Biogas from sugarcane
Project results and lessons learnt

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Contact name: Professor Ian O'Hara	
Title: Project Manager	
Email: i.ohara@qut.edu.au	**Phone:** (07) 3138 1551
Website: https://research.qut.edu.au/biorefining/projects/biogas-from-sugarcane/	

Report authors: I. O'Hara, P. Kaparaju, P. Paulose, F. Plaza, C. Henderson, A. Latif, Z. Zhang, W. Doherty, L. Moghaddam, A. Baker, M. Renouf, K. Mirskaya, N. Ketsub, H. Asad

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Table of Contents

Project Summary

The *Biogas from Sugarcane* project addresses an opportunity to reduce or completely replace the use of fossil fuels in sugarcane transport with biomass derived fuels from sugarcane processing by-products, and hence reduce production costs, increase revenue, reduce GHG emissions from sugar production and improve the sugar industry sustainability and viability.

The project concept is based on the use of sugarcane trash and / or bagasse as a bioenergy feedstock with the potential to be converted into fuels to replace diesel in sugarcane transport and in sugarcane production. In this project, sugarcane trash is anaerobically digested to produce biogas and upgraded to compressed biomethane. The residue from this process, known as digestates, is converted to a diesel-like fuel via hydrothermal liquefaction (HTL).

The project was undertaken in four stages with pilot scale demonstration of the associated technologies in each project stage and include:

1. Assessing the supply chain for sugarcane harvest residues including a novel system for separating trash from sugarcane;
2. Developing and demonstrating biomass pretreatment and anaerobic digestion technologies to produce biogas;
3. Demonstrating the upgrading of biogas to biomethane for use as a renewable transport fuel in sugarcane production and transportation; and
4. Developing and demonstrating a process for the hydrothermal liquefaction (HTL) of digestate to convert organic wastes to diesel-like fuel for use in the factory for process heating or upgrading to renewable diesel.

Analysis has identified that the digestion and upgrading of as little as 10% of the available trash from sugarcane regions would satisfy the requirements to replace diesel use in sugarcane and sugar products transport. Supply chain modelling work undertaken in the project assessed the relative supply chain costs of various sugarcane trash collection strategies. It was identified that, while there are regionally specific issues associated with the availability of sugarcane trash, in general the lowest cost trash collection strategy is to collect trash during harvesting and transport it to the factory for separation from the cane prior to milling. The novel QUT trash separation and recovery technology has demonstrated that it is fit for purpose but requires commercial scale validation.

The project results identified that several different mild biomass treatments improved glucan digestibility and hence enhanced biogas production. However, steam explosion pretreatment was selected as the preferred pretreatment technology because no catalyst was used, a short treatment time, and a small reactor footprint compared to other treatments. Laboratory scale anaerobic digestion trials indicated that optimum conditions were achieved at organic loading rates of around 2.5 g VS/L/day and achieved methane yields of ~210 L/kg.VS and methane concentrations of 53-55% in the biogas.

HTL trials of digestate resulted in a biocrude yield of around 40% with the biocrude having a higher heating value of 33 MJ/kg. Thermal analysis of the oils indicated that the oils were predominantly of a light oil fraction that can be readily be upgraded to diesel. The aqueous phase resulting from the HTL treatment underwent further HTL treatment to produce hydrogen and methane.

Techno-economic modelling was undertaken for two scenarios. Scenario 1 includes the full process design that includes trash separation, pretreatment, biogas production and upgrading, and biocrude production from digestate. In Scenario 2, biocrude production from digestate via HTL was not included and digestate was instead produced as a biofertiliser.

The modelling results show that Scenario 1 provides a significantly greater financial return than Scenario 2. This outcome results from the significantly greater energy conversion of the sugarcane trash into energy products in Scenario 1 from the HTL of anerobic digestion residues. HTL is at a lower level of commercial readiness than anaerobic digestion technologies, however, is rapidly advancing given the significant amount of development in this area both in Australia and internationally.

The supplementation of the sugarcane trash feedstock with around 10-20% of other wastes such as food waste or manure leads to significantly improved financial viability and provides an extremely attractive option for creating a viable project. It would be valuable to explore potential food waste or manure options in the vicinity of potential project locations.

The processing of sugarcane trash into biomethane and biocrude oil products shows significant potential for commercial viability. The analysis shows that it is worthwhile to progress to develop a business case for potential facilities with consideration given to the scale of the facility, offtake agreements for surplus biomethane produced, and assessment of co-digestion feedstocks within the local area of proposed facility locations.

The greenhouse gas (GHG) implications of producing biogas from sugarcane trash were assessed. This was done by estimating the changes in GHG emissions when sugarcane trash is collected and used as a biomass feedstock to produce biogas and renewable diesel derived from a biocrude oil. Emissions reductions were calculated using accepted GHG accounting methods based on environmental life cycle assessment (LCA).

In producing the biogas and biocrude oil products, additional emissions are generated from trash separation and the process inputs including electricity and urea. However, these additional emissions are more than offset by the avoided emissions from the assumed displacement of CNG and diesel, resulting in an overall net reduction of around 8,000 t $CO_{2\text{-}e}$/y for a facility processing 35,000 t/y sugarcane trash.

In summary, this project has developed new capacity and capability for bioenergy and biogas related research in Australia. In particular, development of an integrated biogas reactor, compression and upgrading system, and HTL technology will be of significant value to the Australian research and bioenergy communities.

Project Overview

Project scope

Introduction

The Australian sugar industry delivers products worth over $2 billion per year and is the third largest exporter of raw sugar globally. In addition to crystal sugar, the sugar industry is a significant producer of bioenergy (steam and electricity) from sugarcane bagasse for use in co-located industrial processes with surplus electricity exported to the grid.

While the sugar industry produces large amounts of bioenergy, significant quantities of petroleum-based fuels are used in growing, harvesting and transporting sugarcane, and in factory operations (up to 5 L/t sugarcane). This fuel use results in a significant cost burden (~$3 /t sugarcane) to the industry.

Opportunity

The *Biogas from Sugarcane* project has identified opportunities to reduce fossil fuel use across the sugar industry. Currently there are three major sources of fossil fuel consumption in sugarcane production and sugar processing:

- Diesel use on-farm in farm machinery for planting, cultivation and harvesting;
- Diesel use in sugarcane and sugar products transportation; and
- Coal use as a supplementary fuel for cogeneration (mostly during the non-crushing season in factories with co-located industries operating year-round).

The opportunity is to reduce or completely replace the use of these fossil fuels with biomass derived fuels from sugar processing by-products, hence reducing production costs, increasing revenue, reducing GHG emissions from sugar production and improving industry sustainability and viability.

The project concept is based on the use of sugarcane trash and / or bagasse as a bioenergy feedstock with the potential to be converted into fuels to replace diesel in sugarcane transport and in the future in sugarcane production. In this project, sugarcane trash is anaerobically digested to produce biogas and upgraded to compressed biomethane. Digestate from the process is upgraded to a diesel-like fuel via hydrothermal liquefaction (HTL).

Preliminary analysis has identified that the digestion and upgrading of as little as 10% of the available trash from sugarcane regions would completely satisfy the requirements for diesel use in sugarcane and sugar products transport. Sugarcane transportation occurs in dedicated fleets of trucks or via rail that could be upgraded to utilise compressed biomethane fuels. Surplus biogas or biomethane is potentially available for use to reduce supplementary fuel use in sugar factory boilers and for sale as a fuel to other regional heavy transport enterprises.

Producing biogas from sugarcane project has the potential to turn create new bioenergy opportunities for the sugar industry by:

- Producing sufficient transport grade biomethane to displace diesel used in harvesting, sugarcane and product transport operations;
- Providing an opportunity to displace ancillary coal use in cogeneration boilers;
- Reducing the carbon footprint of raw sugar and refined sugar production; and

- Increasing income from electricity export and the sale of biofuels to industrial and agricultural users.

Challenges and barriers

In realising this opportunity, the key challenges and barriers identified in developing an effective and economic process are:

- Developing a supply chain for the recovery and supply of sugarcane trash (and / or bagasse) that delivers the biomass to the process at a cost-effective price;
- Developing a cost-effective pretreatment process for the sugarcane biomass that results in high yields of biogas from anaerobic digestion;
- Optimising the anaerobic digestion process to deliver high biogas yields with minimum capital and operating costs;
- Demonstrating the application of biogas upgrading technology in Australia; and
- Developing technology to further recover energy from the residual organic materials in the digestate.

Figure 1 Sugarcane harvesting in Australia

Outcomes

Assessing the supply chain for sugarcane harvest residues including a novel system for separating trash from sugarcane

Sugarcane harvest residues (trash) are an underutilised resource in sugarcane production. The collection, transport and separation of trash can be expensive and cost-effective processes are required for an economically viable biogas production process. Trash recovery technologies can be categorised based on the following strategies:

- Trash is separated from the sugarcane during harvesting and recovered from the field in a post-harvest operation (e.g. via raking and baling);
- Trash is separated from the sugarcane and recovered during the harvesting operation (e.g. dual harvesting bins); or
- Trash is harvested with the sugarcane crop and transported to a factory-based separation plant where the trash is recovered prior to processing of the sugarcane.

Supply chain modelling work was undertaken in the project to assess the relative supply chain costs of these options based on case study factory areas. It was identified that, while there are regionally specific issues associated both with the availability of sugarcane trash and with the optimal solutions, in general the lowest cost trash collection strategy for large scale trash collection is to collect trash during harvesting and transport to the factory for separation from the cane prior to milling. Raking and baling of trash for transportation will also be a viable technology in some applications.

While biomass recovery technologies through processes such as raking and baling are well understood, there is no effective factory scale technology for efficient sugarcane trash separation that meets efficiency and environmental performance targets. To this end, QUT with the support of Sugar Research Australia, developed a novel factory-scale trash separation technology based on a non-pneumatic separation technology, with minimal billet loss, high efficiency, low energy requirements and a smaller physical and environmental footprint than technologies in operation in other countries.

The *Biogas from Sugarcane* project supported the further development of the novel trash separator technology through the installation of a pilot scale trash separator and the conduct of separation trials at the Rocky Point sugar mill in Woongoolba, Queensland. As a result of these trials, improvements to the unit were made that resulted in a 290% increase in throughput with increased separation efficiency. Figure 2 shows harvested sugarcane in buckets before feeding to the cane pilot cleaner and the separated leaves and billets after processing. The pilot scale non pneumatic cane cleaner has a throughput of approximately 20 t/h at 74% separation efficiency for an initial cane supply trash content of approximately 4% by mass, with minimal billet loss and no sucrose loss. Data from the trials were used to inform an engineering design of a full-scale commercial trash separator for 150 t/h operation.

Figure 2 Novel QUT trash separation technology inputs (top left), removed trash (bottom left), and de-trashed sugarcane output, (right)

Developing and optimising biomass pretreatment and anaerobic digestion technologies to produce biogas

Sugarcane processing residues like bagasse and trash are carbohydrate-rich feedstocks and have the potential to produce biofuels such as biogas. However, commercial biogas production from lignocellulosic agricultural residues is limited in Australia because of the low biogas yield and productivity of these recalcitrant materials. Pretreatment processes physically and/or chemically alter the structures of lignocellulosic biomass and improve the yield of sugars and organic acids, which can be more readily converted to biogas in anaerobic digestion. However, pretreatment also leads to an increase in biogas production cost and it is necessary to develop low-cost biomass pretreatment processes for cost-effective biogas production.

The recovery of the energy within the pretreated sugarcane trash in the form of biogas occurs through the process of anaerobic digestion. Anaerobic digestion is a biological process where organic waste is converted into biogas by microorganisms under anaerobic conditions. In engineered systems, biogas is produced through fermentation of various organic wastes including manure, municipal sewage sludge, industrial wastes and energy crops. Sugarcane bagasse and trash is not currently used for biogas production and the process needs optimisation and pilot scale demonstration prior to commercialisation at full factory scale.

This project assessed a wide variety of biomass pretreatment technologies to identify a preferred pretreatment technology and optimise pretreatment conditions to maximise biogas yields with minimal pretreatment costs. Pretreatment trials were undertaken both at the laboratory scale (QUT, Brisbane) and at the pilot scale at the Mackay Renewable Biocommodities Pilot Plant which is based on a sugar mill site in Mackay, Queensland. Figure 3 shows the pilot scale biomass pretreatment reactor that was used.

Figure 3 Pilot scale biomass pretreatment reactor at the Mackay Renewable Biocommodities Pilot Plant

High temperature pretreatments were undertaken with liquid hot water, dilute sulfuric acid or dilute alkali (at low catalyst concentrations) while low temperature pretreatments were undertaken with alkali catalysts at higher catalyst loadings.

Anaerobic digestion trials (Figure 4) were undertaken at Griffith University, Brisbane in both batch fermentation and continuous stirred tank reactors to determine biomethane potential, and optimise key process parameters including inoculum to substrate ratio, codigestion ratio, dry fermentation for high solids digestate production, carbon / nitrogen supplementation, and trace nutrient requirements.

Figure 4 Laboratory scale anaerobic digestion trials at Griffith University

The pretreatment and biogas production results showed that for liquid hot water and dilute acid pretreatment, sugar degradation products such as furans could inhibit the biomethane production. Dilute alkali pretreatment did not inhibit BMP production, however, alkali salts presented issues with recovery and reuse of the liquid streams.

The project outcomes identified that mild treatments based on steam explosion, liquid hot water, dilute acid, or dilute alkali pretreatments all improved glucan digestibility to enhance biogas production. Steam explosion was selected as the optimal pretreatment technology based on having no catalyst cost, short treatment time, and a small reactor size compared to other treatments.

Laboratory scale anaerobic digestion trials indicated that optimum conditions were achieved at organic loading rates of around 2.5 g VS/L/day and achieved methane yields of ~200 L/kg.VS and methane concentrations of 53-55% in the biogas.

Development of pilot scale integrated biogas reactor and biomethane upgrading system

Prior to this project there were no pilot scale or commercial scale biogas upgrading facilities in Australia that enabled the testing and demonstration of biogas to transport fuel-grade biomethane. Prior to use in vehicles, the methane component of the biogas must be purified through removal of carbon dioxide and other potential contaminants to a concentration of ~95% methane and compressed to increase the energy density of the fuel.

As a result, one of the key focus areas of this project was the development of an integrated biogas production facility and biogas upgrading facility to produce fuel quality biomethane.

Biogas reactors were developed in accordance with a design by Utilitas Pty Ltd and Griffith University. The installation consisted of 2 x 1.2 m^3 stirred tank biogas reactors, 2 x 1.2 m^3 hydraulic mixed reactors, 20 m^3 biogas storage bag, and 10 m^3/h raw biogas upgrading unit with high pressure compressor and gas bottling units and other associated feeding and ancillary systems (Figure 5-Figure 6).

There are several commercial technologies available in the market for biogas upgrading based on adsorption, absorption (physical and chemical), permeation and cryogenic processes. These technologies primarily focus on the separation of methane (CH_4; typically present at around 50–70% by volume in raw biogas) and carbon dioxide (CO_2; 25–45% in raw biogas). While several of the technologies can also remove moderate concentrations of other contaminants, most processes require additional processes for reduction of other contaminants such as water, H_2S and siloxanes (if present) prior to CO_2 removal.

Technologies available for impurity removal include water scrubbing, pressure swing adsorption, chemical scrubbing, cryogenic, physical adsorption, membrane separation. For this project, a biogas upgrading unit based on high pressure water scrubbing technology was purchased from Metener Oy, Finland (Figure 6). This unit is capable of treating 10 m^3/h of raw biogas to increase biomethane concentrations to ~96% and compress through a three-stage compressor to 200 bar. The installation also includes a filling station and 2 x 50 L gas storage bottles.

The biogas production and upgrading system was installed at the Mackay Renewable Biocommodities Pilot Plant in Mackay, Queensland. Picture of the installation is shown in Figure 5 and Figure 6.

Figure 5 Pilot-scale integrated biogas production and upgrading unit

The biogas upgrading process was optimised with a synthetic biogas mixture (commercial gas standard) of 60% methane and 40% carbon dioxide by volume. The product gas (biomethane) quality of 96% methane was achieved.

Figure 6 Biogas upgrading unit

Upgrading of digestates to produce a high heating value liquid fuel

Typically, digestate resulting from anaerobic digestion are beneficially applied to land to supply nutrients for crop growth. When lignocellulosic biomass *e.g.*, trash is anaerobically digested, the digestate that results is lignin-rich and with a high energy content. Hydrothermal liquefaction (HTL) technology is a suitable technology to convert the lignin-rich digestate into products including resins and high heating value fuels. A diagram of conversion of sugarcane trash or bagasse to drop-in fuel presented in Figure 7.

Compared to other thermochemical methods for biomass conversion to energy and chemicals, such as pyrolysis and gasification, HTL requires wet biomass as feedstock and so avoids the need for high energy requirements for biomass drying. During the process about 85% of oxygen in biomass can be removed as carbon dioxide and water. The HTL bio-oils have oxygen contents of 10-20%, which are lower in comparison to that of the pyrolysis bio-oils, and so have higher calorific values.

Figure 7 Schematic of the conversion of sugarcane trash/bagasse to drop-in fuel

In this project, the HTL trials of digestate resulted in a biocrude yield of ~40% having a higher heating value of 33 MJ/kg. Thermal analysis of the oils gave a maximum temperature of volatilisation of ~160 °C, indicating that the oils were predominantly of a light oil fraction that can be readily be upgraded to good quality fuel. Compositional analysis of the biocrudes showed that they contained phenyl-based hydrocarbons, high energy density straight chain hydrocarbons (C12-C24), and straight chain carboxylic acids such as n-hexadecanoic acid (*e.g.*, palmitic acid). Ammonium phosphate (25 wt%) fertiliser by-products were also obtained. Fractional distillation of the biocrude via vacuum distillation determined that fuel yields were greater than 75% of biocrude oil processed.

Analysis of the gas phase from HTL showed that most of the gases produced by the HTL process are linear and branched alkanes and alcohols of carbon chain sizes C3 to C5. Organic acids such as formic and acetic acid were also detected. Thus, in a commercial plant, these hydrocarbons (and H_2) can be recycled to the HTL for deoxygenation of the biocrude, increasing its energy content.

The aqueous phase contains many types of glycolic and polyol substances as well as organic acids such as formic acid and levulinic acid. The chemical oxygen demand (COD) of the aqueous phase was high and of a composition that allows it to be recycled back to the anaerobic digestion process. In another phase of the project, the aqueous phase was treated by HTL to produce hydrogen and methane, and process water.

A continuous HTL pilot reactor at the QUT Banyo pilot was used to demonstrate the upgrading of the digestate at pilot scale (Figure 8). The QUT continuous pilot reactor is capable of processing up to 10 L/h of feedstock and is supported by several auxiliaries including an air compressor, a chilled cooling water system, process water and exhaust and ventilation systems. The reactor is housed in a 20-foot shipping container divided via a blast wall into two segregated rooms. The first room is used to house the continuous reactor components operating at high temperature and pressure, whilst the other room is used by the operator for sample preparation, collection, and monitoring.

Figure 8 Continuous HTL reactor: feed tank (left) and operator's room (middle), reactor piping (right)

A total of 18.4 L was processed through the continuous reactor over 4.5 h and 10.4 L of aqueous product collected from the exit of the reactor for laboratory analysis. Total biocrude produced using the continuous reactor was 44.6%, which was composed of DEE fraction (30.9%) and acetone fraction (13.7%). The total solid residue was 16.8%.

Techno-economic assessment of the process

A techno-economic analysis of the process was undertaken for a sugarcane region processing 35,000 t of trash into biomethane and biocrude oil. The analysis is based on processing sufficient trash to supply biomethane to meet the full energy needs for sugarcane transportation to this factory and ancillary processing requirements. While sugar factories typically operate for ~22 weeks per year, the analysis assumes that the biogas production plant operates for 52 weeks of the year and biomethane produced during the non-crushing season is stored for use during the crushing season.

This extended season operation also requires an amount of trash to be stored for processing in the non-crushing season.

There are opportunities to increase the capacity of the process to supply biomethane to other industry participants (e.g. for use in harvesters and farm machinery) and also for sale to commercial customers in the region depending on the profitability and demand for the biomethane product.

Techno-economic modelling was undertaken for two scenarios. Scenario 1 includes the full process design that includes trash separation, pretreatment, biogas production and upgrading, and biocrude production from digestate. In Scenario 2, biocrude production from digestate via HTL was not included and digestate was instead produced as a biofertiliser.

The techno-economic model was based on the best available data produced from project experimental results, mass and energy balances, and literature. From 35,000 t of trash (4.1 t/h), approximately 5,840 t (4.5 million m^3) of biogas is produced. Following removal of the CO_2 and other impurities and compression to 200 bar, around 1,700 t (8,100 m^3) of compressed biomethane is produced. This equates to around 91,000 GJ of biomethane.

In both scenarios, a nutrient rich stream is produced that can be applied to sugarcane fields as a biofertilizer. Between 146,000 and 157,000 tonnes of these streams are produced across both scenarios. These streams will contain similar quantities of nutrients, but the digestate will also contain a higher quantity of organic carbon. From HTL, approximately 7,800 t (~9.0 ML) of biocrude oil is produced for sale to a refinery to be upgraded into hydrocarbon fuels.

Scenario 1 provides a significantly greater financial return than Scenario 2. This outcome results from the significantly greater energy conversion of the sugarcane trash into energy products in Scenario 1 that results from the HTL of anerobic digestion residues. HTL is at a lower level of commercial readiness than anaerobic digestion technologies, however, is rapidly advancing given the significant amount of development in this area both in Australia and internationally.

This analysis shows that the co-digestion of other waste feedstocks and sugarcane trash leads to significantly improved financial viability and provides an extremely attractive option for creating a viable project. It would be valuable to explore potential food waste or manure options in the vicinity of potential project locations.

The processing of sugarcane trash into biomethane and biocrude oil products shows significant potential for commercial viability. The analysis shows that it is worthwhile to develop a business case for a potential facility with consideration given to the scale of the facility, offtake agreements for surplus biomethane produced and assessment of co-digestion feedstocks within the local area of the proposed facility location.

The project will likely be implemented into an existing, operational sugar mill and based on demonstrated economics for that specific installation. Preliminary and detailed engineering are required to determine overall plant size, validate project economics, and inform a timeframe for delivery. Approvals are required at local and state levels both for the development and operational licences. Key process equipment requires significant timeframes for manufacture and delivery, with construction activities needing to be timed around mill crushing season operations before commissioning of the entire plant at full capacity allows for final integration into the operating sugar mill.

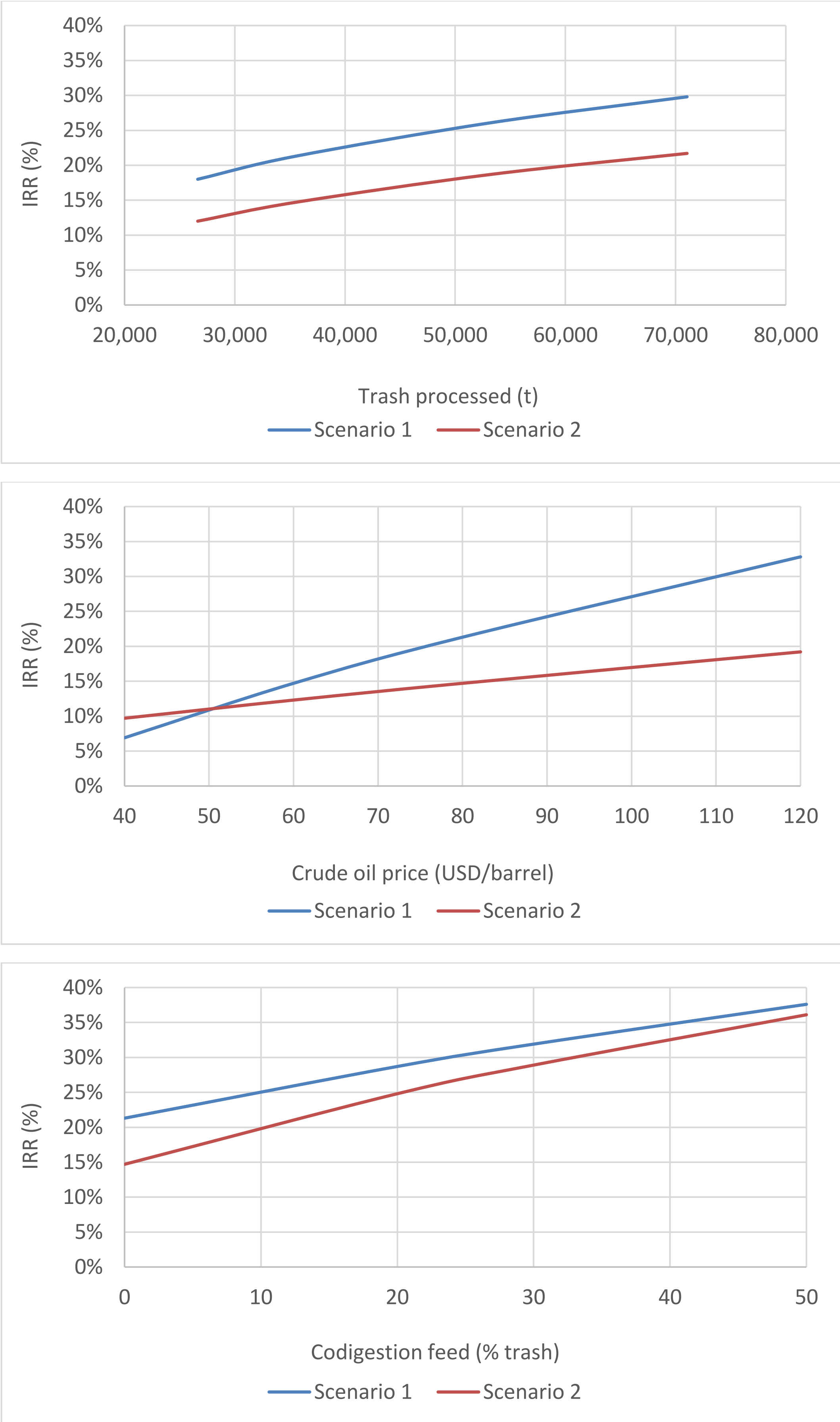

Figure 9 Impact of throughput (top), oil price (middle) and codigestion (bottom) on project IRR

Greenhouse gas sustainability benefits of the process

The project quantified the greenhouse gas (GHG) implications of producing biogas from sugarcane trash. This was done by estimating the changes in GHG emissions when sugarcane trash is collected and used as a biomass feedstock to produce biogas and renewable diesel from the biocrude oil. Emissions reductions were calculated using accepted GHG accounting methods based on environmental life cycle assessment (LCA).

Figure 10 shows the GHG emissions over the life cycle of products derived from sugarcane systems. They include carbon dioxide (CO_2) but also nitrous oxide (N_2O) and methane (CH_4) emissions. In GHG accounting methods, a distinction is made between fossil CO_2 that is counted, and biogenic CO_2 that is not counted. Biogenic CO_2, such as that generated from burning biomass or biogas, is not counted because it is regarded as a short-term release considered part of the natural biogenic carbon cycle and assumed to be re-fixed by biomass growth.

GHGs are generated along all steps in the supply chain, including the production of farming inputs (especially fertilisers), on-farm cane growing activities (diesel combustion in tractors and harvesters, use of coal-derived electricity for irrigation), and in the downstream processing of cane or cane residues to make products.

The project concept for producing biogas from sugarcane is expected to reduce GHG emissions due to the displacement of fossil fuel when the bio-energy products substitute fossil-fuel equivalents in the market. However, processing of trash into the bioenergy products introduces new GHG emissions associated with the input of electricity and other inputs. This analysis evaluates the GHG implications by comparing emissions from the biogas production process with emissions from the 'baseline' process, in line with approved methods used in carbon credit schemes. These methods focus on the processes that change as a result of the transition from the 'baseline' system to the 'project' system.

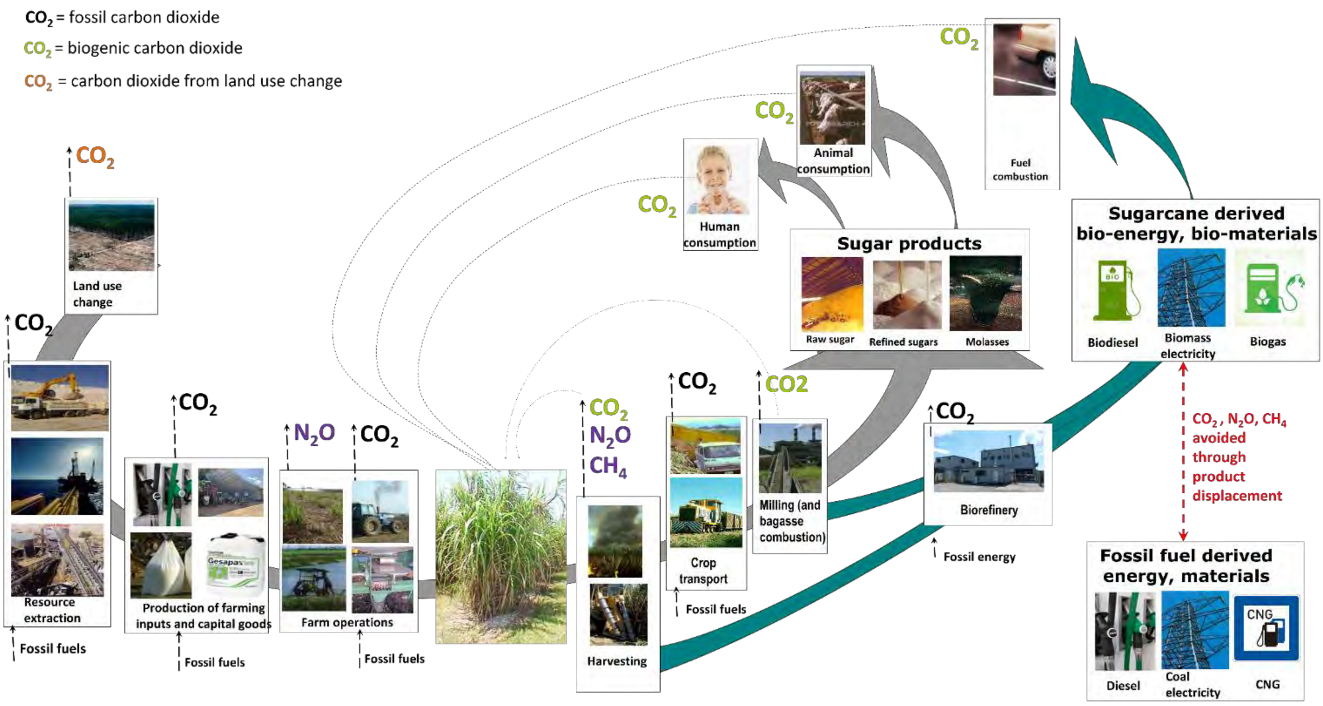

Figure 10 Greenhouse gas (GHG) exchanges in the life cycles of sugarcane-derived product systems

Figure 11 shows the estimated annual GHG emissions associated with the trash to biogas project, relative to baseline emissions. The final result of interest is the 'change in emissions' per year, which is the annual project emissions minus the annual base case emissions. The objective is for the change in emissions to be negative, meaning that the project's implementation results in a net emission reduction.

For the production process, there are additional emissions for trash separation, and electricity and urea inputs to the process. Based on the processing of 35,000 t trash, the additional emissions would amount to around 9,000 t $CO_{2\text{-}e}$/y.

Avoided emissions associated with not combusting fossil-based CNG and diesel in the baseline case (i.e. emissions that are avoided in the project case) are around 17,000 t $CO_{2\text{-}e}$/y. If the whole value chain is considered there would be a net reduction in emissions of around 8,000 t $CO_{2\text{-}e}$/yr. If these emission reductions could be monetised via Australia's Emission Reduction Fund, it could generate revenue of between \$124,000/y, assuming Australian Carbon Credit Units (ACCU) of A\$16 / t $CO_{2\text{-}e}$.

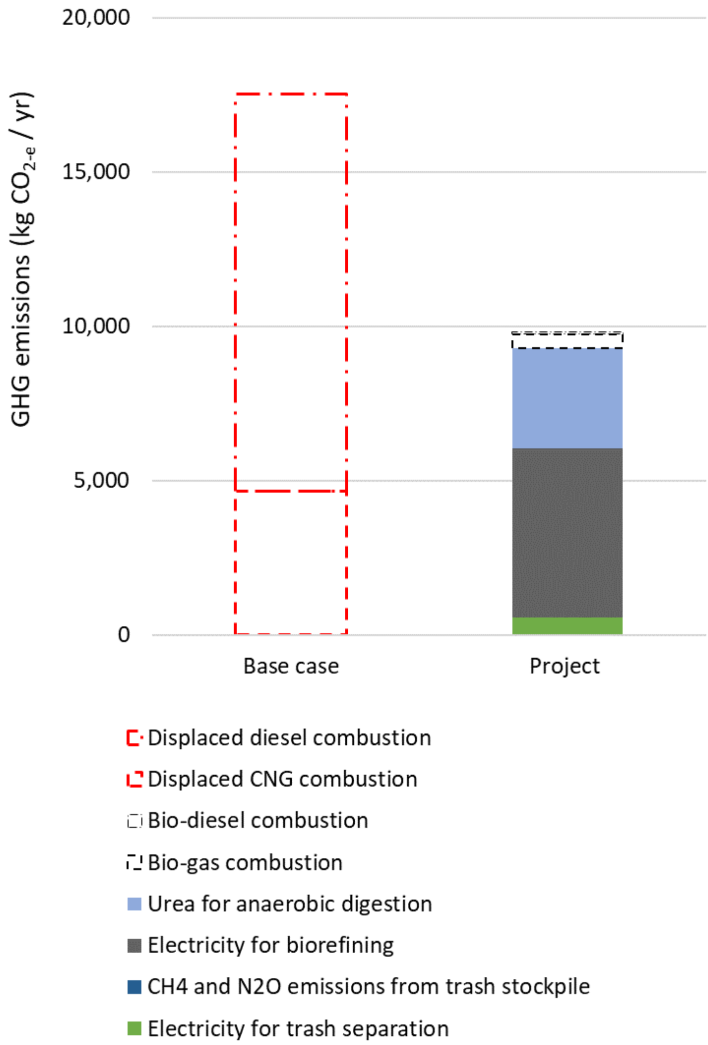

Figure 11 GHG emissions from the trash to biogas project relative to base case

Transferability

Knowledge Sharing

A wide range of knowledge sharing activities were undertaken during the project and some of these are highlighted below. Detailed project information has been communicated to project partners through project milestone reports, project workshops and regular project meetings. Non-confidential information has been made available to other interested parties with interests in renewable energy policy, biofuels, and waste management. Project findings are progressively being published in international peer-reviewed journals in relevant areas to ensure a knowledge transfer to the academic community.

Other key knowledge sharing activities include:

Conferences presentations and posters

Project progress was reported through conference presentations including:

- I. O'Hara. Biogas from sugarcane. Bioenergy Australia Industry Breakfast. Brisbane, April 2016.
- I. O'Hara. Biogas from sugarcane trash to reduce fossil fuel use. Bioenergy Australia Annual Conference. Brisbane, Nov 2016.
- P. Kaparaju, A. Latif, Y. Jothiraj, P. Paulose and Z. Zhang. The effect of sulphuric acid pretreatment on chemical composition and methane yields of sugarcane bagasse and sugarcane trash. 15th IWA World Conference on Anaerobic Digestion – Beijing, China, October 2017.
- P. Kaparaju. Biogas production from energy crops and agricultural residues. International TropAg Conference – Brisbane, November 2017.
- P. Kaparaju, A. Latif and P. Paulose. The effect of solids content on methane production during anaerobic dry fermentation of sugarcane bagasse. Bioenergy Australia Annual Conference, Sydney, November 2017.
- P. Kaparaju. Biogas production from sugarcane industry residues and upgrading to biomethane for vehicle fuel use. Tasmania's Bioenergy Future 2020, Bioenergy Australia Conference, Webinar, November 2020.

Sugar Industry forums

The Australian sugar industry has a particular interest in the outcomes of this project. Project progress was presented to sugar industry forums including:

1. ARENA / Australian Society of Sugar Cane Technologists Workshop (ASSCT) – 28 April 2016
    - An ARENA / ASSCT sugar industry workshop was held in conjunction with the ASSCT conference in Mackay, Queensland. The workshop included presentations from 4 ARENA projects including the *Biogas from Sugarcane* project. The workshop was attended by an estimated 200 people with representatives from across the sugarcane growing, milling and research sectors present.
2. Sugar Milling Regional Research Seminars
    - F. Plaza, P. Hobson, C. Henderson. Upscaling of a non-pneumatic cane cleaner. Sugar Milling Regional Research Seminars. Cairns, Townsville, Mackay, Bundaberg, Ballina. April / May 2018.
    - I. O'Hara. Biogas from sugarcane residues. Sugar Milling Regional Research Seminars. Cairns, Townsville, Mackay, Bundaberg, Ballina. April / May 2018.

- I. O'Hara. Biogas from sugarcane residues - update. Sugar Milling Regional Research Seminars. Cairns, Townsville, Mackay, Bundaberg, Ballina. April / May 2019.
- I. O'Hara. Biogas from sugarcane. Sugar Milling Regional Research Seminars. Webinar. May 2020.
- P. Kaparaju. Biogas production from sugarcane industry wastes for vehicle fuel. Sugar Milling Regional Research Seminars. Webinar. May 2020.

3. Case IH Step-Up Conference – Mackay, March 2018
   - I. O'Hara, New revenue opportunities from sugarcane. Case IH Step-Up Conference for next generation cane farmers.

Media and public reports

Several media releases and events were undertaken during the project which included:

- QUT media release – 28 April 2016. https://www.qut.edu.au/institute-for-future-environments/about/news/news?news-id=103723).
- Sydney Morning Herald media story – 1 July 2016. Sugar cane offcuts may be used to fuel vehicles. The article is available at the following link: https://www.smh.com.au/technology/sugar-cane-offcuts-may-be-used-to-fuel-vehicles-20160630-gpvpf0.html
- ARENA Blog – 30 August 2017: https://arena.gov.au/blog/sugarcanetrash/.
- IEA Bioenergy task report – March 2018. Information on the project was provided for the IEA Bioenergy Task 37 Country Report for Australia in March 2018.
- Griffith University and Utilitas Pty Ltd "*Industry and university collaborate to boost biogas technologies*, in Engineers Australia. The article is available at the following link: https://www.engineersaustralia.org.au/News/industry-and-university-collaborate-boost-biogas-technologies

Journal publications

- N Ketsub, A Latif, G Kent, WOS Doherty, IM O'Hara, Z Zhang, P Kaparaju, 2021. A systematic evaluation of biomethane production from sugarcane trash pretreated by different methods. Bioresource Technology, 319, article no. 124137
- X Wang, L Cao, R Lewis, T Hreid, Z Zhang, H Wang, 2020. Biorefining of sugarcane bagasse to fermentable sugars and surface oxygen group-rich hierarchical porous carbon for supercapacitors. Renewable Energy, 162, 2306-2317.

Enhancing capability for biogas research in Australia

This project has developed new capacity and capability for bioenergy and biogas related research in Australia. In particular, the development of the integrated biogas reactor, compression and upgrading system will be of significant value to the Australian research and bioenergy community. The development of this equipment and the expertise developed in operating the equipment will provide value in exploring future the potential of biogas production from other biomass feedstocks. The biogas upgrading unit will also be of value in demonstrating the upgrading and compression of biogas to biomethane in a variety of other sectors.

The project has also trained two PhD students and 1 MPhil student.

Conclusion and next steps

The *Biogas from Sugarcane* project has identified opportunities to reduce fossil fuel use across the sugar industry. Activities undertaken within the project have advanced the project concept based on the use of sugarcane trash and / or bagasse as a bioenergy feedstock with the potential to be converted into fuels to replace diesel initially in sugarcane transport and in the future in sugarcane production. In this project, sugarcane trash is being anaerobically digested to produce biogas and upgraded to compressed biomethane. Biogas digestates are also being upgraded via hydrothermal liquefaction (HTL) to diesel-like fuels.

Analysis has identified that the digestion and upgrading of as little as 10% of the available trash from sugarcane regions would completely satisfy the requirements for diesel use on farm and in sugarcane and sugar products transport. Supply chain modelling work undertaken in the project assessed the relative supply chain costs of various sugarcane trash collection strategies. It was identified that, while there are regionally specific issues associated both with the availability of sugarcane trash and with the optimal solutions, in general the lowest cost trash collection strategy is to collect trash during harvesting and transport to the factory for separation from the cane prior to milling. The novel QUT trash separation and recovery technology has demonstrated fit for purpose but requires further scale-up towards full commercial size for full validation.

The project outcomes identified that several different mild biomass treatments all improved glucan digestibility to enhance biogas production, however, steam explosion pretreatment was selected as the optimal pretreatment technology based on having no catalyst cost, short treatment time, and small reactor scale compared to other treatments. Laboratory scale anaerobic digestion trials indicated that optimum conditions were achieved at organic loading rates of around 2.5 g VS/L/day and achieved methane yields of ~200 L/kg.VS and methane concentrations of 53-55% in the biogas.

HTL trials of digestate resulted in a biocrude yield of around 40% with the biocrude having a higher heating value of 33 MJ/kg. Thermal analysis of the oils indicated that the oils were predominantly of a light oil fraction that can be readily be upgraded to good quality fuels.

This project has developed new capacity and capability for bioenergy and biogas related research in Australia. In particular, the development of the integrated biogas reactor, compression and upgrading system will be of significant value to the Australian research and bioenergy communities.

Lessons Learnt

Lessons Learnt Report: Developing pilot infrastructure

Knowledge Category:	Logistical
Knowledge Type:	Construction
Technology Type:	Bioenergy
State/Territory:	Queensland

Key learning

The development of project infrastructure, even at a pilot scale, is subject to considerable challenges including financial, timing, and regulatory. A lesson learnt in the planning and development stages of the project is to ensure sufficient contingency in both budget availability and milestone schedule to account for the significant engineering challenges associated with designing, constructing and commissioning of new equipment. Delays in building and commissioning of the pilot scale upgrading unit and biogas reactors affected milestone delivery and the budget availability for the project. Costs associated with safety and regulatory compliance of small pilot projects are significant. For example, the annual costs associated with a gas and petroleum licence for a biogas plant in Queensland are the same for a small research project as for a large commercial installation.

Implications for future projects

The project team has developed significant expertise that will assist in delivering future projects. Future projects should ensure that contingency in timing and budget are sufficient for project requirements. The project risk management plan did identify this issue, however the extent of potential delays and cost impacts from varying exchange rates and contractor costs were unexpected.

Knowledge gap

A knowledge gap would be the type and number of delays that had occurred during the building and commissioning of the pilot scale biogas upgrading unit and biogas reactors. The delays in installation works, rectifications around electrical installations and delivery delays for purchase orders also where to purchase certain type of equipment and commissioning of third parties for work on the pilot scale upgrading unit and biogas reactors is a knowledge gap in the planning and budgeting for milestone delivery. This knowledge can be transferred when planning and budgeting for future similar projects.

Background

Objectives or project requirements

The Arena funded Biogas from sugarcane project was required to design, construct and commission an integrated biogas reactor and biogas upgrading unit as part of Stage 3 of the project. At the commencement of the project, there were no full scale or pilot scale biogas upgrading facilities in

Australia. Furthermore, there is still little or no experience in Australia of producing biogas from lignocellulosic biomass such as sugarcane bagasse/trash.

Process undertaken

A key component was the delivery of a biogas upgrading unit supplied from an international supplier. During the first year of the project, considerable work was undertaken to validate the requirements of the unit, conduct due diligence and to commence a process of ensuring compliance of the unit to Australian standards. An independent engineering assessment against Australian design standards was conducted.

Delays in finalising the design and purchasing the biogas reactors and biogas upgrading units were associated with the need to ensure that the equipment meets Australian safety, quality standards and regulatory requirements, to ensure that the equipment was appropriate for the proposed trials and to contain purchase costs. There had been significant delays in the construction and shipping of these components to the Mackay pilot plant site.

Installation works for the biogas reactor and upgrading pilot plant were also delayed resulting from delays in manufacture of some core components, minor rectification works to comply with the electrical, hazardous zoning and structural designs to Australian Standards.

To ensure appropriate consideration of these complex issues, variations were required to the milestone dates to ensure that sufficient time was allocated to the operations phase to provide the necessary data for a robust performance assessment and for economic analysis.

Supporting information (optional)

N/A

Lessons Learnt Report: Biogas production from trash

Knowledge Category:	Technical
Knowledge Type:	Technology
Technology Type:	Bioenergy
State/Territory:	Queensland

Key learning

A key learning for the project, was the interaction between technology choice for optimised feed pretreatment conditions and effective biogas production. Based on the screening pretreatment trials and biomethane potential (BMP) results achieved in the project, we found that many pretreatments were suitable to generate digestible biomass for biogas production. However, steam explosion was selected for preparation of trash for pilot scale demonstration of biogas production because steam explosion is rapid, reliable and low-cost.

However, results of experiments indicate that further work is needed to fully optimise pretreatment conditions for enhancing methane yields and in particular to understand the correlation between total carbon source availability and BMP and the economic costs of the process.

Implications for future projects

The key learnings from pretreatment trials have implications on decision making for future projects with similar objectives. Pretreatment technologies can be further assessed based on the results and findings from this project and used to optimise these processes for enhanced results.

Knowledge gap

Knowledge gaps in the project include the optimum pretreatment conditions for sugarcane bagasse for use as a desirable digestion feedstock. Laboratory experiments had been conducted in batch and semi-continuous reactors as well to evaluate the optimum operational conditions for the biogas operating unit and to analyse the effect of pretreatment on biomass composition and methane yields.

These experiments included analysis of the effect of acids, alkalis, C/N ratio may have on methane yield from sugarcane trash. Experiments conducted also included analysis of the effect of high solids content and optimization of biogas production through anaerobic digestion using continuous stirrer tank reactor. Pretreatment results also indicated that trials with a higher glucan digestibility with the same type of catalyst led to higher BMP yield. However, further work needs to be conducted to enhance pretreatment conditions for higher methane yields, to find the optimum low-cost pretreatment conditions for biogas production.

Background

Objectives or project requirements

QUT researchers have extensive experience in biomass processing for digestibility improvement. Pretreatment using dilute acid, alkali, and 'green' solvent-based systems including glycerol-based pretreatments have been studied previously (Harrison et al., 2013; Zhang et al., 2013a-c; 2015). These previous studies have focused on pretreatment for the production of bioethanol and biochemicals by microbial cultures at high efficiency in industrial fermenters. Pretreatment makes the hemicellulose and cellulose components of sugarcane trash and bagasse more digestible and thus will improve biogas yield and productivity. Compared to other pretreatment methods, low cost dilute acid and autohydrolysis pretreatment techniques are more likely to provide an economically feasible process for biomethane production.

Process undertaken

Pretreatment of sugarcane bagasse and trash was initially conducted at laboratory scale to screen potential acid and alkali catalysts and for preliminarily optimisation of pretreatment conditions. Pretreatment trials included with and without steam explosion, various solid to liquid ratios and inclusion of hot water with mild alkali/acid in the pretreatment mix.

Biomass digestibility and BMP was analysed in accordance with standard procedures and results analysed. Following screening and preliminary optimisation the biomass pretreatment process was scaled up using a 4.5 L (working volume) Parr reactor and further optimised in terms of process conditions and catalyst selection.

Lessons Learnt Report: Solids materials handling

Knowledge Category:	Technical
Knowledge Type:	Technology
Technology Type:	Bioenergy
State/Territory:	Queensland

Key learning

Materials handling introduces additional challenges for small pilot-scale demonstration of technologies. Significant issues were found with the handling and pumping of sugarcane trash in anaerobic digestors both at laboratory and pilot scale. Wrapping of trash particles around stirrers and blockages in pipes were an ongoing challenge for the project. Many of these challenges would be less pronounced at larger scales where particle size is smaller relative to the size of pipework, etc.

Implications for future projects

The challenges of running some processes, particularly slurry based processes at small scale are well known, however, these small pilot trials are still important. Lignocellulosic feedstocks are not as soft as many other feedstocks commonly used in AD processes. Future projects should consider these material handling challenges in the equipment design and then design either to eliminate blockages or to allow ready cleaning of potential blockage areas.

Knowledge gap

During the project, there were a number of challenges and barriers the researchers faced. Some of these challenges included developing a cost-effective supply chain model that delivers the biomass to the process and developing and optimising pretreatment and anaerobic digestion processes. Further demonstration of these technologies including the biogas upgrading technology would also further the findings of the project. These processes were dependant on the integration of the technologies. Optimisation and integration of technologies would result in value-adding to the sugarcane and bioenergy sectors within Australia.

Background

Objectives or project requirements

The project required cellulosic biomass to be treated for processing. Large quantities of biomass were dried, pretreated and stored for use. The biomass was then digested in the AD reactors to demonstrate the production of biogas and optimise biogas yields.

Process undertaken

Materials handling challenges included size reduction of the raw biomass, storage for extended periods, both prior to and post-pretreatment. Mixing of biogas with water to feed into reactors was done manually and the resultant slurry pumped into the reactors. This pumping process was prone to blocking, however this problem was mostly solved through flushing water through the pipework after feeding. As the total solids of the reactors increased, blockages were also noted during the draining of digestate from the reactors.

Supporting information (optional)

N/A