PROJECT SUMMARY

Project Number and Title: 4C-119 ***Bio-upgrading piggery biogas by growing algae, for value-add end uses***

Project Leader: Paul D. Jensen

Project Participants:
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Aims and Objectives:
The core goal of the technologies was to remove H_2S and CO_2 from piggery biogas to improve the safety of piggery biogas and to increase CH_4 concentration (not amount).

Aims related to the development of PPB (purple phototrophic bacteria) technology to remove H_2S from biogas were to:

1. Investigate a fully autotrophic process for sulphide removal via PPB to estimate sulphide removal rates as well as biomass yield.
2. Demonstrate PPB based sulphide removal in a continuous process and identify important design parameters for a full-scale process.
3. Assess the viability of a continuous PPB based sulphide removal process, including comparison to existing desulfurization technologies.

Aims related to development of algae technology to remove CO_2 from biogas were to:

1. Integrate effluent treatment with biogas purification using a saline microalga, which has not been done before.
2. Determine the growth characteristics, biomass composition and maximum quantum yields marine microalga *Tetraselmis suecica* using synthetic biogas as a source of CO_2, and ADPE as a source of nutrients.
3. Explore the impact of pH and the resulting CO_2 partial pressure on microalgae growth.
4. Assess the effect of CH_4 in biogas on microalgal cultivation of *Tetraselmis sp.*

Key Findings:
Key findings from PPB work:
The project was successful at proof-of-concept using PPB to reduce the H_2S content of biogas.

The impacts of nutrient medium and light intensity were tested using batch experiments. The PPB process was able to utilise CO_2 in the biogas as a carbon source and nutrients in anaerobic digestion centrate for growth with no significant decrease in performance. Light intensity was shown to have a significant impact of sulphide removal rates. The average volumetric sulphide removal rate from low intensity light (27 $W.m^{-2}$) was 1.79 $mgS.L^{-1}.h^{-1}$. The average volumetric sulphide removal rate from higher intensity light (56 $W.m^{-2}$) was 2.9 $mgS.L^{-1}.h^{-1}$.

The PPB utilised inorganic carbon (i.e., CO_2) at the theoretically expected ratio of 2 mole carbon per mole H_2S. Considering the relative concentrations of CO_2 and H2S in biogas, the CO_2 used for PPB growth would not reduce the CO_2 concentration of the biogas in a meaningful way.

A continuous PPB desulphurization process was developed and applied to treat a synthetic biogas mixture containing 2000 ppm H_2S, 30% CO_2 and ~70% CH_4. The process achieved an average H_2S removal of 69-77% in the continuous process, with a maximum removal of 90%. The average residual H_2S concentration in the gas was 575 ppm. Initial designs for a continuous process indicated a H_2S loading rate of 10 $g.h^{-1}.m^{-3}$ can be achieved, corresponding to a reactor size of less than $1m^3$ for a 500 SPU piggery. Mass transfer of H_2S into the liquid phase was identified as the primary limiting factor limiting H_2S removal performance. Hydraulic retention times of 2 – 4 days can be used to manage the pH in the reactor and therefore allow the process to operate without chemical addition, and the shorter 2-day retention times allow for a higher and more optimal pH.

Protein-rich PPB biomass was generated in the process. While protein rich biomass is a potential high-value by-product of PPB technology, the production rates within the process were very low and not sufficient to generate any significant revenue to offset the high treatment cost.

Key findings from algae work:

The project was successful at proof-of-concept using the marine algae *T. suecica* to remove CO_2 and waste nutrients in a batch biogas-effluent treatment process.

Experiments tested the impact of culture pH and associated CO_2 content on algae growth. In general, there was an increase in biomass productivity as the pH set point decreased, with the highest biomass productivity of 59.8 $mg.L^{-1}.d^{-1}$ found at pH set point of 7.5. In terms of composition, lipid and carbohydrate productivities appeared to mirror the overall biomass productivity results. *Fq'/Fm'* were above 0.68 for experiments with pH control, indicating that the algae was not subjected to any significant stress. However, when pH was not controlled the Fq'/Fm' values were found to decrease gradually over the light period and further decreased to a low of 0.55 during the dark period. Values below 0.6 typically represent a level of stress.

The average CO_2 capture efficiencies of *T. suecica* cultures varied between 83% and 94% in the tests, with the highest CO_2 removal of 94% occurring at pH 7.5. This corresponds to the maximum overall algal growth also at pH 7.5. The algal biomass fixed carbon at rates between 20.7 and 24.2 $mgC.L^{-1}.d^{-1}$; representing the rates of CO_2 removal and consumption.

Experiments used piggery effluent after anaerobic pond treatment (ADPE) as a source of nutrient for algae growth. The ADPE was added to seawater to generate a saline nutrient medium (approx. 20 mL ADPE per L media). The diluted ADPE did not show any apparent inhibitory effects on the growth of *T. suecica*, with > 90% of nitrogen removed in the experiments and up to 73% of the phosphorous removed.

Additional experiments tested the impact of CH_4 content on algae growth. The results suggested an adaptation period. However, the system recovered and across the whole experiment, CH_4 in the test gas did not show a significant effect on the growth rate or Fq'/Fm' values of *T. suecica* at the pH 7.5 set point.

Applications to Industry:

Applications of PPB work:

The project was successful at proof-of-concept using purple phototrophic bacteria to treat a gas mixture containing 2000 ppm H_2S, 30% CO_2 and ~70% CH_4 in a continuous process. The process achieved an average H_2S removal of 69-77% in the continuous process, with a maximum removal of 90%. The process can run chemical-free and can integrate with existing anaerobic pond technologies. The removal efficiencies achieved in the project reduced H_2S to levels suitable for on-farm uses such as boilers, CHP and microturbines, and therefore represent an alternative to conventional iron sponge scrubbers for on farm use. However, multi-stage rectors or a secondary treatment step would be required to achieve complete H_2S removal required for transport fuel uses and/or export into natural gas grids.

Currently, the cost of the PPB process was estimated at approximately \$85 kgS^{-1}; which is prohibitively high. The major cost for the PPB process is the electricity used to irradiate the reactor overnight, and these irradiation costs would need to be eliminated for PPB desulphurization to be viable. Research would be required into the continuous process dynamics under light-dark-cycling conditions, where light is only available for ~12 hours of the day (i.e., during daylight hours). PPB biomass was generated in the process. While protein rich biomass is a potential high-value by-product of PPB technology, the production rates within the process were very low and not sufficient to generate any significant revenue to offset the high treatment cost.

Applications of algae work:

The project was successful at proof-of-concept using the marine algae *T. suecica* to remove CO_2 and waste nutrients in a batch biogas-effluent treatment process. The process achieved a CO_2 removal up to 94%. When applied to piggery biogas, the treated biogas could have a CH_4 content of 94 to 98%, making the upgraded gas suitable for use as a transport fuel (after compression) or to export biogas into centralised natural gas grids. Nutrients were removed from the wastewater during treatment; however, due to the high nutrient content of piggery wastewater, only a small portion of the available waste nutrients (~6% nitrogen and ~1% phosphorous) appear required to support sequestration of all CO_2 in the piggery biogas.

The process supported relatively good biomass productivity (59.8 $mg.L^{-1}.d^{-1}$). Most importantly, no inhibitory effects were seen from the CH_4 content of the synthetic biogas. The next stage of development could be to explore a continuous process, possibly at pilot stage, to clarify the biomass yields, carbon uptakes rates, harvesting costs and allow a more detailed assessment of the viability of biogas-based microalgae cultivation systems.