4,080	1,430	1,200	267
27-Jul-16	2,160	900	840	105
03-Aug-16	1,470	790	809	183
10-Aug-16	2,010	1,680	1,070	314
17-Aug-16	1,400	678	1,400	221
24-Aug-16	2,960	846	611	118
31-Aug-16	2,520	1,600	184	116
Median	**5,265**	**2,180**	**1,180**	**278**

After 1 year of operation, neither CAL appears to be showing any signs of crusting under the cover.

5.4.3 CAL performance – Biogas generation & quality

The Rockhampton CALs produced 1,390,000m^3 in the verification year at an average methane content of 67%. The reduced biogas quantity is largely due to reduced production and the difficulties with damage to CAL2 in late 2015, which probably resulted in biogas losses to atmosphere, which are unable to be quantified.

Figure 35 to Figure 37 present the biogas composition as sampled and analysed by JEPL at Teys Rockhampton during 7 – 9 December 2016. In these figures the red data refers to the methane concentration in %v/v and the blue data refers to the biogas H_2S concentration in ppm. The sampling was performed over three days post biogas refrigeration and immediately prior to combustion in the boiler. Table 20 summarises the composition data for the period.

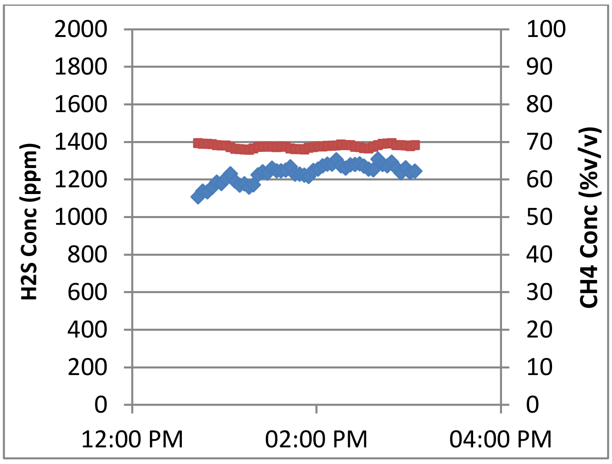


Figure 35. Post chiller (7/12/16)

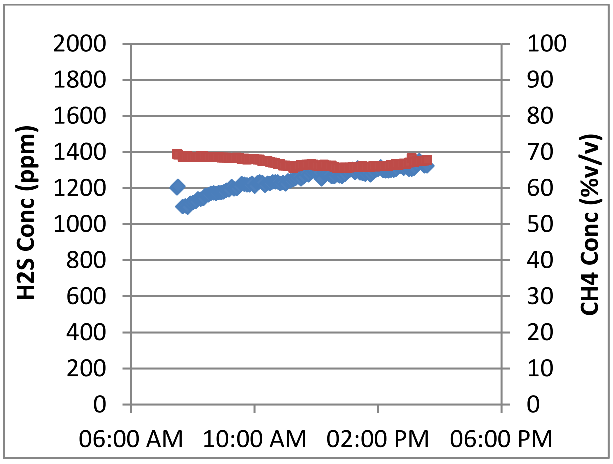


Figure 36. Pre KO pot (8/12/16)

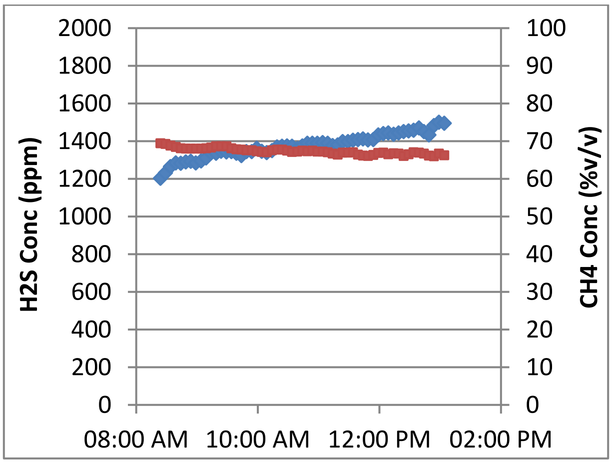


Figure 37. Post chiller (9/12/16)

Table 20. Teys Rockhampton raw biogas composition

Parameter	7-Dec	8-Dec	9-Dec
Location	Post Chiller	Pre KO Pot	Post Chiller
Methane, CH_4 (%v/v)	68.8	67.1	67.4
Carbon dioxide, CO_2 (%v/v)	26.3	26.1	27.0
Oxygen, O_2 (%v/v)	0.1	0.2	0.2
Carbon monoxide, CO (ppm)	22	18	15
Hydrogen sulphide, H_2S (ppm)	1,240	1,250	1,380

The biogas was sampled as detailed in Section 5.2.3. The results are very similar to those for the Beenleigh CAL biogas with both methane and H_2S content a little lower (methane 67 – 68%v/v) and H_2S at approximately 1,200 – 1,500ppm. As with Beenleigh, there was only slight variation during the day and between days.

Airlabs Environmental (Gladstone) collected 'grab' samples of the raw, un-combusted biogas for analysis off site in December 2016. Their results are provided in Table 21. These results agreed reasonably well with those from the JEPL measurements. Oxygen levels were very low, suggesting that the CAL was well sealed from ingress of air.

Table 21. Biogas composition from Airlabs testing

Parameter	Teys Rockhampton
Date	*6-Dec*
Temperature (ºC)	34
Moisture content (%v/v)	1.3
Methane, CH_4 (%v/v)	72.1
Carbon dioxide, CO_2 (%v/v)	27.6
Oxygen, O_2 (%v/v)	0.2
Hydrogen sulphide, H_2S (ppm)	1,100
Nitrogen, N_2 (%v/v)	<0.1
Hydrogen, H_2 (%v/v)	<0.01

5.4.4 Biogas System Performance

As with the Beenleigh facility, a high level of reliability was achieved for the biogas system during the verification year despite the issues with the loss of CAL2 in late 2015. Approximately 84% of the total biogas generated in the CAL at Rockhampton was combusted in the biogas boiler with only 16% being sent to flare.

Airlabs Environmental also performed stack testing on the biogas boiler to determine the concentrations of key pollutants in the combusted exhaust gas. The results are presented in Table 22. Comparison with the coal fired fluidised boiler was not performed.

Teys Rockhampton has limits regarding the concentration of nitrogen oxides and hydrogen sulphide in the flue gas from their biogas boiler. The concentration limits are 350 mg/Nm^3 and 5 mg/Nm^3 respectively. The stack test results (Table 22) indicate that the biogas boiler is operating well within the licence limits.

Table 22. Biogas boiler emissions at Rockhampton

Parameter	Biogas boiler
Date	*6-Dec*
Temperature (ºC)	173
Velocity (m/s)	8.43
Flow rate (Am^3/min)	194
Moisture content (%v/v)	6.15
Oxygen dry, O_2 (%v/v)	3.80
Carbon dioxide dry, CO2 (%v/v)	15.5
Nitrogen Oxides, NO_2 (mg/Nm^3)	73
Hydrogen Sulphide (H_2S) (mg/Nm^3)	2.1

5.5 Verification Year Site Comparison

The performance of the Beenleigh and Rockhampton sites during the verification year in relation to their fuel usage and carbon abatement is compared in Table 23. The facilities achieved similar overall outcomes. The most significant difference is the much greater production of biogas (57% more) at the Beenleigh facility despite similar levels of annual throughput.

In view of this it is perhaps surprising that Rockhampton (364 $kgCO_2e/tHSCW$) achieved a higher degree of carbon abatement than Beenleigh (335 $kgCO_2e/tHSCW$). Reasons for this are discussed in Section 6.3. Both facilities obtained significant benefit from the displacement of fossil fuel by biogas combustion – 44-48,000 GJ displaced in the verification year – and a high proportion of their biogas (~ 84% min) was used for this purpose.

Table 23. Site comparison during verification year

Parameter	Units	Beenleigh	Rockhampton
Total biogas captured	m^3/yr	2,180,000	1,390,000
	GJ/yr[1]	57,500	35,200
Proportion to boiler	%	86	84
Proportion to flare	%	14	16
Total carbon abatement	$kgCO_2e/tHSCW$	335	364
	tCO_2e/yr[2]	30,200	32,800
	tCO_2e[3]	603,000	655,000
Fossil fuels displaced	MJ/tHSCW	534	486
	GJ/yr[2]	48,000	44,000
	GJ[3]	960,000	870,000

Notes

[1] The biogas GJ/yr figure is calculated using the calorific value of the methane fraction of the biogas. However, there is also a significant CO_2 fraction in biogas which lowers the combustion temperature and efficiencies relative to natural gas.

[2] Assuming 90,000 tHSCW/yr of production throughput.

[3] Assuming 20 years as project life.

Whilst electricity usage between the measurement and verification years has changed at both sites, this is largely due to use of energy intensive blowers to inject air into the Biolac. The CAL and flare consume very little electricity. Therefore, the marginal increase in energy and carbon intensity due to additional electricity consumption is not considered to be material to this project.

5.6 Impact on Energy Intensity and Carbon Abatement

5.6.1 Teys Beenleigh

The project was highly successful in achieving very real and substantial reductions in the energy and carbon intensity of meat production at the Beenleigh facility. Overall energy intensity fell from 2,820 to 2,330 "purchased" MJ/tHSCW. Inherently, there is no change in energy intensity by the substitution of energy derived from natural gas as opposed to biogas. There is however, a 17.4% reduction of purchased energy per tonne of meat production and this represents a saving of 44,100 GJ energy over the production year (on a 90,000 tHSCW basis).

The impact on carbon abatement is more profound falling by 52% from 628 kgCO_2e/tHSCW to 302 kgCO_2e/tHSCW. Most of this resulted from the elimination of carbon emissions from the anaerobic treatment of the facility's wastewater (308 kgCO_2e/tHSCW) with some small contribution from displacement of natural gas by biogas (28 kgCO_2e/tHSCW). As noted above, there was a small increase in emissions related to increased electrical consumption (9 kgCO_2e/tHSCW).

Table 24. Beenleigh pre- and post WWTP upgrade comparison

Parameter	Units	Baseline Year (2011-12)	Verification Year (2015-16)
Throughput	tHSCW	91,900	85,000
Energy consumption (electricity)	kWh	26,020,000	25,090,000
	GJ	93,700	90,300
Energy consumption (natural gas)	GJ	165,700	107,900
Energy intensity (electricity)	MJ/tHSCW	1,020	1,060
Energy intensity (natural gas)	MJ/tHSCW	1,800	1,270
Energy intensity (combined)	MJ/tHSCW	2,820	2,330
Carbon intensity (electricity)	kgCO_2e/tHSCW	224	233
Carbon intensity (natural gas)	kgCO_2e/tHSCW	93	65
Carbon intensity (wastewater)[4]	kgCO_2e/tHSCW	311	3
Carbon intensity (combined)	kgCO_2e/tHSCW	628	302

Notes

[4] Only considers CH_4 related GHG emissions from wastewater treatment, which is consistent with Australian NGERs estimation methodology.

5.6.2 Teys Rockhampton

The Rockhampton facility obtained lower reductions in energy intensity and carbon abatement largely due to the much reduced quantity of biogas recovered from the CALs during the verification year, despite a similar production to the Beenleigh site. Nevertheless, significant benefits were obtained including:

- A reduction in overall purchased energy intensity of 8.6%, despite a sizeable growth in electricity consumption per tonne HSCW;
- A 38.8% reduction in combined carbon intensity despite an increase of 19% in carbon intensity from increased electricity use.
- A reduction in combined carbon intensity from 811 to 496 $kgCO_2e/tHSCW$.

Most of the reduction in carbon intensity derived from the almost complete elimination of carbon emissions from the anaerobic treatment process, as with Beenleigh. Despite the capture and use of 57% more biogas at Beenleigh, the carbon abatement due to reduced fossil fuel consumption at Rockhampton was still sizeable – 20% fewer emissions due to coal burning than the baseline year on a per tonne HSCW basis.

Table 25. Rockhampton pre- and post-WWTP upgrade comparison

Parameter	Units	Baseline Year (2011-12)	Verification Year (Sep 15 - Aug 16)
Throughput	tHSCW	93,100	79,600
Energy consumption (electricity)	kWh	30,090,000	30,620,000
	GJ	108,000	110,000
Energy consumption (black coal)	GJ	241,000	168,000
Energy intensity (electricity)	MJ/tHSCW	1160	1385
Energy intensity (black coal)	MJ/tHSCW	2590	2105
Energy intensity (combined)	MJ/tHSCW	3820	3490
Carbon intensity (electricity)	$kgCO_2e/tHSCW$	255	304
Carbon intensity (black coal)	$kgCO_2e/tHSCW$	234	190
Carbon intensity (wastewater)[4]	$kgCO_2e/tHSCW$	322	3
Carbon intensity (combined)	$kgCO_2e/tHSCW$	811	496

Notes

[4] Only considers CH_4 related GHG emissions from wastewater treatment, which is consistent with Australian NGERs estimation methodology.

5.7 CAPEX Data and its Use in the Cost Benefit Scenarios

5.7.1 CAPEX information

Capital cost data relating to the construction of the WWTP upgrades were provided by Teys and are summarised in Table 26 for the Beenleigh facility and in Table 27 for Rockhampton. The amounts are split between the major works categories on advice from Teys personnel. The cost includes earthworks for the in-ground CALs and Biolac, direct equipment purchase cost (e.g. biogas flares, aeration blowers, CAL liner & cover, etc), transport to site, installation of equipment (structural/electrical/mechanical), protective structures and buildings and commissioning. For both projects, most of these activities occurred over the 2013 – 2014 years.

The Beenleigh upgrade cost almost $8.7 million and the Rockhampton upgrade, $14.2 million. The higher cost of the Rockhampton upgrade reflected:

- difficult site conditions;
- greater distance of the WWTP from the boiler house (including the need for pipelines to go under a major road and railway);
- the Rockhampton design allowed for a significant future increase in production;
- purchase & installation of a new biogas boiler compared to the upgrade of an existing unit at Beenleigh.

The capital costs for the “project” component – the CALs, flare, biogas conditioning, pipeline and boiler/boiler upgrade – were $3.9 million and $11.7 million for Beenleigh and Rockhampton, respectively. The relative split of capital cost between these categories for each site is shown in Figure 38 and Figure 39, respectively.

Table 26. Teys Beenleigh CAPEX

Category	Capital Cost ($)	Inclusions
1	$2,690,514	CAL - Earthworks, structural & civil, CAL liner, vent, pits etc.
2	$607,677	Flare - Slab, structure, flare, chiller, heat exchanger, positive displacement blower, control board, pipework, compressor
3	$4,674,059	Biolac - Design, structural, hydraulics, liner, clarifier, piping etc.
4	$355,266	Biogas pipeline
5	$325,280	Boiler upgrade - redesign to boiler house, dual fire upgrade, boiler house pipework, vent system, burner upgrade etc.
Total	**$8,652,796**	
Sub-total	**$3,980,000**	**Ex Biolac (outside of system boundary for this project)**

Table 27. Teys Rockhampton CAPEX

Category	Capital Cost ($)	Inclusions
1	$7,153,898	CAL - Electrical, hydraulics, civil, structural, stormwater pumps, fire system, liner etc.
2	$1,043,857	Flare - Electrical, infrastructure, slab, piping, chiller etc.
3	$2,454,625	Biolac - Design, commissioning, electrical, hydraulics, mechanical, structural, concrete, basin, controls, blower pipework
4	$966,958	Biogas pipeline
5	$546,058	Biogas boiler itself
6	$1,972,866	Biogas boiler electrical, installation, plumbing, slab, structural etc.
Total	**$14,138,262**	
Sub-total	**$11,680,000**	**Ex Biolac (outside of system boundary for this project)**

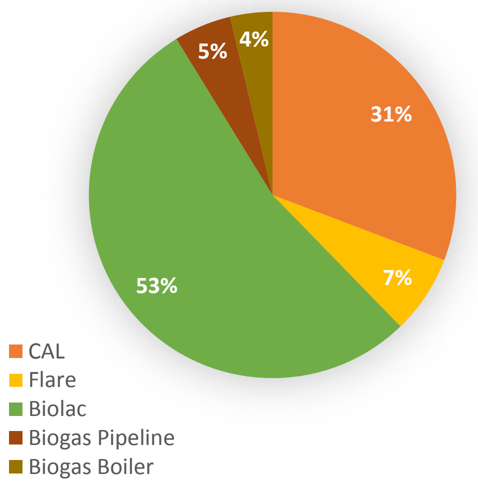


Figure 38. Teys Beenleigh CAPEX contributions

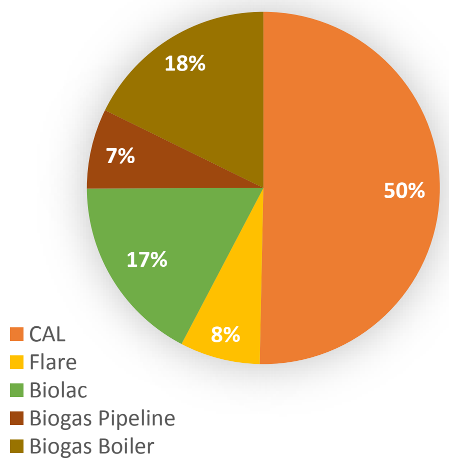


Figure 39. Teys Rockhampton CAPEX contributions

5.7.2 Allocation of CAPEX by Scenario

Table 28 summarises the allocation of capital expenditure for each of the scenarios developed in Section 4.8.1. As noted in that section, Scenario 1- 1b and 2-2b explore the financial return of the Beenleigh and Rockhampton upgrades, respectively using different assumptions.

Scenarios 3 to 6 explore the financial return for a generic meat processing facility of a similar size to the two Teys sites, processing approximately 90,000 tonnes HSCW per year. The diminishing CAPEX allocation for these scenarios reflects their different start infrastructure with less investment required as the scenarios progress.

Table 28. CBA scenario CAPEX summary

#	Capital Cost ($)	Inclusions
1	$1,990,000	Beenleigh WWTP described in Section 5.2 with the portion of funding contributed by CTIP subtracted
1a	$3,980,000	Beenleigh WWTP described in Section 5.2
1b	$3,980,000	Beenleigh WWTP described in Section 5.2
2	$5,840,000	Rockhampton WWTP described in Section 5.4 with the portion of funding contributed by CTIP subtracted
2a	$11,680,000	Rockhampton WWTP described in Section 5.4
2b	$11,680,000	Rockhampton WWTP described in Section 5.4
3	$7,310,000	CAL & flare, biogas boiler, biogas pipeline
4	$4,790,000	CAL & flare, biogas boiler upgrade, biogas pipeline
5	$3,020,000	Biogas boiler and biogas pipeline
6	$830,000	Biogas boiler upgrade and biogas pipeline

5.8 OPEX Data and its Use in the Cost Benefit Scenarios

The annual operating cost for the WWTPs at the two Teys sites are provided in Table 29 and Table 30. Note that this cost is only for the CAL and biogas conditioning and usage component of the WWTP. The component of OPEX for the Biolac BNR plants installed downstream of the CALs at both sites is omitted since they are not strictly within the project boundary. The OPEX relating to the Biolac system is more significant. Since it was not possible to easily separate the maintenance costs for the year to the individual components of the WWTP, the OPEX for the CAL, flare, biogas conditioning system and boiler was assumed to be 50% that of the total WWTP.

Table 29. Teys Beenleigh annual operating expenditure

Expense	Annual Operating Cost ($/year)	Comment
WWTP Operator Labour	$34,560	0.25 FTE
WWTP Maintenance	$36,000	50% of the total maintenance cost for the WWTP (including Biolac).
Total	**$71,000**	

Table 30. Teys Rockhampton annual operating expenditure

Expense	Annual Operating Cost ($/year)	Comment
WWTP Operator Labour	$26,000	0.25 FTE
WWTP Maintenance	$36,000	50% of the total maintenance cost for the WWTP (including Biolac)
Boiler Maintenance	$5,500	1% of boiler capital cost [12]
Total	**$68,000**	

The OPEX for the generic meat processing plant in Scenarios 3 to 6 was taken to be the average of Teys Beenleigh and Rockhampton operating costs as given in Table 31.

Table 31. Annual Operating Expenditure per Scenario

	Annual Operating Cost ($/year)
Scenario 1	$71,000
Scenario 1a	$71,000
Scenario 1b	$71,000
Scenario 2	$68,000
Scenario 2a	$68,000
Scenario 2b	$68,000
Scenario 3	$71,000
Scenario 4	$66,000
Scenario 5	$5,500
Scenario 6	$0

As scenario 4 involves using an existing boiler, the boiler maintenance cost was not included on the basis that maintenance costs would remain largely the same. There is the possibility that the use of biogas rather than the cleaner natural gas may increase operating costs for the boiler, but the quantum of this increase, if any, is unknown.

Similarly, as Scenario 5 already assumes that there is a pre-existing CAL & flare in place prior to the upgrade, the OPEX for the WWTP operator salary and the maintenance for the WWTP equipment is removed. For scenario 6, all of these operating costs can be removed as only a new biogas pipeline is being constructed and an existing boiler is being repurposed. It is assumed that the increment in annual operating cost is negligible.

6 Discussion

6.1 CAL Performance

The CALs installed at both Teys sites performed to design expectations and in the case of Beenleigh, much better than expected. Comparisons of key metrics for the CALs are given in Table 32 for Beenleigh and Table 33 at Rockhampton.

The Beenleigh CAL was fast to commission achieving design performance within 3 months. This was almost certainly due to the inoculation of the new CAL with active anaerobic sludge from the previous anaerobic pond which was still active. The flow and wastewater feed quality was similar to the design values, although the reduced COD of the feed meant that the CAL was performing at the lower end of the preferred design organic load range. For relatively weak wastewater strength there is a compromise between optimal organic load and minimum hydraulic retention time to obtain the required treatment.

As a result of the low organic loading, high organic removal was achieved over the verification year and no crust was reported. The biogas yield was approximately 8,700 m^3/day was in the design range, after allowing for the greater degree of COD removal performance than design.

Table 32. Beenleigh CAL performance

Parameter	Units	Design	Actual
Flow (production day)	ML/day	3.4	3.4
COD in	mg/l	6,000/ 9,000	6,110
BOD in	mg/l	-	2,120
COD out	mg/l	1,200/ 1,800	500
BOD out	mg/l	170 – 230/ 600	78
COD removal	%	80	92
BOD removal	%	NS	96

Table 33. CAL performance at Rockhampton

Parameter	Units	Design	Actual
Flow (production day)	ML/day	4.8/ 6.0	4.5
COD in	mg/l	7,500	5,265
BOD in	mg/l	2,850	2,180
COD out	mg/l	1,500	1,180
BOD out	mg/l	500	278
COD removal	%	80	78
BOD removal	%	NS	87

The Rockhampton CAL performance data do not distinguish between the two CALs installed, since:

- Both CALs discharged into a common outlet pit from where all sampling was conducted;
- CAL2 was off-line early in the verification year while under repair and remained off-line from that point on.

Consequently, the performance of the Beenleigh and Rockhampton CAL are comparable. With CAL2 off-line much of the year, the CAL1 lagoon worked hard at Rockhampton since it was receiving high flows and about 14% higher load than the Beenleigh CAL. Nevertheless it returned near design performance in terms of COD removal and outlet concentrations for COD and BOD_5 were lower than design.

The biogas production is approximately 5,500 $m^{3/}$day, well below the design value of 14,400 m^3/day. The reasons for this include:

- The damage to CAL2 in November 2015 resulted in significant losses of biogas while work was undertaken to repair it and divert wastewater to CAL1;
- The Rockhampton facility was operating at reduced throughput for much of the verification year due to a tight cattle market, which reduced the total weekly load to the CAL1. The design figure assumes 5-day/week operation at full production.
- The incoming wastewater feed was weaker than the design value. Even adjusting the design value for this factor still suggests an amended design biogas production of 10,100 m^3/day – the actual figures is only 55% of this value.

In essence the Rockhampton CAL installation treated the wastewater very effectively but due to the factors mentioned above, the biogas quantity generated fell far short of what can be expected during a normal 5-day/week production year. This shortfall is clearly shown by comparison of the biogas quantities generated at the two facilities for roughly similar incoming organic loads.

6.2 Biogas System Performance

6.2.1 Biogas quantity & quality

The CAL infrastructure installed at both sites operated successfully and robustly to generate large volumes of methane-rich biogas. The methane content of between 67 – 70%v/v at both sites was relatively stable during the production week and falls in the range normally seen for beef processing plants both in Australia [7] and in North America. The high quality of the biogas permits its usage in biogas boilers with relatively little modification required.

Beenleigh's CAL generated large volumes of biogas compared to Rockhampton. The reasons for this are discussed in Section 6.4. Nevertheless, there were excellent reductions in energy and carbon intensity at both sites.

6.2.2 Biogas corrositivity & operating issues

The presence of hydrogen sulphide gas in the biogas is the result of the microbial breakdown of sulphur-containing proteins in the wastewater. The challenges of H_2S in biogas are well known and catalogued in the AMPC/MLA Biogas Manual [8].

Measurements of H_2S in biogas generated by CALs treating meat processing wastewater over the last 5-6 years has shown that H_2S levels fall within a range of 700 – 4,000 ppm [9]. Direct measurements by both JEPL and Airlabs at the Teys sites were within this range. Beenleigh biogas had levels of 1,500 – 1,750 ppm whereas Rockhampton produced biogas with slightly lower H_2S levels at 1,200 – 1,500 ppm. The variation in level was muted both within a production day and over the production week. This is a benefit of positive pressure CAL covers, since it is probably the result of the equalisation of biogas that occurs during storage under the cover prior to extraction.

The primary concern of the presence of H_2S in biogas is corrosion of boiler equipment, especially when the biogas is wet and exposed to high temperatures and oxygen. This is the benefit of chilling the biogas before combustion in the boiler.

At Teys Beenleigh the combustion of biogas in the GE gas boiler for over one year has resulted in no evidence of corrosion of the boiler internals. These are inspected regularly when the boiler is serviced. The lack of corrosion has been attributed by Teys personnel largely to the fact that this boiler runs on a combination of natural gas and biogas. It is started up and shut down on natural gas alone, which allows it to run at a much higher flame temperature than when using biogas alone. This higher temperature prevents oxidised sulphur acids condensing on the boiler internals, which can occur if the exhaust temperatures fall below the dew point.

It is also notable that there is no economiser installed on the Beenleigh gas boiler. It has been widely found that these devices, while valuable for recovering waste heat from stack exhausts, tend to become extensively corroded in biogas applications.

Unlike Teys Beenleigh, the gas boiler at Teys Rockhampton was a purpose-built biogas boiler that was purchased specifically as part of the WWTP upgrade. As Teys Rockhampton use coal as boiler fuel for steam generation, natural gas was unavailable for the start up and shutdown of the biogas boiler. Consequently the boiler burns at a lower flame temperature (as biogas contains approximately 30% inert CO_2). Initially, an economiser was installed in the stack of the Rockhampton biogas boiler to capture waste heat from the flue gases in the stack and transfer it to the incoming boiler feedwater. However, the low combustion temperatures combined with the heat loss through the economiser, meant that flue gases cooled to the point that some of the water vapour in the flue gas was condensing on the finned economiser tubes. This vapour was rich in sulphur, and promptly caused rapid corrosion of the economiser and increased fouling factors due to large deposits of yellow sulphur which inhibit heat transfer efficiency; this can be seen in Figure 40 and Figure 41.

Figure 40. Teys Rockhampton biogas boiler economiser

Figure 41. Sulphur deposits on the Teys Rockhampton economiser

Following the Beenleigh experience, it is likely that if the biogas boiler was able to start up and shut down on natural gas, the resulting higher temperatures in the flue gas may have assisted in minimising the damage to the economiser.

The economiser was subsequently removed once the fouling was noticed. Teys Rockhampton personnel do not note any significant drop in efficiency with the removal of the economiser. Other processors have been known to keep the economiser in place to capture the benefits of increased thermal efficiency, and accept that it needs frequent replacement. This can be fairly expensive however, and may require the boiler to be serviced more frequently to examine the degree of corrosion in the economiser.

This further highlights the need for biogas conditioning to remove water vapour. At both Teys sites, the biogas firstly went through a knockout pot to remove bulk water that condensed in the pipeline between the CAL and the flare pad. Subsequently, the biogas was chilled using glycol refrigerant. The knockout pot and biogas refrigeration systems are proven technology and produced biogas with negligible moisture content (~ 1% by volume)

Overall, the biogas systems at both facilities are working well.

6.3 Reductions in Carbon and Energy Intensity

A primary goal of this project was to reduce the energy and carbon intensity of the Teys facilities through the installation of the CAL technology coupled with use of the biogas for boiler fuel. Table 34 demonstrates that this aim was achieved handsomely, especially for carbon abatement.

For comparison, the latest environmental benchmarking data from the meat processing industry [10] is provided. The baseline values are sourced from the 2008/09 benchmarking study and the verification year values from the 2013 study published in 2015. Some care is needed when comparing the benchmarking numbers from period to period since a different mix of industry facilities typically participate in each study. Nevertheless the industry values give a useful indication of the extent of industry-wide improvement over the timeframe of this project.

Table 34. Improvements in energy & carbon intensity

Parameter	Units	Beenleigh	Rockhampton	Industry
Energy intensity baseline year	MJ/tHSCW	2,820	3,820	4,108
Energy intensity verification year	MJ/tHSCW	2,330	3,490	3,005
Improvement	%	17.4	8.6	26.8
Carbon intensity baseline year	kgCO_2e/tHSCW	628	811	554
Carbon intensity verification year	kgCO_2e/tHSCW	302	496	432
Improvement	%	52.0	38.8	22.0

As noted in Section 5.6.1, the impact of the project on energy and carbon intensity is impressive. The notable achievement being the 52% reduction in carbon intensity, well above the industry improvement and more impressive given that Beenleigh uses natural gas for boiler fuel, which is far less carbon intensive than coal. The 17.4% reduction in energy intensity is also impressive given that Beenleigh started with an already low baseline value relative to the industry. Meat processing is an energy intensive manufacturing process and this project illustrates the challenges implicit in reducing this intensity.

The Rockhampton facility achieved excellent reductions also, but the gain was diminished by the factors summarised in Section 6.1, especially the reduced throughput during the verification year (since energy usage for refrigeration is required for the full 7-day week regardless of the reduced processing days) and the poor recovery of biogas relative to Beenleigh. Despite this, an almost 40% abatement of carbon emissions was obtained, more than 50% better than the industry-wide improvement over a similar period.

6.4 Comparative Analysis of Factors influencing Site Performance

The project allowed comparison of two large beef processing sites operating similar treatment technology to obtain energy reduction and carbon abatement. This section examines which factors might be important in determining these outcomes. This is useful because it allows these influential factors to be carefully considered in future industry projects.

The various factors initially identified as potentially influential in the project outcomes are listed in Table 35 with corresponding values collated for each of the sites. A number of these factors were of little influence in this project. These include:

- **Mean air temperature**, which was essentially the same at each site. Mean air temperature is important in heat loss from lagoons and where there is significant variation between sites (i.e. between a site in Tasmania and Queensland) major impact would be expected. As Table 35 shows, this is not the case here.

- **CAL operating temperature** was very similar and fell in an optimal range for mesophilic anaerobic activity.

- **Animal type and weight (HSCW)** were also very similar between the two sites with a similar mix of grass vs. grain fed animals. It is very unlikely that these factors were influential in the outcomes.

- **Extent of primary treatment.** The primary wastewater treatment at the two sites is quite different. Beenleigh has a reasonably limited primary system, whereas Rockhampton had substantially upgraded its primary system to state-of-the-art equipment prior to the commencement of this project.

  Primary treatment removal of oil and grease upfront protects the CAL from crusting underneath the cover, which stops pipes from blocking and fouling and reduces the likelihood of large quantities of fat aggregating under the cover, which can damage it. However, oil and grease contains higher energy content relative to other wastewater components such as manure, paunch grass and proteins. Removal of oil and grease upfront results in reduced COD loading to the CAL, and thus carbon and energy available for conversion into biogas. This is a challenging compromise for beef processing CAL systems. In the event, both sites had very similar oil and grease evels in the wastewater entering the CALs (~5% difference) so this factor was unlikely to have influence the comparative results obtained.

Table 35. Site comparison (verification year)

Parameter	Units	Beenleigh	Rockhampton
Climate (mean max air temperature)[1]	ºC	26.0	28.4
CAL operating temperature	ºC	34.3	33.7
Production throughput	Tonne HSCW	85,000	80,000
Grass vs. grain fed cattle	% grass fed	60	>50
Average HSCW	kg	300	280
Annual Wastewater Flow to CAL	ML/yr	543	579
Median COD concentration to CAL	mg/L	6,100	5,300
Annual COD load to CAL	tonne COD/yr	3,310	3,070
Raw bypass to Biolac	% of total flow	21	7
Primary treatment	-	moderate	extensive
Oil and grease to CALs	mg/L	650	685
No. of CALs	#	1	2
Anaerobic Volume	ML	28	56
Residence times (CALs)	days	19	18
CAL organic removal performance	% COD rem.	90	78
Fuel being offset	N/A	Natural gas	Coal
Disruption due to severe weather event	N/A	No	Yes

Notes
[1] Data from Bureau of Meteorology (BoM) for Logan City Water Treatment Plant and Rockhampton Airport weather stations.

- **Number of CALs.** Having multiple CALs increases the total anaerobic volume available for treatment of the effluent. Rockhampton has 2 CALs as it was designed with the capacity for expansion of throughput. Assuming that the CALs are appropriately sized for the effluent, this will have no effect on the biogas production. In fact for the majority of the verification year Rockhampton only operated one CAL with the same anaerobic volume as Beenleigh, so this factor will not have affected the total biogas production.

Factors that were more influential in the outcomes observed during the project are identified and discussed below.

6.4.1 Production throughput

Both sites had similar throughput (≈6% difference) during the verification year and at first glance this might suggest this factor is unlikely to have had an impact on the outcomes of this project. However it was a challenging year for the red meat industry in terms of animal supply and the Rockhampton facility was unable to operate the full production week. Inevitably this impacts energy and carbon intensity of production, since refrigeration (which typically consumes 50% of total electricity energy) must continue to operate over the entire week even though throughput is impaired. It is probable that the verification year energy and carbon intensity values represent a worst case scenario for both sites and especially for the Rockhampton facility which invested for future increased production capacity.

6.4.2 Biolac bypass fraction

Most meat processing plants with BNR systems downstream of anaerobic ponds require some bypass of the carbon-rich raw wastewater around the CAL to ensure that the carbon to nitrogen ratio entering the BNR plant is sufficient to drive microbial denitrification for nitrogen reduction. The two sites showed a surprising difference (Table 35) in the extent of this fraction with Beenleigh using 21% bypass and Rockhampton only 7%. Most Biolac systems installed in Australia operate at the higher value used at Beenleigh.

The bypass fraction represents the same sort of treatment integration compromise as oil & grease removal in the primary system. From an energy and carbon intensity viewpoint, it is preferable to maximise biogas production in the CAL and minimise diversion of COD to other uses. Unfortunately, modern activated sludge BNR systems require the bypass, especially when the upstream CALs are too efficient in COD removal (as was the case at Beenleigh).

In part, Johns Environmental prefers SBR BNR technology for this reason since it is possible to use the diverted carbon in the bypass more efficiently in SBRs than the Biolac. This allows typical bypass fractions to be lower with SBR systems which in turn allow better biogas production in the upstream CAL.

It is likely that the higher bypass fraction at Beenleigh was needed due to the high efficiency of the CAL (>90% organic removal). In contrast, the Rockhampton CAL worked at design organic removal which meant that less bypass was required. The difference in bypass fraction would make a large contribution to the results observed. Typically a large bypass (Beenleigh) is detrimental to biogas production. It is likely that the impact has been masked by the problems with CAL damage at the Rockhampton site.

6.4.3 CAL Operating Performance

Increased CAL performance means greater conversion of the incoming COD load into biogas. The Beenleigh CAL was extremely efficient with 90% removal of COD over the verification year compared to 78% at Rockhampton. COD that is removed from the wastewater is converted into biogas. Consequently, the higher efficiency of the Beenleigh CAL was responsible for 15% of Beenleigh's increased biogas production compared to Rockhampton.

6.4.4 Nature of boiler fossil fuel being offset by biogas

The generation of biogas at each of the sites resulted in the offset of the existing fossil fuel that was used for steam generation in the facility. At Beenleigh, this was natural gas, at Rockhampton, it was black coal. The fuel being offset does not have any impact on the generation of biogas in the CALs, but does affect the ease of implementation of biogas use into the existing facility.

Depending on the boiler specifications (specifically maximum allowable H_2S concentrations), biogas and natural gas can often be co-fired together in the same boiler. This is often beneficial and necessary as the combusting of biogas alone can result in poor boiler performance and poorer quality emissions from the stack due to the large inert (CO_2) fraction in the biogas. The natural gas is also often necessary to start up the boiler and bring it to the correct temperature to prevent corrosion due to H_2S. As such, implementation of this system into a facility with existing natural gas combustion has the benefit that a new boiler may not be required depending on the degree of biogas conditioning required prior to combustion. This significantly reduces capital expenditure (see Table 26).

Furthermore, the offset of natural gas with biogas has significant benefits in so far that natural gas is an expensive fuel compared to black coal. Offset of natural gas results in substantial reductions in operating expenditure, which is less notable for sites that use black coal. This will be explored further in the cost benefit analysis section below.

Nevertheless, there are significant environmental benefits to offsetting coal with biogas. Coal has much higher emissions per GJ of heating value compared to natural gas, meaning that each of GJ of coal that can be replaced with biogas substantially reduces the total carbon emissions of the site. It is notable that on the basis of equivalent throughput at both sites, the total carbon abatement is superior at Rockhampton due to the displacement of coal emissions relative to natural gas at Beenleigh (Table 23).

Reduction of carbon emissions would reduce the site's liability under any future carbon emissions trading scheme where the 25,000 tCO_2e threshold to liability is retained as per the original scheme introduced by Rudd's Labour Government. However, this benefit is not carried through under the Turnbull Government.

6.4.5 Severe weather events

Severe weather was almost certainly the overwhelming contribution to the fact that Beenleigh produced significantly more biogas than Rockhampton despite similar throughput in the verification year. During November 2015, a short duration storm resulted in substantial damage to the CAL 2 liner and cover at Teys Rockhampton. For approximately 3-4 months following this event, the biogas produced in that CAL was not captured (although flow to that CAL was also stopped). Fortunately, after some remedial work, the remaining CAL1 treated all the wastewater with biogas capture. Had this weather event not occurred, the biogas captured by the two facilities would probably not have differed as greatly.

6.5 Cost Benefit Analysis

6.5.1 Overview

The cost benefit analysis comprises three separate groups of analyses:

1. An analysis of the Teys Beenleigh and Rockhampton site outcomes under three settings:
    - Performing the analysis on the basis of the Teys investment only (i.e. excluding the CTFFIP contribution towards CAPEX) which is the true basis for the CBA (Scenario 1, Beenleigh; scenario 2, Rockhampton). The verification year value of carbon (zero) was applied since this is the true situation currently.
    - Performing the analysis on the basis of the total investment i.e. including the CTFFIP contribution towards CAPEX (Scenario 1a, Beenleigh; scenario 2a, Rockhampton). The baseline year value of carbon ($23/tonne in the first year of the CPM) was applied to explore the impact of carbon price on the outcome.
    - Performing the analysis on the basis of the total investment i.e. including the CTFFIP contribution towards CAPEX (Scenario 1b, Beenleigh; scenario 2b, Rockhampton). The verification year value of carbon (zero) was applied.
2. An analysis considering a generic meat processing site at which there is no existing infrastructure to produce and capture biogas, condition it and use it to displace fossil fuel. Two sub-groups of plant were evaluated:
    - A generic site using black coal (Scenario 3)
    - A generic site using natural gas (Scenario 4)
3. An analysis considering a generic meat processing site, which has already installed a CAL and biogas flare. The only capital requirement needed is a biogas pipeline to convey the biogas from the flare to a boiler. This analysis has the lowest capital cost of the three. The same two sub-groups of plant are evaluated as for the second analysis:
    - A generic site using black coal (Scenario 5)
    - A generic site using natural gas (Scenario 6)

Table 36 summarises the main outcomes.

Table 36. Summary of the outcomes from the cost benefit analyses

Site	Scenario	Capital Expenditure	Savings	OPEX	Payback period	Annual net benefit (initial)	Net Present Value (NPV)
		$	*$/hd*	*$/hd*	*years*	*$/year*	*$*
Beenleigh	1	$1,990,000	$1.66	$0.24	5	$426,000	$4,040,000
	1a	$3,980,000	$3.71	$0.24	5	$1,041,000	$7,930,000
	1b	$3,980,000	$1.66	$0.24	10	$426,000	$2,240,000
Rockhampton	2	$5,800,000	$0.42	$0.21	N/A	$66,000	-$4,820,000
	2a	$11,700,000	$3.09	$0.21	N/A	$927,000	-$2,140,000
	2b	$11,700,000	$0.42	$0.21	N/A	$66,000	-$10,100,000
Generic	3	$7,310,000	$0.45	$0.24	N/A	$62,000	-$6,200,000
	4	$4,790,000	$1.66	$0.24	13	$425,000	$1,560,000
	5	$3,020,000	$0.45	$0.02	N/A	$62,000	-$1,520,000
	6	$830,000	$1.66	$0.00	2	$425,000	$5,940,000

The following key assumptions have been made in generating the CBA results in the table:

- Capital costs are incurred during the first two years of the project (i.e. during construction & commissioning).
- The WWTP operates over a 20 year lifetime.
- There is no emissions trading scheme in place, except for scenarios 1a and 2a which have a fixed carbon price of $23/tonne CO_2-e since without abatement, both Teys sites would trigger the 25,000 tonne CO_2-e/year Scope 1 emissions threshold and be liable.
- Natural gas burning facilities do not have an Annual Contract Quantity (ACQ) in their natural gas supply contract. This is discussed further below.
- There is a 7% cash discount rate, to account for the time value of money and the opportunity cost of the investment. This is why EBITDA falls in real terms over time in the present value graph below.

6.5.2 Teys Beenleigh & Rockhampton CBA outcomes

The outcome of the three settings for each of the Teys sites is shown in Figure 42 expressed as the net present value (NPV) of scenarios 1 to 2b over the 20 year operational life of the investment. Capital costs are recovered in the form of natural gas or coal savings for all scenarios and the outcome includes the financial savings accruing from the abatement of carbon emissions below the carbon tax liability threshold where applicable (only scenarios 1a, 2a).

Scenarios that have a positive value after the 20 years of operation (Year 22 in the model) are deemed to have paid themselves back over the lifetime of the project.

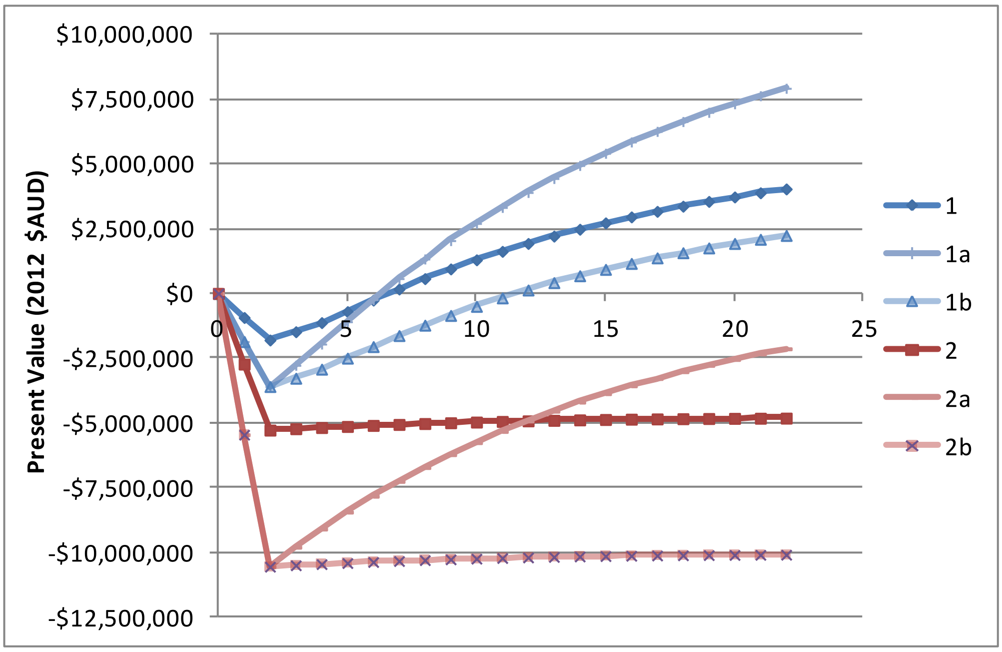


Figure 42. Scenarios 1 to 2b NPV outcomes

Teys Beenleigh outcomes

Scenario 1 is the actual Beenleigh scenario, where the CAPEX figure is the quantity of money that Teys contributed to the project (the other half was supplied in the form of CTIP funding). Comparatively, scenario 1b represents the Beenleigh scenario if CTIP grant funding had not been available and Teys had had to contribute the entire CAPEX budget. Scenario 1a represents a hypothetical scenario in which Teys contributed the entire capital funding for the project (as per scenario 1b) but there was a carbon tax in place with a fixed price of $23/tonne of carbon so that there was ongoing offset of liability (i.e. the facility remained under the liability Scope 1 emissions threshold during the 20 year period).

The primary outcomes for Teys Beenleigh are:

- Scenario 1 had a payback period of 5 years, half that of scenario 1b. This demonstrates that the viability of the project was very dependent on the availability of the CTIP government funding. The loss of the CTIP scheme going forward makes it much more difficult to justify the capital expenditure on the basis of displacement of fossil fuel in boilers alone.

- Scenario 1a also had a payback half that of scenario 1b, despite the exclusion of the CTIP CAPEX contribution under this scenario. This demonstrates the sensitivity of the return on investment to the price of carbon at the settings under the Gillard Labour Government. If a carbon tax were implemented, the savings due to eliminating carbon tax liability would be greater than the fuel savings obtained by substituting fossil fuel with biogas for either a natural gas or coal burning processor. Table 36 indicates that the per head saving is $3.71 compared to $1.66 in the absence of the carbon tax liability.

Natural gas contract impediments

Scenarios 1, 1a and 1b do not consider the fact that Teys Beenleigh has a contract with their natural gas supplier which stipulates an Annual Contract Quantity. This imposes a significant price penalty on the cost of natural gas if a minimum quantity of gas is not consumed. This largely negates any savings from reduced natural gas usage through its displacement by burning biogas, since the penalty is greater than the value of utilising the biogas. It is more economical to flare the biogas and continue to use natural gas for steam generation under the terms of the contract.

This is a strong disincentive for processors using natural gas as boiler fuel with contracts of this type to proceed with substitution of natural gas by biogas. This has not been factored into this CBA and it is important that any processors considering this technology are aware of the contract arrangements with their natural gas supplier.

Despite this, there are still significant savings to be made for a plant with an ACQ in place if a carbon tax is implemented. Alternatively, if a processor is looking to expand their facility's throughput but is at their natural gas pipeline capacity limit, the biogas may provide the additional energy that is needed for the expansion. This ensures that the biogas provides value even if an ACQ is in place.

Teys Rockhampton outcomes

Scenario 2 is the actual Rockhampton scenario, where the CAPEX figure is the quantity of money that Teys themselves contributed to the project (as in scenario 1). Additionally, Rockhampton constructed 2 CALs rather than 1 at Beenleigh, so the capital expenditure is much higher. For these reasons, Scenario 2b examines the same scenario if CTIP grant funding was not available. Scenario 2a is a hypothetical scenario in which a carbon tax was in place for Rockhampton as has been explained for Beenleigh above.

The main outcomes for Teys Rockhampton are:

- As coal is a much cheaper fuel source than natural gas, the savings realised by substitution with biogas are much smaller than Beenleigh ($0.42/head compared to $1.66) and merely cover the operating costs of the WWTP. While this is useful, the annual net benefit for scenarios 2 and 2b are close to negligible. Consequently, this relatively low annual saving and the high CAPEX of the Rockhampton WWTP mean that the investment does not achieve a positive NPV within the project lifetime (Figure 42).

- Black coal has a much greater carbon emission intensity per GJ of embodied energy than natural gas. For scenario 2a, where the carbon tax liability is avoided through investment in the WWTP, the carbon tax liability savings are much more pronounced than for the equivalent Beenleigh scenario 1a. Despite this, the additional savings are insufficient to ensure the WWTP a positive NPV within the project lifetime. The payback period exceeds 20 years.

- The outcomes for Rockhampton are highly sensitive to the introduction of a carbon tax.

Again, it is important to note that intangible benefits of the WWTP have not been included in this analysis and are in addition to the financial benefits considered.

6.5.3 Outcomes for a generic meat processor lacking any biogas infrastructure

To assess the applicability of the project findings to the broader red meat processing industry, the CBA was extended to generic plants with either some or no existing biogas production infrastructure. The scenarios are for facilities processing 90,000 tonnes HSCW per year, with no carbon tax, and no ACQ on their natural gas contracts. The decision tree in Figure 43 can be used by processors to determine which scenario best applies to their facility.

Scenario 3 is for a coal burning processor that is either a greenfield site (i.e. has no existing anaerobic ponds of any kind), or has existing uncovered anaerobic ponds for wastewater treatment. Such a facility would require a CAL & flare, a biogas pipeline to the facility, a new biogas boiler and associated protective structure. This would cost in the vicinity of $7,300,000. Scenario 4 is similar to scenario 3, but is for a natural gas facility, and it assumes that they have an existing boiler which simply requires minor repurposing for use with biogas. The capital cost for this scenario is much less at approximately $4,800,000.

Figure 44 presents the NPV results for scenarios 3 and 4 among others. In essence the outcomes mirror those for the Teys facilities.

- Scenario 3 (the coal burning facility) has a low EBITDA, a significantly negative NPV after 20 years and payback is not achieved. Investment for the returns gained by substitution of coal fuel with biogas in the absence of a carbon tax and any CAPEX support by the government is simply not an economic proposition without other drivers (e.g. odour issues, etc).

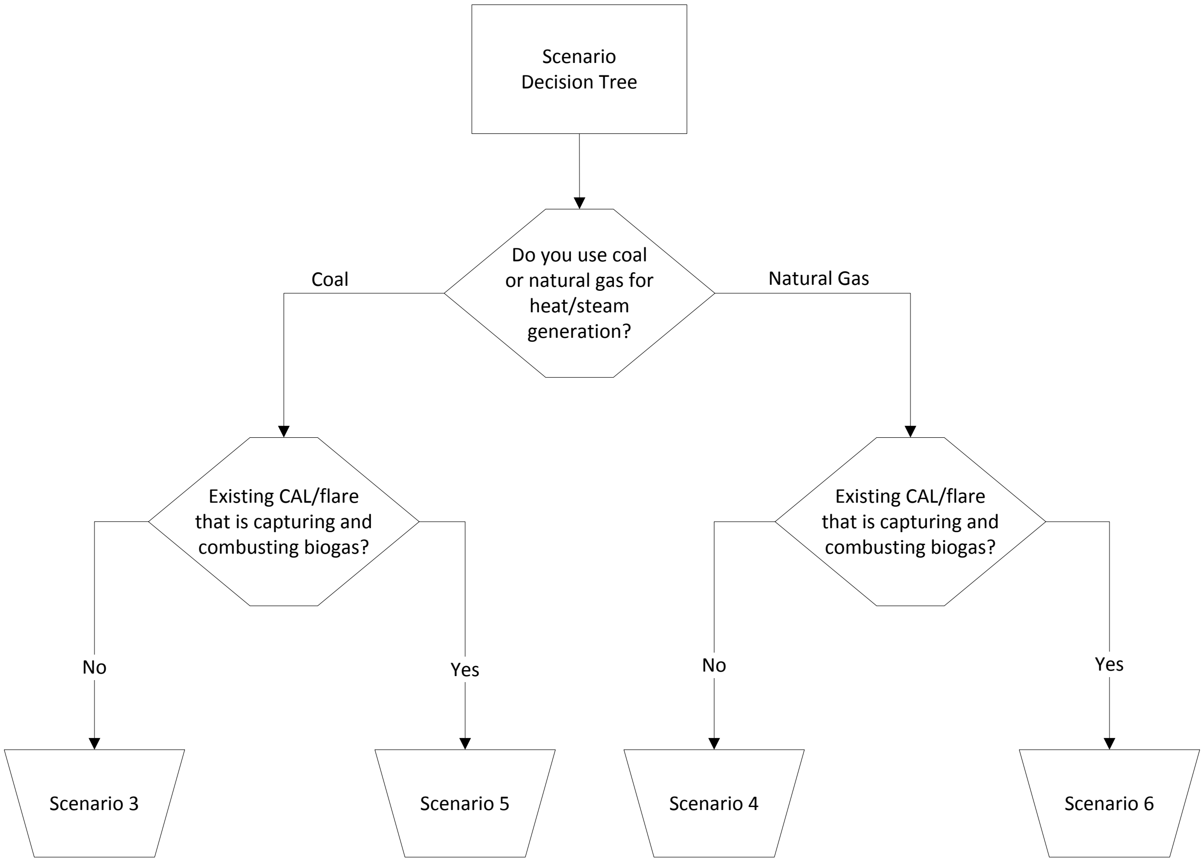


Figure 43. CBA generic scenario decision tree

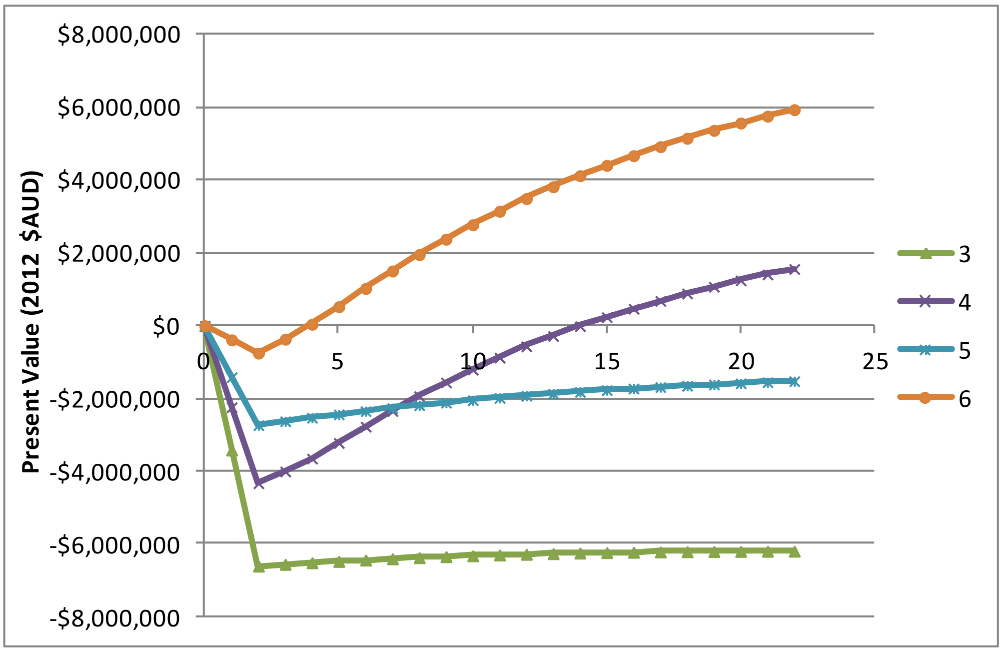


Figure 44 - Scenarios 3 to 6 Present Value Graph

- For the natural gas burning facility (scenario 4) the payback period is 13 years and NPV is positive. The EBITDA is much higher for this scenario as the natural gas is a higher cost fuel than coal and the CAPEX required to gain the benefit is significantly less than that required for the coal plant.

6.5.4 Outcomes for a generic meat processor with existing CAL & flare

Scenario 5 was conducted for a coal burning facility that already had an existing CAL & flare, but which was not reusing any of the biogas in the facility. The biogas was simply flared to destroy odour and the CO_2-e associated with the methane. It is assumed that the investment required to utilise the biogas consists of a biogas pipeline back to the facility and a new biogas boiler and protective structure. This would cost around $3,000,000 in CAPEX.

Scenario 6 is for a similar facility as scenario 5, but burning natural gas. It is assumed the biogas can be reused in the existing boiler. The facility would only require a biogas pipeline and some repurposing of the natural gas boiler. The capital cost is estimated at around $830,000.

Figure 44 presents the NPV results for scenarios 5 and 6. For the coal burning scenario 5 plant, the outcome remains a negative NPV after 20 years, despite the initial low capital investment relative to the others. The savings in coal are insufficient to justify the initial investment of $3,000,000.

Scenario 6 returned the highest NPV and shortest payback period of any of the scenarios where the carbon price was set to zero (Table 36). This is in part due to the low capital investment required, the negligible additional OPEX since little maintenance and labour input is required for the new equipment combined with the large natural gas savings. Processors in this situation (who are looking to expand production, or are without an ACQ in their gas contract) should find this encouraging and would benefit from implementing this technology.

6.5.5 Effect of throughput on payback

A sensitivity analysis was performed for the generic natural gas scenarios 4 and 6 to assess the effect of throughput over the range from 70,000 to 200,000 tonnes HSCW on the payback period required. The results are provided in Table 37. The analysis demonstrates that economies of scale benefit larger plants, because CALs and other process units become cheaper per unit of volume/capacity as they become larger.

Table 37. Payback periods as related to production throughput

Throughput (tHSCW/yr)	**70,000**	**90,000**	**110,000**	**200,000**
Scenario 4	15	13	11	8
Scenario 6	3	2	2	2

6.5.6 Effect of carbon price

A sensitivity analysis was not performed on the effect of carbon price on the outcomes since there appears to be little movement in Australia towards imposing a carbon price and the impact on meat processing facilities depends very much on the threshold setting (tonne CO_2-e/year) at which it would be imposed. The original Rudd government threshold setting for large emitters was 25,000 tCO_2-e/year. At least 10 Australian sites were captured for liability when first introduced in 2012. However, most if not all of these sites now have installed CALs and probably most would fall below the original threshold setting.

The other factor in addition to the threshold, is the actual price of carbon. This report used the original 2012 Australian price for carbon of $23/tonne CO_2-e. The reality is that the current carbon price worldwide in early 2017 is much less. The California cap & trade program spot carbon price is presently US $12 – 13 (approx. AUD15.60) with a small volume of trade [11]. The EU ETS carbon price in the UK for the 2017 year is £4.67 (equivalent to AUD 7.60) although in the UK the government imposes a minimum price of £18/tonne for large industrial emitters. These prices are unlikely to increase significantly in the foreseeable future due to the vast overhang of free carbon credits in the EU market, the uneasy political scene in the western world and the increasingly negative public reaction to increased energy prices (electricity/gas) all of which reduce political will to push pricing of carbon higher.

Consequently, the outcomes concerning the value of savings of carbon tax costs are almost certainly overstated. Small to medium sized facilities will pay no direct carbon tax for the foreseeable future. Large facilities (of which there are an increasing number) may trigger a future carbon tax but it is likely to be set at a price of carbon that is one-third to one half that in this report.

In reality, it is energy costs and security that are more likely to drive Australian use of biogas to displace fossil fuels or electricity than adverse carbon taxes.

7 Conclusions and Recommendations

7.1 Conclusions

1. The CALs designed for both facilities worked well after commissioning, removing 92% and 78% of COD in the first year of operation at Beenleigh and Rockhampton, respectively. BOD removal was 96% and 87% respectively. Stable treatment performance occurred during the verification year.

2. Beenleigh and Rockhampton produced 2,180,000m^3 and 1,390,000m^3 of biogas at average methane contents of 70% and 67% respectively. The methane content is within the usual range observed for beef processing plants. H_2S levels in the biogas were less than 0.2%v/v and varied little with time.

3. Both facilities achieved a high level of biogas use with approximately 85% of the biogas produced being used in the boilers and only a small fraction combusted in the flare. The biogas conditioning (chilling only) and combustion system worked reliably.

4. The WWTP upgrade resulted in both sites significantly reducing their carbon emissions compared to the baseline year.
   a. Teys Beenleigh reduced overall carbon emission intensity by 52% to 302 kg CO_2-e/tonne HSCW. Total carbon abatement over 20 years is estimated as approximately 603,000 tonne CO_2-e.
   b. Teys Rockhampton reduced overall carbon emission intensity by 39% to 496 kg CO_2-e/tonne HSCW. Total carbon abatement over 20 years is approximately 655,000 tonne CO_2-e.

   For comparison, the 2015 industry environment performance review [7] found the industry average red meat processing industry carbon emission intensity was 432 kg CO_2-e/tonne HSCW representing a 22% average reduction from the previous report.

5. The elimination of carbon emissions from wastewater treatment through capture and combustion of biogas was the dominant contribution to the improvement in carbon intensity at both sites. A secondary contributor was substitution of fossil boiler fuels by biogas. This represented significant savings at both sites - Teys Beenleigh saved almost $500,000 per year in natural gas costs (~$1.66/head). Teys Rockhampton saved approximately $135,000 per year in coal costs (~$0.42/head).

6. There was also a reduction, albeit small, in overall energy intensity for both facilities. Beenleigh saw a 17% reduction (to 2,330 MJ/tonne HSCW) and Rockhampton a 9% reduction (to 3,490 MJ/tonne HSCW). This was despite increased electricity consumption related to nutrient removal in the downstream Biolac process.

7. The figures for Rockhampton generally underperform those of Beenleigh. This is most likely due to storm damage to one of the CALs early in the verification year resulting in large biogas losses as seen by the difference in total biogas recovery for a similar annual throughput. Subsequent year results are expected to improve substantially.

8. The Teys Beenleigh WWTP had a payback period of 5 years (with CTIP grant funding) where issues with the ACQ are disregarded, whereas the Teys Rockhampton WWTP did

not pay itself back over the project lifetime. In large part this is due to the much higher CAPEX of the Rockhampton WWTP, the relative cheapness of coal as the fossil fuel source and the much reduced quantities of biogas due to the damage to CAL2.

9. The CTIP government funding resulted in carbon abatement at a cost of \$3.30/tCO_2e at Teys Beenleigh and \$8.85/tCO_2e at Teys Rockhampton. From a purely economic perspective, neither Beenleigh, nor Rockhampton's WWTP upgrades are viable without a carbon tax in place, under which both sites were liable for carbon tax.

10. The financial outcomes reported in this report are highly sensitive to externalities. In particular, the imposition of a carbon tax or an ACQ in the natural gas contract dramatically influence the returns on investment. A carbon tax at the cost of carbon used in this report (\$23/tonne CO_2-e) acts as an enormous incentive for large processors that would exceed the liability threshold. However, given the political flux in the western world and concerns over energy security and price in Australia, the reintroduction of the carbon tax at a rate similar to the original \$23/tonne CO_2-e seems unlikely.

11. The presence of an Annual Contract Quantity in natural gas contracts is a very strong disincentive for any processor considering CAL biogas technology since if the ACQ quantity is not consumed, the financial penalty can overwhelm the value of natural gas saved using biogas substitution. By contrast, most coal burning processors will not have this disincentive.

12. Processors looking to increase their throughput, but limited by utilities, such as natural gas pipeline capacity into the facility, can use the biogas generated by CAL biogas technology to produce the additional steam/heat required to power the upgrade. This is also useful insofar that it allows natural gas burning plants with an ACQ to use the biogas profitably without breaching the ACQ.

13. Processors burning natural gas will have much greater savings in terms of reduced fuel bills upon implementing CAL biogas technology, as natural gas is a much more expensive fuel per GJ of embodied energy (assuming there is no ACQ as mentioned above) than coal. The return on investment of using biogas to displace natural gas is especially excellent where the site already has CAL and flare technology installed but is only flaring the biogas.

14. Coal burning processors only benefit from CAL technology in an economic sense if the coal price was very high (>\$200/tonne), and/or if a carbon tax is implemented, as coal has a much higher carbon emissions intensity than natural gas per GJ of embodied energy. Nevertheless, it is likely that other drivers, such as failing older anaerobic ponds, odour issues and EPA demands for best practice treatment will drive CAL technology adoption in these instances.

15. Significant corrosion occurred in the economiser of the Teys Rockhampton biogas boiler. This is attributed to the fact that natural gas was not used to start up and shutdown the boiler, resulting in H_2S-rich water vapour in the flue gas condensing on the economiser and corroding it.

7.2 Recommendations

1. The 1:1 CAPEX subsidy provided to the two facilities (and other meat processing companies) through the CTIP funding is clearly identified as one of the major factors in stimulating widespread adoption of the CAL and biogas use technology since it permitted company investment with attractive returns on investment. Significantly improved facility and industry-wide environmental outcomes were captured. This subsidy was facilitated by active work including R&D by the industry through MLA and AMPC. No other industry sector received this subsidy. This suggests that future opportunities to support the industry in technology adoption by such R&D should be actively pursued.

2. The presence of an Annual Contract Quantity in natural gas contracts is a strong disincentive for any processor considering CAL biogas technology since if the ACQ quantity is not consumed, the financial penalty can overwhelm the value of natural gas saved using biogas substitution. This results in poor environmental outcomes since it is more economic to flare the useful energy in the biogas than utilise it for gas displacement. Given the widespread use of natural gas in the red meat industry, the concern regarding future supply security and pricing, perhaps this merits an industry-wide investigation of how to tackle the issue.

8 Key Messages

CAL technology is now well proven for application in the red meat processing industry for treatment of large wastewater organic loads with the benefit of energy-rich biogas production. Most elements of wastewater treatment facilities are typically considered to be sunk costs for a processor. This project indicates that the use of CAL-generated biogas in boilers can return value over a long period.

In the absence of a carbon tax with a liability capture threshold set at a level which ensnares meat plants, coal burning sites gain little economic value from capturing and burning biogas in boilers. The payback is typically too long to justify the investment on purely economic terms alone. Nevertheless, other drivers typically may drive the decision.

For meat processing facilities burning natural gas, the economic return of using CAL generated biogas in boilers is far more compelling since natural gas is a more expensive fuel than coal. This is especially true where there is an existing CAL and flare already on-site. In this case, the payback on the additional investment required to pipe the biogas to a refitted boiler can be rapid (< 2 years).

However, for natural gas burning sites, there is a need to ensure that the benefit is not compromised by ACQ clauses in the gas contract which penalise the processor if gas consumption falls below a set amount.

Finally, the project provides further evidence that the biogas generated in CALs at beef processing plants is energy-rich (67 – 70% methane), contains relatively low concentrations of H_2S (< 0.2%v/v), is generated reliably through the typical production week and can be used in boilers will little conditioning other than glycol chilling and some alterations to procedures used to startup and shutdown the boiler.

9 Bibliography

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10 Appendix

10.1 Future energy pricing

The sources of future energy pricing are outlined here.

There are three primary sources of energy consumed on the sites – thermal coal, natural gas and electricity.

It is necessary to get pricing predictions for the three products for 20 years into the future. Generally, the only entities that are willing to forecast that far ahead are Statutory Authorities or Government entities/departments.

10.1.1 Electricity

Electricity pricing forecasts from present-day to 2036 for the state of Queensland were extracted from a report commissioned by the Australian Energy Market Operator (AEMO).

The Australian Energy Market Operator (AEMO) is responsible for operating Australia's largest gas and electricity markets and power systems. As Australia's independent energy markets and power systems operator, AEMO provides critical planning, forecasting and power systems information, security advice, and services to their stakeholders

The report "*Retail electricity price history and projections – Public*", published on 23 May 2016, was commissioned by AEMO and completed by Jacobs Australia Pty Limited.

Data from report page 47, Figure 18: "Comparison of Queensland retail prices by scenario and market" was used for this CBA.

Important issues to note:

1. The report is a very detailed summary of an even more detailed analysis of electricity supply and demand across the entire Australian electricity market. It is important to consider the report's scope, methodology and assumptions when contextualising the resultant electricity price forecasts.
2. Electricity prices are strongly influenced by externalities such as:
    a. extreme weather events,
    b. influence on costs of potential future emissions trading schemes, or,
    c. major shifts in demand – e.g. current contraction of the manufacturing sector.

10.1.2 Gas

Wholesale gas pricing forecasts for the Brisbane demand node from present-day to approximately 2040 were extracted from a report commissioned by the Australian Energy Market Operator (AEMO).

The report "*AEMO – Gas Price Consultancy*", published in August 2015, was commissioned by AEMO and completed by Core Energy Group Pty Limited.

Data from report page 11, Figure 2.5: "The movement in retail delivered price for major R&C demand nodes under the reference scenario" was used for the basis of this CBA.

Important issues to note:

1. The report is a very detailed summary of an even more detailed analysis of gas supply and demand across the entire Australian wholesale gas market. It is important to consider the report's scope, methodology and assumptions when contextualising the resultant gas price forecasts.
2. Gas prices are strongly influenced by externalities such as:
    a. Wholesale contract costs,
        i. Oil price linkage
        ii. Production costs
        iii. Availability of supply source
    b. Transmission costs
        i. pipeline capacity reservation/utilisation, and
    c. Peak supply costs
        i. Pricing linked to export LNG supply contracts
        ii. Decline in peak demand
        iii. Availability of peak supply
3. Typically large gas users enter into supply agreements which can have significant:
    a. capacity management issues if the meat processing facility plans to expand production, or
    b. penalty clauses which may become a significant cost if the natural gas is supplemented or replaced by biogas.

10.1.3 Coal

Thermal coal pricing forecasts from present-day to approximately 2030 are based on Australian thermal coal export price forecasts. The data has been generated by the Australian Government's Treasury for the purpose of informing its long-run forecasts of Australia's Terms of Trade [13].

Forecasts used do not reflect the immediate past and current volatility in Australian export coal prices.

There is little public data on the domestic price forecasts for thermal coal. This is partly due to:

1. The local market being highly fragmented.
2. Demand is fulfilled through local supply contracts where transport is a significant cost to the consumer. Very little domestic coal consumption, outside power stations' demands, is transported by rail due to it not being practical nor economic for the contracted haulage company.