



final report

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Solids Anaerobic Digestion Plant Cost Benefit Analysis

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1. Pilot Plant Details

The following details have been summarised from the report provided by the Environmental Biotechnology CRC Pty Limited, entitled "Solids digestion pilot study at Teys Bros Beenleigh (Extension), MLA Project A.ENV.0099", dated 20th January 2011.

| Plant | Function | Volume | Temperature | Residence time |
|-------|--------------|--------------------|-------------|----------------|
| R1 | Pretreatment | 20 m ³ | 60 °C | 2-4 days |
| R2 | Digester | 95 m ³ | 35 °C | 12-20 days |
| Total | | 115 m ³ | | 14-24 days |

Please note that although the installed volume was 115 m³, the effective volume was approximately 90 m³ (ie 78% of total installed capacity, 10m³ of R1 and 80m³ of R2). For a full scale operation, reactors would run at effective volume of 85% of installed capacity (pers comm, Paul Jensen, UQ).

| Parameter | Details |
|----------------------|--|
| Capital cost | \$350 K for 115 m ³ , or \$3 K per m ³ installed 65 % process vessels, 35 % ancillaries |
| Feed characteristics | 2-5 % solids Green wastewater ¹ , 2010 and 2011 sampling (95 % CI) Volatile solids % of Total Solids 71-86 % (79-85 %) Volatile solids % of COD 48-50 % (90-92%) Paunch ² , (95 % CI) Volatile solids % of Total Solids 86 % (89 %) Volatile solids % of COD 76 % (73 %) |
| Loading | 40 kg volatile solids (VS) per day or 0.5 kg VS/m ³ /day (based on 90 m ³ effective volume or 0.39 kg VS/m ³ /day based on total volume of 115m ³). This was 40 % of the design loading rate and was used |

¹ 2010 based on 48 measurements, 2011 based on 43 measurements, figures in brackets are error margins indicating 95% confidence intervals

² based on 27 measurements, figures in brackets are error margins indicating 95% confidence intervals

| Parameter | Details | | | | | | | | | |
|--------------------------------|--|-----------------------|-----|--------|-----------------------|-----|-----------------------|---------------------|-----|--------|
| | due to blockages and other operational issues. | | | | | | | | | |
| Heating demand | 2.4 kWh/ m ³ / day (or 8.64 MJ/ m ³ / day) provided by: <ul style="list-style-type: none"> • 10.8 kW electric hot water system (not metered) • Biogas (50 m³ per day or 30-35 m³ methane per day) to meet entire heating load. This equates to 1,885 MJ/day, based on 37.7 MJ/ m³ conversion factor for biogas (from NGER) and includes a 50% margin to allow for inefficiencies. | | | | | | | | | |
| Labour | 0.5 FTE | | | | | | | | | |
| Electrical demand ¹ | 2.4 kWh/ m ³ / day, made up of: <ul style="list-style-type: none"> • Mixing, 24 hours per day, 93% of total • Pumping, 1.5 hours per day, 2% of total • Macerating, 5 hours per day, 5% of total | | | | | | | | | |
| Repairs & Maintenance | \$6.4K in 14 months for replacement parts ie 0.02% of capital cost (excluding labour) | | | | | | | | | |
| Biogas production | 240 L methane per kg VS loaded or 9,600 L methane per day. Based on a conversion factor of 0.0377 MJ/L methane, this equates to 361.92 MJ per day. Note that the biogas went directly to an onsite boiler and was metered. | | | | | | | | | |
| Energy balance | <table> <tbody> <tr> <td>Heat input required</td> <td>778</td> <td>MJ/day</td> </tr> <tr> <td>Biogas energy content</td> <td>326</td> <td>MJ/day (41% of total)</td> </tr> <tr> <td>Gross energy demand</td> <td>452</td> <td>MJ/day</td> </tr> </tbody> </table> <p>ie 140% of biogas production</p> <p>Basically, the biodigester does not produce enough biogas to meet its own heating requirements.</p> | Heat input required | 778 | MJ/day | Biogas energy content | 326 | MJ/day (41% of total) | Gross energy demand | 452 | MJ/day |
| Heat input required | 778 | MJ/day | | | | | | | | |
| Biogas energy content | 326 | MJ/day (41% of total) | | | | | | | | |
| Gross energy demand | 452 | MJ/day | | | | | | | | |

Notes:

1 – optimised electrical demand for a full scale system is reported as using 0.01-0.02 kW per m³ per hour, which equates to 0.05 – 0.25 kWh/ m³/ d.

It should be noted that the above feed characteristics are similar to those previously published by E. P. Taiganides ("Animal Wastes, 1977), which indicated that beef cattle wet excreta waste was 4.6% of the total live weight per day and volatile solids were 83% of total solids.

2. Plant Sizing

The sizing of a full sized paunch digester would depend on:

- the solids percentage of the feed,
- the required residence time,
- effective volume (compared to total volume),
- the proportion of the sites paunch waste that was to be treated and
- the size of the site (head per day)

The pilot plant was located at a beef only processing plant. The following analysis provides an indication of sizing for a beef plant. This indicated that 0.35 – 0.6 m³ of biodigester volume per head of beef cattle is required to treat 100% of paunch material. If the solids percent is higher, water may be need to dilute the feed material, meaning a greater volume biodigester is required.

| Parameter | Details |
|------------------------|---|
| Beef paunch (mass) | 20kg per head, 5% of live weight or 10% of HSCW (based on 50% LW → HSCW conversion) |
| Solids % | 6% (as received ie assumes wet dumping) |
| Residence time | Shortest – 14 days Longest – 24 days |
| Effective volume | 85% |
| Required system volume | 0.33 – 0.56 m ³ per head |

3. Full size paunch digester

The following table summarises the details proposed by the researchers as being applicable for a full sized digester.

| Parameter | Details | | | | | | | | |
|---------------------------|--|------------|--------------------------------|---------------------------|--------------------------------|-----------------------|------------------------------|------------------|-------------------------------|
| Capital cost | \$1.5 K per m ³ installed with 5% contingency, 25 year operating life and 85% effective volume | | | | | | | | |
| Feed composition | 6 % solids | | | | | | | | |
| Feed rate | 2 kg VS/ m ³ / day (4 times what was used in trial) | | | | | | | | |
| Heating demand | 2.4 kWh/ m ³ / day (or 8.64 MJ/ m ³ / day) provided by heat from boiler (which is fired partly with biogas). | | | | | | | | |
| Electrical demand | 2.4 kWh/ m ³ / day | | | | | | | | |
| Repairs & Maintenance | Assumed to be 4% of capital cost (including labour) ie \$0.06 K per m ³ installed | | | | | | | | |
| Labour | 0.25 FTE operations | | | | | | | | |
| Biogas production | 240 L methane per kg VS loaded or 480 L methane per m ³ per day. Based on a conversion factor of 0.0377 MJ/ L methane, this equates to 18 MJ per m ³ per day. | | | | | | | | |
| Energy balance | <table> <tbody> <tr> <td>Heat input</td> <td>8.64 MJ / m³/ day</td> </tr> <tr> <td>(corrected³)</td> <td>10.8 MJ / m³/ day</td> </tr> <tr> <td>Biogas energy content</td> <td>18 MJ / m³/ day</td> </tr> <tr> <td>Energy available</td> <td>7.2 MJ / m³/ day</td> </tr> </tbody> </table> <p>or 70% of biogas used to heat biodigester and 30% available for offsets.</p> <p>Not that in this instance, there is energy available after heating requirements are met, as the loading rate is four times that used in the trial, so the biogas production rate is four times also.</p> | Heat input | 8.64 MJ / m ³ / day | (corrected ³) | 10.8 MJ / m ³ / day | Biogas energy content | 18 MJ / m ³ / day | Energy available | 7.2 MJ / m ³ / day |
| Heat input | 8.64 MJ / m ³ / day | | | | | | | | |
| (corrected ³) | 10.8 MJ / m ³ / day | | | | | | | | |
| Biogas energy content | 18 MJ / m ³ / day | | | | | | | | |
| Energy available | 7.2 MJ / m ³ / day | | | | | | | | |

³ Corrected for boiler efficiency, assumes 80%

| Parameter | Details | |
|--------------------|----------------------------|--|
| Greenhouse balance | Savings | |
| | Biogas emission (BAU case) | 480 L methane/ m ³ / day or 0.93 kgCO _{2-e} / m ³ / day ⁴ |
| | Gas offset | 7.2 MJ/ m ³ / day 0.37 kgCO _{2-e} / m ³ / day |
| | Emissions | |
| | Biogas combustion | 740 L/ m ³ / day ⁵ or 0.13 kgCO _{2-e} / m ³ / day |
| Net savings | | 1.17 kgCO_{2-e}/ m³/ day |

Data that would be specific to a site would include:

| Required data | Assumed for this CBA |
|---------------------------------|----------------------|
| Required payback period | 2 years |
| Electricity tariff | 10c/kWh |
| Natural gas tariff | \$10/GJ |
| Boiler efficiency | 80% |
| Project Life | 25 years |
| Plant size | 625 head/day |
| Labour saving – paunch handling | 0.75 FTE |
| Transport fuel saving - paunch | \$10,000 |

⁴ Biogas and gas offset: 480L x 0.0377MJ/L x 0.05133 kgCO_{2-e}/MJ

⁵ 480L x 100/65 = 740L, offset = 480L x 0.00483 kg CO_{2-e}/MJ x 0.0377 MJ/L x 100/65

4. Results

Paunch in added to the system on working days, but the system requires mixing and heating every day. The table below outlines the base case (using the parameters from section 3) and sensitivities to different parameters. **This indicates that the economics are most sensitive to the boiler fuel price reductions and capital cost increase.** If the capital cost rises above \$2,100 per m³, then the payback period will be over 2 years.

| Case | \$/head | Payback period (years) | Annual net benefit \$K | NPV \$M | Capital \$M | IRR | Grant \$M | \$/tCO _{2-e} abated |
|---|---------|------------------------|------------------------|---------|-------------|-----|-----------|------------------------------|
| Base (best case) | -851 | -11.7 | -532 | -11.6 | 6.25 | | n/a | |
| Base + ↓25% boiler fuel + ↑25% electricity cost + | 51 | 195 | 32 | -5.5 | 6.25 | | 6.19 | 260 |

In the base case, the grant required to achieve a 2 year payback would be over \$7M, as the plant loses over \$0.5M each year. As appendix 1 indicates, electricity is the greatest cost (\$365K/year), with repairs and maintenance next (\$250K/year). If the R&M could be reduced to 1% of capital cost (or less), the electricity and gas price increased by 25% and the electricity use reduced to the minimum reported (0.05 kWh/m³/day) then there would be an annual saving. In this instance, the grant required would be \$6.19M (out of a total capital cost of \$6.25M and the \$ invested per tonne of CO_{2-e} abated would be \$260 (compared to a carbon price of \$25/t).

Appendix 1 - details of base case

| CBA Outputs | | | | | | | | | | |
|-----------------|---------------|-------------|------------|--------------------|-------------|---------------|-----------------|-------------------------|----------------------|--------------|
| \$ /head saving | | -\$ 827 | | Annual net benefit | | -\$ 516,951 | | Capital investment | | \$ 6,250,000 |
| Payback period | | -12.1 years | | Net Present Value | | -\$11,471,334 | | Internal Rate of Return | | #NUM! |
| Year | Capital cost | Costs | | | Savings | | | Annual cash flow | Cumulative cash flow | |
| | | Elect | R&M | Labour | Boiler fuel | tCO2-e | Paunch handling | | | |
| 0 | -\$ 6,250,000 | | | | | | | -\$ 6,250,000 | -\$ 6,250,000 | |
| 1 | | -\$365,000 | -\$250,000 | -\$ 20,000 | \$ 24,250 | \$ 23,799 | \$ 70,000 | -\$ 516,951 | -\$ 6,766,951 | |
| 2 | | -\$365,000 | -\$250,000 | -\$ 20,000 | \$ 24,250 | \$ 23,799 | \$ 70,000 | -\$ 516,951 | -\$ 7,283,901 | |
| 3 | | -\$365,000 | -\$250,000 | -\$ 20,000 | \$ 24,250 | \$ 23,799 | \$ 70,000 | -\$ 516,951 | -\$ 7,800,852 | |
| 4 | | -\$365,000 | -\$250,000 | -\$ 20,000 | \$ 24,250 | \$ 23,799 | \$ 70,000 | -\$ 516,951 | -\$ 8,317,802 | |
| 5 | | -\$365,000 | -\$250,000 | -\$ 20,000 | \$ 24,250 | \$ 23,799 | \$ 70,000 | -\$ 516,951 | -\$ 8,834,753 | |
| 6 | | -\$365,000 | -\$250,000 | -\$ 20,000 | \$ 24,250 | \$ 23,799 | \$ 70,000 | -\$ 516,951 | -\$ 9,351,704 | |
| 7 | | -\$365,000 | -\$250,000 | -\$ 20,000 | \$ 24,250 | \$ 23,799 | \$ 70,000 | -\$ 516,951 | -\$ 9,868,654 | |
| 8 | | -\$365,000 | -\$250,000 | -\$ 20,000 | \$ 24,250 | \$ 23,799 | \$ 70,000 | -\$ 516,951 | -\$10,385,605 | |
| 9 | | -\$365,000 | -\$250,000 | -\$ 20,000 | \$ 24,250 | \$ 23,799 | \$ 70,000 | -\$ 516,951 | -\$10,902,555 | |
| 10 | | -\$365,000 | -\$250,000 | -\$ 20,000 | \$ 24,250 | \$ 23,799 | \$ 70,000 | -\$ 516,951 | -\$11,419,506 | |
| 11 | | -\$365,000 | -\$250,000 | -\$ 20,000 | \$ 24,250 | \$ 23,799 | \$ 70,000 | -\$ 516,951 | -\$11,936,457 | |
| 12 | | -\$365,000 | -\$250,000 | -\$ 20,000 | \$ 24,250 | \$ 23,799 | \$ 70,000 | -\$ 516,951 | -\$12,453,407 | |
| 13 | | -\$365,000 | -\$250,000 | -\$ 20,000 | \$ 24,250 | \$ 23,799 | \$ 70,000 | -\$ 516,951 | -\$12,970,358 | |
| 14 | | -\$365,000 | -\$250,000 | -\$ 20,000 | \$ 24,250 | \$ 23,799 | \$ 70,000 | -\$ 516,951 | -\$13,487,308 | |
| 15 | | -\$365,000 | -\$250,000 | -\$ 20,000 | \$ 24,250 | \$ 23,799 | \$ 70,000 | -\$ 516,951 | -\$14,004,259 | |
| 16 | | -\$365,000 | -\$250,000 | -\$ 20,000 | \$ 24,250 | \$ 23,799 | \$ 70,000 | -\$ 516,951 | -\$14,521,210 | |
| 17 | | -\$365,000 | -\$250,000 | -\$ 20,000 | \$ 24,250 | \$ 23,799 | \$ 70,000 | -\$ 516,951 | -\$15,038,160 | |
| 18 | | -\$365,000 | -\$250,000 | -\$ 20,000 | \$ 24,250 | \$ 23,799 | \$ 70,000 | -\$ 516,951 | -\$15,555,111 | |
| 19 | | -\$365,000 | -\$250,000 | -\$ 20,000 | \$ 24,250 | \$ 23,799 | \$ 70,000 | -\$ 516,951 | -\$16,072,062 | |
| 20 | | -\$365,000 | -\$250,000 | -\$ 20,000 | \$ 24,250 | \$ 23,799 | \$ 70,000 | -\$ 516,951 | -\$16,589,012 | |
| 21 | | -\$365,000 | -\$250,000 | -\$ 20,000 | \$ 24,250 | \$ 23,799 | \$ 70,000 | -\$ 516,951 | -\$17,105,963 | |
| 22 | | -\$365,000 | -\$250,000 | -\$ 20,000 | \$ 24,250 | \$ 23,799 | \$ 70,000 | -\$ 516,951 | -\$17,622,913 | |
| 23 | | -\$365,000 | -\$250,000 | -\$ 20,000 | \$ 24,250 | \$ 23,799 | \$ 70,000 | -\$ 516,951 | -\$18,139,864 | |
| 24 | | -\$365,000 | -\$250,000 | -\$ 20,000 | \$ 24,250 | \$ 23,799 | \$ 70,000 | -\$ 516,951 | -\$18,656,815 | |
| 25 | | -\$365,000 | -\$250,000 | -\$ 20,000 | \$ 24,250 | \$ 23,799 | \$ 70,000 | -\$ 516,951 | -\$19,173,765 | |

Appendix 2 - details of best case

| CBA Outputs - with grant | | | | | | | | | | |
|--|---------------|-----------|------------|------------------------|-------------------|-----------|-----------------|-------------------------|----------------------|--------------|
| \$/head saving | | \$ | 51 | Annual net benefit | | \$ | 32,107 | Capital investment | | \$ 6,250,000 |
| Payback period | | | 194.7 | years | Net Present Value | | -\$5,447,333 | Internal Rate of Return | | -12% |
| Grant required to meet required payback period | | \$ | 6,185,787 | grant \$/tCO2-e abated | | | \$260 | | | |
| Year | Capital cost | Costs | | | Savings | | | Annual cash flow | Cumulative cash flow | |
| | | Elect | R&M | Labour | Boiler fuel | tCO2-e | Paunch handling | | | |
| 0 | -\$ 6,250,000 | | | | | | | -\$ 6,250,000 | -\$ 6,250,000 | |
| 1 | | -\$ 9,505 | -\$ 62,500 | -\$ 20,000 | \$ 30,313 | \$ 23,799 | \$ 70,000 | \$ 32,107 | -\$ 6,217,893 | |
| 2 | | -\$ 9,505 | -\$ 62,500 | -\$ 20,000 | \$ 30,313 | \$ 23,799 | \$ 70,000 | \$ 32,107 | -\$ 6,185,787 | |
| 3 | | -\$ 9,505 | -\$ 62,500 | -\$ 20,000 | \$ 30,313 | \$ 23,799 | \$ 70,000 | \$ 32,107 | -\$ 6,153,680 | |
| 4 | | -\$ 9,505 | -\$ 62,500 | -\$ 20,000 | \$ 30,313 | \$ 23,799 | \$ 70,000 | \$ 32,107 | -\$ 6,121,573 | |
| 5 | | -\$ 9,505 | -\$ 62,500 | -\$ 20,000 | \$ 30,313 | \$ 23,799 | \$ 70,000 | \$ 32,107 | -\$ 6,089,467 | |
| 6 | | -\$ 9,505 | -\$ 62,500 | -\$ 20,000 | \$ 30,313 | \$ 23,799 | \$ 70,000 | \$ 32,107 | -\$ 6,057,360 | |
| 7 | | -\$ 9,505 | -\$ 62,500 | -\$ 20,000 | \$ 30,313 | \$ 23,799 | \$ 70,000 | \$ 32,107 | -\$ 6,025,253 | |
| 8 | | -\$ 9,505 | -\$ 62,500 | -\$ 20,000 | \$ 30,313 | \$ 23,799 | \$ 70,000 | \$ 32,107 | -\$ 5,993,147 | |
| 9 | | -\$ 9,505 | -\$ 62,500 | -\$ 20,000 | \$ 30,313 | \$ 23,799 | \$ 70,000 | \$ 32,107 | -\$ 5,961,040 | |
| 10 | | -\$ 9,505 | -\$ 62,500 | -\$ 20,000 | \$ 30,313 | \$ 23,799 | \$ 70,000 | \$ 32,107 | -\$ 5,928,933 | |
| 11 | | -\$ 9,505 | -\$ 62,500 | -\$ 20,000 | \$ 30,313 | \$ 23,799 | \$ 70,000 | \$ 32,107 | -\$ 5,896,826 | |
| 12 | | -\$ 9,505 | -\$ 62,500 | -\$ 20,000 | \$ 30,313 | \$ 23,799 | \$ 70,000 | \$ 32,107 | -\$ 5,864,720 | |
| 13 | | -\$ 9,505 | -\$ 62,500 | -\$ 20,000 | \$ 30,313 | \$ 23,799 | \$ 70,000 | \$ 32,107 | -\$ 5,832,613 | |
| 14 | | -\$ 9,505 | -\$ 62,500 | -\$ 20,000 | \$ 30,313 | \$ 23,799 | \$ 70,000 | \$ 32,107 | -\$ 5,800,506 | |
| 15 | | -\$ 9,505 | -\$ 62,500 | -\$ 20,000 | \$ 30,313 | \$ 23,799 | \$ 70,000 | \$ 32,107 | -\$ 5,768,400 | |
| 16 | | -\$ 9,505 | -\$ 62,500 | -\$ 20,000 | \$ 30,313 | \$ 23,799 | \$ 70,000 | \$ 32,107 | -\$ 5,736,293 | |
| 17 | | -\$ 9,505 | -\$ 62,500 | -\$ 20,000 | \$ 30,313 | \$ 23,799 | \$ 70,000 | \$ 32,107 | -\$ 5,704,186 | |
| 18 | | -\$ 9,505 | -\$ 62,500 | -\$ 20,000 | \$ 30,313 | \$ 23,799 | \$ 70,000 | \$ 32,107 | -\$ 5,672,080 | |
| 19 | | -\$ 9,505 | -\$ 62,500 | -\$ 20,000 | \$ 30,313 | \$ 23,799 | \$ 70,000 | \$ 32,107 | -\$ 5,639,973 | |
| 20 | | -\$ 9,505 | -\$ 62,500 | -\$ 20,000 | \$ 30,313 | \$ 23,799 | \$ 70,000 | \$ 32,107 | -\$ 5,607,866 | |
| 21 | | -\$ 9,505 | -\$ 62,500 | -\$ 20,000 | \$ 30,313 | \$ 23,799 | \$ 70,000 | \$ 32,107 | -\$ 5,575,760 | |
| 22 | | -\$ 9,505 | -\$ 62,500 | -\$ 20,000 | \$ 30,313 | \$ 23,799 | \$ 70,000 | \$ 32,107 | -\$ 5,543,653 | |
| 23 | | -\$ 9,505 | -\$ 62,500 | -\$ 20,000 | \$ 30,313 | \$ 23,799 | \$ 70,000 | \$ 32,107 | -\$ 5,511,546 | |
| 24 | | -\$ 9,505 | -\$ 62,500 | -\$ 20,000 | \$ 30,313 | \$ 23,799 | \$ 70,000 | \$ 32,107 | -\$ 5,479,440 | |
| 25 | | -\$ 9,505 | -\$ 62,500 | -\$ 20,000 | \$ 30,313 | \$ 23,799 | \$ 70,000 | \$ 32,107 | -\$ 5,447,333 | |