International Specialised Skills Institute

Anaerobic Digestion Systems and Deep Litter Waste Management for Rural Primary Industry Enterprises

Stanley Pietsch

Higher Education and Skills Group Overseas Fellowship.

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i. Executive Summary

The Fellow undertook a study tour focussing on cost effective Aniaerobic Digestive Systems and Deep Litter Waste Management for Rural Primary Industry Enterprises.

To determine the relevant areas to research, the Fellow liaised with key national Australian agricultural industry representative groups from the pork, poultry, dairy and beef industries.

It was concluded that there were four key research areas to be pursued. These were cost effective biogas production, the management and uses of the energy produced from biogas production, nutrient recovery and utilisation, and, the processing of deep litter agricultural waste (more appropriately termed agricultural residue).

During the study tour the Fellow attended the 21st Biomass Conference and Exhibition held at Copenhagen in Denmark to gain an overview of the global situation with respect to biogas production and to develop networks. The Fellow subsequently visited 11 sites in Germany, Denmark and Belgium to organisations ranging from research centres, educational institutions, private enterprise organisations operating biogas plants and biogas consulting and system providers.

The key outcomes from visiting each of the sites, including the conference are documented in the report in detail. The Fellow developed key findings and conclusions from all the data gathered during the study tour.

The first significant and rewarding conclusion was that the study tour research aspects correlated closely to the focus of international research and development of biogas production.

The Fellow was amazed at the amount of information available and level of assistance provided by all the hosts visited. It is believed that emailing a set of questions centred around the key research areas to host organisations four to six weeks prior to the study tour facilitated the gathering of relevant information. It seemed to provide hosts with clear direction and time to prepare for the visits (see Attachment One).

Some of the insights and conclusions for each of the four key research areas are now briefly presented.

Key Study Area Number One

The cost effective production of biogas.

There were a number of innovative and cost effective production systems for biogas production which were prominent such as garage, plug flow and vertical top fed digesters.

There was generally a focus on the co-digestion of animal manure slurry with other high energy substrates such as solid cow manure, including straw, to produce higher energy yields from biogas production.

Significantly, there is a general transition to processing agricultural residues rather than energy crops as a viable means of producing energy.

The appropriate approach to determining the viability of different digesters for a proposed site was agreed to be an holistic critical approach where the local drivers, and in particular the type of substrates available are considered in a detailed situational analysis. It was concluded that there are no rules which can be generally applied. It is really a matter of what works to suit a situation and its' specific needs.

A key conclusion to draw is that the research, design and trialling phase of a biogas project must be considered the most critical phase of a project to achieve the optimal outcomes.

Some other key areas identified for cost effective biogas production were:

- The need for more detailed understanding of the AD process
- The need to conduct biochemical methane potential (BMP) trials for substrates over extended periods up to 18 months to allow nutrient deficiencies and the make-up of the microbial population to impact on biogas production. This is critical in ensuring that biogas plants are not established on unrealistic expectations
- The employment of early warning systems and sensors to indicate that interventions into the anaerobic digestion (AD) process are needed to maintain optimal conditions and the needs of microbial populations
- Reducing operating and maintenance costs
- The potential to use centralised biogas treatment equipment and generators in a hub arrangement servicing a number of biogas plants
- The use of online process control.

Key Study Area Number Two

Cost effective primary enterprise use of energy from biogas production.

The use of biogas as an energy source was found to be versatile and extremely promising.

For example, biogas is being used to:

- Increase production in agricultural enterprises in a range of ways through generating electricity and operating heating and cooling systems
- Power vehicles
- Supplying gas to natural gas grids following biogas being upgraded to 91.5% methane (CH_4). Technology innovations are developing quickly in this area.

Key Area Number Three

The profitable use of nutrients and other bi-products from biogas

The recovery of nutrients from biogas production is generally perceived to be important and viable in the long term with phosphorous (P), nitrogen (N), potassium (K) and sulphur (S) being the main nutrients being recovered.

The digestate, used as a soil conditioner, is also seen as a valuable bi-product of AD and it is perceived to be important for sustainable agricultural production.

Methods of treating the digestate to make it economical to transport is a key area of research being pursued.

Key area Number Four

The effective processing of deep litter waste for biogas production.

This is a major area of research and development in Europe. There are a number of exciting new types of digesters which can handle high levels of dry matter (DM) of up to 30 to 50%, and pre-treatment strategies which are producing some significant improvements in biogas yields.

By processing deep litter, DM feed in rates have been quadrupled compared to traditional continuously stirred tank reactors (CSTRs). Biogas yields from straw based deep litter have been increased by 25 to 30%. This has been achieved by the use of pre-treatment strategies making the ligno-cellulose molecules of straw more accessible to microbial populations in reactors.

Cereal straw is seen as major energy source by a number of countries such as China, Denmark, Germany and Greece.

A pre-treatment of deep litter residue which is particularly impressive is the Xergi Chain Crusher from Denmark. It is a continuous feed crusher for deep litter residue pre-treatment. Biogas production was increased by 25% following the pre-treatment of straw based deep litter with the Crusher.

An increase in the types of substrates being used for biogas production is being pursued and is likely in the future. Research in Denmark at the Foulum Campus of Aarhus University have shown that the inclusion of 20% chicken litter can be achieved without causing inhibiting levels of ammonia (NH_3). This offers another high energy substrate that can be used.

The overall conclusion from the visits to people overseas was that they understand why the agricultural industry in Australia has adopted the strategies of using lagoons. In the Australian context it seems that the ability to adopt and adapt the available technologies to low investment cost operations such as lagoon reactors for example, offers significant potential benefits to agriculture. The ability to use higher quality substrates with higher energy and nutrient recovery rates means there is a lot of potential to increase productivity from AD systems.

It is concluded that there are some exciting innovations which could be utilised to improve the productivity, cost effectiveness and lower capital and operational costs of biogas production in Australia.

It is concluded that the use of AD of agricultural residues and biogas production has enormous benefits to offer industry, the environment and the economy of regional Australia and should not be ignored but acted on proactively. It is seen as an effective technology to reduce greenhouse gas (GHG) emissions, to achieve environmental targets, an effective way to recover energy and nutrients, improve soils and sustain agricultural yields, and achieve sustainable employment outcomes.

The outcomes of this study tour will be made available to the agricultural industries, government and researchers through presentations at forums and also through the delivery of training programs. As this area of technology is advancing rapidly it seems critical to ensure that new developments are monitored and accessed where appropriate and that this information is made available to the agricultural industry in a systemised way.

Industry, government, researchers, educators and professional associations have a key role in this objective in a coordinated effort, otherwise industry and the community in Australia may not benefit from the significant benefits this technology has to offer.

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ii. Abbreviations/Acronyms

AD	Anaerobic Digestion
AM2MA	Methane to Markets in Australian Agriculture Program
Bm^3	Billion cubic metres
BMP	Biochemical methane potential
BT	Billion Tonnes
Ca	Cadmium
CFI	Carbon Farming Initiative
CHP	Combined Heat and Power
CO_2	Carbon dioxide
CSTR	Continuously stirred tank reactor
ct	Euro cents
€	Euro
EU	European Union
DM	Dry matter
GHG	Greenhouse Gas
GIS	Geographic Information System
H_2	Hydrogen
Ha	Hectare
HRT	Hydraulic Retention Time
H_2S	Hydrogen sulphide
IEA	International Energy Agency
JEC	Joint European Commission
JRC	Joint Research Commission, European Commission
K	Potassium
kg	Kilogram
km	kilometres
kW	kilowatt
kW_{el}	kilowatts of electricity
kW/h	kilowatt per hour
M	Million
m	metres
m^3	Cubic metres

ii. Abbreviations/Acronyms

MGRT	Minimum guaranteed retention time
MT	Million tonnes
MW	Mega Watts
N	Nitrogen
N_2O	Nitrous oxide
P	Phosphorous
PCM	Phase change material
pH	Logarithmic units measure for acidity and alkalinity
PSA	Pressure Swing Adsorption
ppm	Parts per million
RPM	Revolutions per minute
RIRDC	Rural Industries Research and Development Corporation
S	Sulphur
SME	Small to medium enterprises
SOFC	Solid oxide fuel cell
TAFE	Technical and Further Education
t	Tonne equal to 1000kg
VS	Volatile solids

iii. Definitions

Anaerobic Digestion (AD)

The breakdown of organic matter by microorganisms in the absence of oxygen[17]

Biogas

The gas produced by anaerobic digestion of organic matter consisting largely of methane, carbon dioxide, hydrogen sulphide and water

Biological filters

Filters that use living micro-organisms to remove components from biogas such as hydrogen sulphide

Biochemical methane potential

The maximum specific methane yield of a substrate expressed as $m^3CH_4kg\text{-}1VS$[14]

CH4

Methane gas

Composting

The digestion of organic matter by aerobic micro-organisms in the presence of oxygen

Combined Heat and Power

This refers to the production of heat and electricity from a generator

Deep Litter Waste

The material produced by animal production where the animals are kept on a bed of organic material such as straw

Digestate

The solution which is the product of anaerobic digestion of organic matter

Greenhouse Gas (GHG)

A gas which contributes to global warming such as carbon dioxide, methane and nitrous oxide

Hydraulic Retention Time

The amount of time it takes for solids to pass through an anaerobic digester reactor. It is the same as the solid retention time (SRT)[14]

Inoculum

The microbial population used to initiate anaerobic digestion of organic matter

Mesophilic bacteria

Bacteria which prefer temperatures between 20 to 45°C[17]

iii. Definitions

Methanogens

Micro-organisms which produce methane

Percolate

The liquid that drains from or collects on the bottom of an anaerobic digester or reactor

Pre-treatment

Treatments performed on organic matter prior to being fed into an anaerobic digester or reactor

Reactors

The vessel in which anaerobic digestion occurs

Stripping

The removal of a gas component from biogas such as hydrogen sulphide

Substrates

The feedstock for an anaerobic digester or reactor

Thermophilic bacteria

Bacteria which prefer temperatures greater than 50°C

Total Solids

Total Solids (TS) or Dry Matter (DM) is used to estimate the water content of a feedstock. The TS is determined by drying a sample in a drying chamber at 103-105°C using standards EN 12880 and APHA 2540 B. The unit is expressed as a percentage of g/l.[14]

Volatile solids

The amount of organic matter in a sample, the volatile solids (VS) are expressed as a percentage in the units g/l and may also be expressed as the organic dry matter (ODM). The test for VS is carried out at the same time as total solids (TS) or dry matter (DM). The test involves drying a sample in a chamber at 103 -105°C. Then the sample is ignited to constant weight in a muffle furnace at 550°C. There are concerns with respect to this measure as a reliable guide to anaerobic degradability. (The relevant standards are EN 12879 and APHA 2540 E.)[14]

1. Acknowledgements

Stanley Pietsch would like to thank the following individuals and organisations who gave generously of their time and their expertise to assist, advise and guide him throughout the Fellowship program.

Awarding Body – International Specialised Skills Institute (ISS Institute)

The International Specialised Skills Institute Inc is an independent, national organisation that for over two decades has worked with Australian governments, industry and education institutions to enable individuals to gain enhanced skills and experience in traditional trades, professions and leading-edge technologies.

At the heart of the ISS Institute are our Fellows. Under the **Overseas Applied Research Fellowship Program** the Fellows travel overseas. Upon their return, they are required to pass on what they have learnt by:

1. Preparing a detailed report for distribution to government departments, industry and educational institutions.
2. Recommending improvements to accredited educational courses.
3. Delivering training activities including workshops, conferences and forums.

Over 200 Australians have received Fellowships, across many industry sectors. In addition, recognised experts from overseas conduct training activities and events. To date, 22 leaders in their field have shared their expertise in Australia.

According to Skills Australia's 'Australian Workforce Futures: A National Workforce Development Strategy 2010':

> Australia requires a highly skilled population to maintain and improve our economic position in the face of increasing global competition, and to have the skills to adapt to the introduction of new technology and rapid change.
>
> International and Australian research indicates we need a deeper level of skills than currently exists in the Australian labour market to lift productivity. We need a workforce in which more people have skills, but also multiple and higher level skills and qualifications. Deepening skills across all occupations is crucial to achieving long-term productivity growth. It also reflects the recent trend for jobs to become more complex and the consequent increased demand for higher level skills. This trend is projected to continue regardless of whether we experience strong or weak economic growth in the future. Future environmental challenges will also create demand for more sustainability related skills across a range of industries and occupations.

In this context, the ISS Institute works with Fellows, industry and government to identify specific skills in Australia that require enhancing, where accredited courses are not available through Australian higher education institutions or other Registered Training Organisations. The Fellows' overseas experience sees them broadening and deepening their own professional practice, which they then share with their peers, industry and government upon their return. This is the focus of the ISS Institute's work.

For further information on our Fellows and our work see http://www.issinstitute.org.au.

1. Acknowledgements

Fellowship Sponsor

The Victorian Government, Higher Education and Skills Group (HESG) formerly Skills Victoria, is responsible for the administration and the coordination of programs for the provision of training and further education, adult community education and employment services in Victoria, and is a valued sponsor of the ISS Institute. The Fellow would like to thank them for providing funding support for this Fellowship.

Supporters

Australia

- Jock Charles, Berrybank Farms, Windermere, Victoria
- Michael Crowley, Regional Manager, Meat & Livestock Australia, Brussels, Belgium
- Dr. Darryl D'Souza, General Manager, Research and Development, Australian Pork Ltd
- Dr. Andreas Dubs, Executive Director, Australian Chicken Meat Federation (ACMF) Inc.
- Tracey Forbes, Director Education, Sunraysia Institute of TAFE, Mildura, Victoria
- Grant Garey, General Manager Feedlots, Teys Australia
- Dougal Gordon, CEO Australian Lot Feeders' Association
- David Halliday, Director, Active Research Pty Ltd, Doncaster, Victoria
- Andrew Lang, SMARTimbers Co-operative Ltd, Ballarat, Victoria
- Don Mackay, Managing Director, Ranger Valley, Australia
- Bob Paton, CEO, Manufacturing Skills Australia
- Des Rinehart, Feedlot Research and Development Project Manager, Meat & Livestock Australia
- Griff Rose, Program Manager, Rural Industry Research and Development Corporation (RIRDC), Australian Methane to Markets in Agriculture (AM2MA)
- Stephen Schuck, CEO and Public Officer, Bioenergy Australia Pty Ltd
- Win Scott, CEO, Sunraysia Institute of TAFE, Mildura, Victoria
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- Michael Köttner, German Biogas Association
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The Fellow would especially like to thank Hinnerk Boorman from CUTEC University in Germany and Lars-Christian Sørensen from the Royal Danish Embassy in Canberra, for their assistance in identifying sites to visit in Germany and Denmark respectively. Their assistance was greatly appreciated and the study tour could not have progressed without their generous support and assistance.

Thanks also go to hosts who generously gave their time and provided the Fellow the benefit of their knowledge, extensive experience, expertise and passion for the field of biogas production.

1. Acknowledgements

Employer Support

The Fellow would like to acknowledge the support provided by the Sunraysia Institute of TAFE in applying and conducting this Fellowship. This support has been critical to the Fellowship being successfully implemented.

The Institute has also provided substantial support to the Fellowship by contributing towards the Fellowship in terms of paying the registration costs to allow the Fellow to attend the 21st European Biogas Conference and Exhibition, held at the Bella Center in Copenhagen in Denmark from June 3 to 7, 2013.

The Fellow would also like to thank the Higher Education and Skills Group, Victoria for sponsoring the study tour and the International Specialised Skills Institute staff for their professional support at all times.

Finally, I would like to thank my wife Janet who travelled with and supported the Fellow over three very busy weeks in Germany, Denmark and Belgium. It was a great experience.

Organisations Impacted by the Fellowship

Government

- Department of Agriculture, Fisheries and Forestry
- Department of Business and Innovation, Victoria
- Department of Environment and Primary Industries, Victoria
- Higher Education and Skills Group, Victoria
- Manufacturing Skills Victoria

Industry

- Australian Chicken Meat Federation (ACMF)
- Australian Lot Feeders' Association
- Australian Pork Limited
- Dairy Australia
- Meat & Livestock Australia
- Primary producers particularly in the area of chicken, pork and beef production
- Rural Industries Research and Development Corporation

Professional Associations

- Australian Biogas Group
- Bioenergy Australia

Education and Training

- Sunraysia Institute of TAFE

2. About the Fellow

Name

Stanley Pietsch

Employment

Pietsch is currently employed as a Teacher/Project Officer in the National Centre for Sustainability at the Sunraysia Institute of TAFE within the Land and Environment Department, located at Mildura in the North West of Victoria.

The Fellow has worked in the areas of biogas production, solar energy generation, dry land agronomy and related programs, delivering programs to industry and the community.

The Fellow develops funding submissions and implements projects including articulation projects with the higher education sector. Recently, the Fellow has developed a short course on the Introduction to the Fundamentals of Commercial Biogas Production and Use. The Fellow has also been developing and writing induction training programs for the construction of a solar power station near Mildura at Carwarp.

Qualifications

- Bachelor of Agricultural Science (Hons), La Trobe University, 1975
- Diploma of Education, La Trobe University, 1976
- Masters in Educational Administration, Deakin University, 1998
- Certificate IV in Training and Education, Sunraysia Institute of TAFE, 2011
- Registered provider of the Auschem Farm Chemical Users Course, 2012

Individual units, short courses, workshops and other training programs:

- Recognition of Prior Learning for Assessors, Broadmeadows College, 1991
- Job Club Leader Training, Department of Employment, Education and Training, 1994
- Applying National Competency Standards to Industry Training, Broadmeadows College, 1994
- Certificate in Workplace Training, Module 2.6 Workplace Assessor, Hawthorn Institute of Education, 1996
- Facilitator Business Growth Through Quality Program, Version 4.0,
- Australian Quality Council,1997
- HACCP Principles and Applications Course (with Distinction), Food Operations 1998
- Associate Food Safety System Facilitator:
  - » Intensive Horticultural Operations
  - » Extensive Broadacre Agriculture Operations, Quality Society of Australasia 1998
- Skills HACCP Practitioner:
  - » Intensive Horticultural Operations
  - » Extensive Broad Acre Agriculture Operations, AGWEST Trade and Development, 1998
- Managing People for Performance, Australian Graduate School of Management, Sydney University and University of New South Wales, 2001
- Internal Quality Auditing NQ06, Certificate IV in Quality Management and Assurance, SAI Global, 2003

- Lead Auditor Training in Quality Management Systems, 2004
- Certificate IV in Quality Management and Assurance Units:
  - » Management Systems Auditing
  - » Workplace Teams
  - » Conflict Resolution and Negotiation, SAI Global, 2004
- Internal Quality Auditor for Sunraysia Institute of TAFE, 2012
- Victorian Farm Chemical Users Course, Registered Trainer, Auschem, 2012

Memberships

- Anaerobic Digestion and Biogas Association (ABDA), UK
- Australian Biogas Group
- Bioenergy Australia
- Mallee Sustainable Farming Group
- Victorian Bioenergy Network
- Vocational Education Learning Group

Brief Biography

Pietsch has been involved with Vocational Education and Training for 36 years at both the secondary and tertiary levels.

He commenced his teaching career in Horsham in 1977 teaching agricultural apprentices and secondary level biology, science and mathematics.

From 1980 to 1982 the Fellow worked in the Special Services Division of the Victorian Education Department producing state wide agricultural curriculum materials.

From 1982 to 1985 the Fellow completed a three-year appointment at Broadmeadows West Technical School as a Mathematics and Science teacher.

In 1985 the Fellow moved to Mildura, Victoria to teach dry land agricultural courses at the Sunraysia Institute of TAFE, for eight years. Programs included Certificates in Agriculture, Farm Apprenticeships, Farm Management courses for mature age farmers, and teaching the Diploma of Natural Resource Management.

The Fellow gathered more than ten years' experience in the capacity of Manager, Active Consulting, a business unit of Sunraysia Institute of TAFE. This unit had the role of developing and managing entrepreneurial educational activity and delivered a range of diverse vocational training and employment services to industry and the community.

Active Consulting conducted commonwealth employment programs such as the Job Network employment services contracts and Work for Dole contracts. Active Consulting also delivered food processing programs including wine production and customised training services to industry and the community.

The Fellow coordinated and participated in the writing of the non-endorsed National Wine Industry training and assessment materials for the Australian National Training Authority.

Work also included tender submission writing, curriculum development and educational research and development.

2. About the Fellow

From 1998 to 2008 the Fellow was a member of the Senior Executive Management team at Sunraysia Institute of TAFE. During this time he managed multi-functional areas of operation including Active Consulting, Strategic Planning, Quality Management, Organisational Reporting, Marketing and establishing and managing the Skills Recognition Centre.

The Fellow conducted a Reframing the Future Project focussed on best practice Recognition of Prior Learning with the final report being published.

The Fellow has also represented Sunraysia Institute of TAFE in delivering addresses at national and state conferences.

3. Aims of the Fellowship Program

The main aim of the Fellowship was to investigate contemporary international technology for cost effective biogas production systems and deep litter waste management systems suitable for rural and primary industry enterprises.

There were four major aspects behind the aim of this research:

- To gain an understanding of current alternative innovative cost effective AD biogas production technology systems being utilised internationally for rural primary industry enterprises
- To establish an understanding of current enterprise cost effective uses of energy and energy management processes for energy recovered from AD biogas production systems in rural primary industry enterprises
- To establish an understanding and the impacts of current innovative and profitable production and use of bi-products produced from AD systems in rural primary industry enterprises
- To gain an understanding and the current impacts of leading edge technology for the processing of deep litter waste from rural primary industry enterprises to recover energy and produce valuable bi-products.

4. The Australian Context

The Status of Biogas Production in Australia

Biogas production from agriculture in Australia is generally considered to be in the development phase as the industry is just starting to adopt this technology on a broader scale.

'CH_4 is the dominant GHG emission from Australian agriculture and, within the livestock sector, has been identified as a priority area for emission reductions under the National Agriculture and Climate Change Plan 2006-2009'[1].

It is estimated that manure management contributes to about 12% of national GHG emissions[2]. CH_4 is considered to operate 20 times more powerful as a GHG compared to carbon dioxide (CO_2), so controlling CH_4 emissions is considered to be an important, cost effective way of mitigating the agriculture sector's contribution to global warming.

The main areas of agriculture involved are the beef, dairy, pork, and poultry industries.

There a number of consultants who have established themselves to promote and build AD plants in Australia.

Past Australian commitment to reducing CH_4 emissions from agriculture has been demonstrated by the funding of the Methane to Markets in Australian Agriculture Program (AM2MA) which was a collaborative venture between government and industry funded by the Federal Department of Agriculture, Fisheries and Forestry with support from the Rural Industries, Research and Development Corporation (RIRDC), Dairy Australia, Australian Pork Limited, Meat and Livestock Australia, the Australian Lot Feeders' Association, and the Australian Chicken Meat Federation[1]. The RIRDC managed the AM2MA Program, which funded fifteen research, development and demonstration projects in rural Australia between 2004 and 2012[2].

Currently the Pork Industry has more than 12 projects underway to install covered lagoons to flare CH_4 to reduce emissions to the atmosphere.

There is an outstanding example of AD being used to produce biogas at Berrybank Farms, Windermere in Western Victoria. The Charles family company, Charles Integrated Farming Enterprise (IFE) commenced biogas production in 1991 to produce electrical power and save 100 ML of water annually through waste water treatment and purification. They have installed two AD insulated in-vessel tanks. They are now starting to use heat from the electrical generators to heat the weaning shed of the 15,000 pig piggery. They are also producing over a million bags of fertilizer per annum with the nutrients extracted from the digestate. Power is also being fed back into the national electricity grid from Berrybank Farms two MW of generating capacity.

In 2004 the first National Environmental Guidelines for Piggeries were released[3]. These have been revised in 2010. The Guidelines encourage pig producers to take every practical step to reduce GHG emissions. The Guideline provides specifications and guidelines for effluent treatment systems. They largely deal with covered pond (lagoon) systems rather than in-vessel AD systems. They provide guidelines for the re-using bi-products.

A significant stimulus to encourage piggeries to adopt carbon reducing technology is the release of the Carbon Farming (Destruction of Methane Generated from Manure in Piggeries) Methodology Determination 2012[5]. This sets out the detailed rules for implementing and monitoring a project under the Carbon Farming Initiative (CFI) to reduce CH_4 generated from manure in piggeries. It refers to the capturing of CH_4 by covering piggery lagoons. Piggery farmers can take advantage of the captured emissions to produce heat and electricity or destroy the gas through the use of flares.

In response to this, the BioEnergy Support Program by the Pork Cooperative Research Centre released an initiative that aims to facilitate the use of Carbon Farming Initiative federal funding[4]. This program has been established to encourage pig producers to adopt biogas systems to reduce carbon emissions by capturing CH_4 and utilise waste and wastewater streams.

Deep litter housing is used in approximately 50% of the Australian piggeries. Pigs are bedded on material such as straw, rice hulls or saw dust. Manure is absorbed into the dry material reducing the need for regular washing[6]. Currently most of this material is heaped and left to compost without accessing recovered energy or nutrients. New methods of dealing with deep litter residue are being sought by industry.

How the Need for Additional Skills Was Recognized

The Fellow, as part of the National Centre for Sustainability of Sunraysia Institute of TAFE conducted a project funded by the Higher Education Skills Group during 2011 and 2012 to develop a short course called 'An Introduction to the Fundamentals of Commercial Biogas Production and Use'. This project involved establishing an industry reference group to guide the development of the course and curriculum. The short course was trialed on two occasions by being delivered to industry. The course was improved following each trial based on course evaluations and feedback from participants.

Evaluation of participant and industry feedback following the course delivery was that the technology and skills were more advanced and abundant in Europe and that managers considering investing in biogas production ventures should first access information from Europe.

Other key outcomes of the course trials were that:

- There needs to be thorough investigation into the cost effectiveness of different biogas production systems and technologies
- There needs to be investigation into how the extraction of valuable nutrients from digestate can be optimized
- The use of the energy generated from biogas production should be optimized as this impacts on the cost effectiveness and the benefits from investing in biogas production systems for agricultural enterprises.

In preparing the application for the study tour, the Fellow contacted Daryl D'Souza of Pork Australia and it was suggested that the Australian Pork industry will be moving to deep litter waste management to save water. It was suggested that this would be a valuable area of research and development to pursue and it was included in the aims of the study tour.

SWOT Analysis

Strengths

- Existing knowledge of the industry
- There are some biogas plants already operating in Australia
- The Agricultural industry is receptive to information about AD

Weaknesses

- Lack of expertise, experience knowledge and skills within Australia compared to overseas
- Lack of proficient and qualified operators and managers
- Lack of systems and operating procedures
- Lack of training and learning resources
- Biogas production is a new industry in Australia
- Lack of government policies, regulations and guidelines for an industry working with a dangerous gas

Opportunities

- Improved productivity
- Incentive for farmers through the CFI
- Reduction in on farm operating costs
- Recovery of highly valued nutrients
- Reduced impact on the environment by reducing GHG emissions
- Use of recovered energy can lead to increased productivity and reductions in operating losses
- Reduced reliance on external energy supplies for enterprises
- Technology is applicable to pig, poultry, beef feedlot and dairy industries

Threats

- Lack of existing industry knowledge
- Biogas is a dangerous product
- Farmer resistance to change
- Capital investment required is too high to allow farmers to enter into biogas production
- Australian agriculture industry has a different operating environment to other countries rendering technologies irrelevant

5. Identifying the Skills and Knowledge Enhancements Required

There are examples of areas in Australian industries where there are weaknesses in innovation, skills, knowledge, experience, policies and/or formal organisational structures to support the ongoing successful development and recognition of individuals and the particular sector.

The focus of all ISS Institute Fellowships is on applied research and investigation overseas by Australians. The main objective is to enable enhancement and improvement in skills and practice not currently available or implemented in Australia and the subsequent dissemination and sharing of those skills and recommendations throughout the relevant Australian industry, education, government bodies and the community.

The areas of applied research for this Fellowship are therefore defined as follows:

1. Investigate and record new proven cost effective technologies for AD for different substrates:

- Identify and assess the relevant methods of current best practice AD processes for different substrates.
- Interpret and analyse the strategies and data to determine the most cost effective outcomes.
- Learn and conclude the methods that bridge the gaps between the skills investigated.

Action: Document the new proven cost effective methods of digesting substrates from rural primary enterprises.

Action: Based on this research develop a draft list of recommendations for the most cost effective technologies for AD substrates from rural primary industry enterprises relevant to Australian conditions.

2. Investigate and record new cost effective technology for utilising energy recovered from anaerobic biogas production to increase production in rural primary industry enterprises:

- Identify and assess the most efficient uses of energy recovered from AD processes to increase production in primary industry enterprises.
- Interpret, analyse and summarise the strategies and data to achieve the most cost effective production outcomes for rural primary industry enterprises.
- Learn the new methods that will close the skill gap between current enterprise energy use strategies.

Action: Document the cost effective energy use strategies for energy recovered from AD of waste from rural primary production enterprises.

Action: Based on this research draft a list of recommendations for the cost effective technologies of energy management including, collection, transfer and energy use for primary industry enterprises relevant to Australian conditions.

3. Investigate and record the new best practice technologies in AD bi-product production and use for rural primary industry enterprises.

- Identify and assess the relevant methods of current best –practice anaerobic bi-product production and use.
- Interpret, analyse and conclude the results to achieve the most cost effective and productive outcomes.
- Learn the new technologies that will close the skill gap between current and potential bi-product production and use.

Action: Document the cost effective strategies for bi-product production and use from AD systems for rural primary production enterprises.

Action: Based on this research draft a list of recommendations for the cost effective technologies for bi-product production and use, including nutrients, from AD systems used in rural primary production enterprises.

4. Investigate and record the new technologies to achieve best practice in deep litter waste management to recover energy and produce valuable bi-products for use in rural primary industry enterprises and external sale.

- Identify the relevant methods of current best practice deep litter waste management systems to recover energy and produce valuable bi-products for primary industry enterprises.
- Interpret, analyse and conclude the results to achieve the most cost effective and productive outcomes.
- Learn the new technologies that will close the skill gap between current and potential deep litter management and bi-product systems for rural primary industry enterprises.

Action: Document the cost effective strategies for deep litter waste management and bi-product production, including nutrients, for rural primary industry enterprises.

Action: Based on this research develop a draft list of recommendations for the most cost effective technologies for deep litter waste management and bi-product production and use for rural primary industry enterprises relevant to Australian conditions.

6. The International Experience

Key Findings and Conclusions

Detailed reports are presented for the 21st European Biomass Conference and Exhibition in Copenhagen and all site visits in Attachments Two to Six. The Fellow was able to identify consistencies in the directions of AD and biogas production and use from touring different sites in Germany, Denmark and Belgium.

Overall Impressions

Disciplines Required for AD and Biogas Production

It was generally agreed by hosts and the Fellow that agriculture, biology, chemistry and engineering are the main disciplines required to have an holistic understanding of AD and biogas production.

AD and Biogas Production Intellectual Capital

There is an enormous amount of knowledge and intellectual capital about AD and biogas production available in Europe which is not freely accessible to Australians. European countries have had more than 30 years experience in developing biogas production, energy management and use of recovered nutrients from AD.

The Fellow discovered and was presented with a good number of valuable resources by people that he visited.

Relevance of Study Tour Objectives

From the experience gained at the 21st European Biomass Conference and Exhibition held in Copenhagen and from the sites visited as part of the study tour, the Fellow concluded that the objectives set for the tour correlated well with current industry directions and research activity in Europe and other countries.

Trends and issues industry and researchers are looking at are:

- Ways to optimise energy production from AD
- Ways to use energy from AD productively
- How to gain a greater understanding of the micro biological processes of AD and biogas production
- Characterisation of microbial communities for AD and microbiological management
- Using different types of microorganisms for AD
- Develop cost-effective pre-treatment technologies for substrates such as straw
- Improved technology options
- The development of AD process measurement and control technologies
- Reduced operational energy usage by biogas plants
- How to use nutrient recovery effectively
- The development of two phase AD systems for higher performance
- How to use co-digestion of animal manures and agricultural residues such as straw to increase DM feed rates and subsequent biogas and energy production
- Early warning systems for AD process disturbances
- Improved treatment of solid and liquid phase of digestate for improved nutrient recovery.

6. The International Experience

The Bella Center, Copenhagen, Denmark where the 21st European Biomass Conference and Exhibition was held from 3-7 June, 2013

Agricultural residues were generally considered to be a reliable source of biomass for AD and biogas production and are considered to be one of the most abundant types of biomass available.

Knowledge Management of Biogas and AD Process Control

There are a number of sites where people can link into networks to access knowledge about AD and biogas production and use. For example, ECOWEB is used to encourage access to improved knowledge transfer and project knowledge.

Knowledge management is a key area of capacity building of AD and biogas production and use.

Advantages of Biogas Production and Use

Generally the following advantages were presented as valid benefits from biogas production:

- Reduces GHG emissions
- Increases nutrient recycling and transportation to deficient areas free of weeds and pathogens
- Protects aquatic environments from nutrient pollution
- Lowers odours produced by agriculture
- Recovers energy
- Provides sustainable agriculture
- Increases energy supply security
- Provides heat and power transportation
- Utilises a wide variety of organic waste
- Minimises the leaching of N in agricultural production areas
- Biogas is not more expensive to produce then diesel or natural gas or ethanol
- AD and biogas production improves relations with neighbours
- Soil conditions improve as a result of using bi-products from biogas production

Future of Biogas Production

Biogas production using AD is generally perceived to have an important role to play in future renewable energy supply.

Currently, 5% of animal manure is being processed through biogas plants in Germany so there is a lot of potential to increase production.

Major issues for increased adoption of AD include:

- Producing energy from renewable sources
- Improved sanitation and odour control of organic wastes
- Reducing the need for use of artificial fertilisers
- Providing income and source diversification for rural businesses
- Creating local employment
- Reducing GHG emissions
- Reducing our carbon footprint due to recycling.

Government incentives for supporting the development of biogas production are important for current and future developments.

Sustainable Employment Opportunities

It has been noted a number of times that AD and biogas production are likely to provide sustainable jobs for future generations.

Growth of Energy Crops for Biogas Production

There is a significant debate and government policy change leading to a reduction in energy crops being grown specifically for biogas production in Germany.

Some of the key issues are:

- Maize grown for an energy crop is not good for soil improvement
- Energy crops can cause farmers to be disadvantaged financially when wheat prices are higher for example. If they are locked into contracts to grow energy crops to supply biogas plants this is to their disadvantage at times
- Denmark has a policy of using agricultural residues for biogas production rather than growing energy crops

Training Requirements for the Future

Future training needs identified were:

- Training in inoculum and inoculation
- The use and interpretation of AD measuring devices
- Management of hydraulic systems such as pumps, tubes and stirring systems
- Safety issues with biogas, CO_2, hydrogen sulphide (H_2S).

Capacity Building

It was generally agreed that to support future biogas production, regulatory frameworks, public support and investment in infrastructure will be required.

This is considered important if Europe is to achieve renewable energy targets. Specifically it is considered that the following aspects are required for capacity building:

- Policy development
- Approving authorities
- Scientists in various areas
- Companies for plant erection
- Technical staff for operation and plant maintenance.

Cost Effective Biogas Production

Holistic Approach for Determining Cost Effectiveness

- In determining the cost effective production of biogas the consensus among hosts was that an holistic and broader context and issues need to be considered such as economic, environmental, social and technological factors
- No general rules apply and it is considered that a case by case analysis is the best approach
- Research needs to be completed for specific situations
- In particular, local drivers need to be considered such as isolation or transport costs
- Alternative energy costs need to be considered also in comparison to biogas production
- It is wise to start with the type of substrate which is required to be digested first and design a system appropriate for this material. Seasonal and annual changes in the substrate need to be considered
- Possible substrate pre-treatments and post-treatments available need to be considered
- Biosecurity is important to consider in agricultural settings, as is the control of vermin such as rats and mice
- It is critical to conduct effective trials for biogas production extending over a number of HRTs to ensure investments are validated and not wasted.

Measures for Cost Effectiveness

There is a need to have units to measure the cost-effective production of biogas to facilitate analytical and evaluative studies.

Measures used include:

- DM feed in rates expressed as kg DM/m^3/day
- The cost of producing energy is expressed in terms of €/kWh and this allows comparisons to be made between different systems
- The BMP of substrates can be estimated through trials.

Operating Costs of Biogas Plants

There were a variety of biogas production costs identified and these include:

- Maintenance and repair costs
- Substrate costs in some cases (up to 50% in some cases)
- The daily work hours required to operate a plant. This can vary substantially depending on the plant
- Insurance costs
- Laboratory tests
- Processing of biogas costs.

Cost Reduction

Generally there is a focus on determining the viable locations for biogas plants where they can access adequate biomass at a reasonable cost.

The costs for maintenance and repairs of CHPs can be minimised by electronic engine control and regulation, especially to account for variations in the quality and quantity of biogas produced from changes in substrates for example.

Transport and processing of biogas such as upgrading biogas are critical costs for cost effective biogas production.

Centralised hubs for biogas plants can provide savings in biomass transport, digestion costs and injector costs.

Sensors and High-tech Measuring Equipment for Process Control

It is generally agreed that there is a lack of detailed knowledge of the AD process. There is research into the use of sensors to monitor the AD process and efforts to control NH_3 and acids more effectively.

The use of lances used for sampling can be retrofitted. The use of sensors throughout a reactor could enhance the understanding of what is happening in a reactor substantially.

High-tech CH_4 production measuring equipment can measure production more accurately over time providing an increased understanding of AD processes occurring and subsequently more effective process control.

Online Process Control

The use of remote online process control can significantly improve the ability to monitor and improve the AD process, making better use of substrate and reducing process breakdowns.

The concentration of H_2 and CH_4 can be used as indicators to monitor the progress of AD.

Improving the AD Environment

An area of research and development is the improvement of the environment for AD. The environment can be modified by stripping NH_3 and acids from the digestate in a range of ways making it possible to process high N substrates such as chicken manure.

Design and Operation of AD Digesters for Biogas Production

The design of digesters need to account for how micro-organisms live to ensure they can perform at optimal rates.

Split AD Systems

Hydrolysis occurs at pH 5.2 to 6.5 whereas CH_4 production occurs at pH 6.7. Split systems can provide more optimal conditions for these processes to occur.

Feeding Micro-organisms an Appropriate Diet and Long Term Impacts of Diet

Micro-organisms need to be supplied a balanced diet.

A common view presented was that trials of different substrates as feed sources need to be conducted over more extended periods of multiple HRTs rather than a few months to gain a full understanding of the longer term impacts of a substrate as a feed source. 400 days are required to conduct effective trails.

Problems often arise 12 to 18 months following continuous AD and it is not always easy to understand why the problems have arisen.

Expensive capital investment outlays can be lost due to unforseen problems.

Trials of substrates for biogas production are conducted over a period of up to 400 days at CUTEC Institute in these larger reactors. The reactors can be controlled remotely using online process control.

Co-digestion of Substrates

The trend to co-digestion of substrates was evident everywhere the Fellow toured. Maize silage digested with pig manure slurry and deep litter were observed a number of times.

At Aarhus University, Foulum it is suggested that chicken manure can be co-digested with other substrates such as pig manure slurry at a rate of 20% without creating too much NH_3 to inhibit AD and increase biogas production.

Wheat and rice straw have low N levels so that high N substrates like chicken manure can be co-digested successfully.

Estimations of biogas yields for different substrates and combinations of substrates have been completed and data is available.

Projected Use of Substrates

Denmark aims to increase the use of animal slurry from 8% to 50% by 2020.

An increased use of agricultural residues for biogas production is predicted, rather than the growth of energy crops, as this does not compete with food production and converts a low value product into a high value product or products. There are also environmental and other financial advantages of using agricultural residues.

Lagoon Digesters

Lagoon digesters may well be the best option to consider because of their low capital cost but their operation could be improved with the use of advanced technology.

Comparison of Digesters

A substantial part of the study tour was spent comparing digesters which were observed. More information is included under the heading of Deep Litter Residue Management in this section.

It was generally concluded that:

- Garage digesters are low capital investment but are rather high in labour costs
- Sauter Lagoon digesters provide a low capital investment biogas plant
- Digesters specifically designed for situations may cost more but are likely to yield more and operate more efficiently as a result
- A thorough situational analysis is required to achieve the best results.

Storage of Substrates and Biogas

Storage of substrates needs to maintain the energy of the substrates rather than lose energy through degradation. Biogas storage needs to be effective as some systems can lose up to 20% of CH_4.

Harvesting of Substrates to Optimise Energy Content

The harvesting time of substrates needs to be planned for the optimal time and conditions to maintain the energy content of the substrate.

Energy Use from Biogas Production

It was generally concluded that biogas is a very flexible and versatile energy source. A summary of some of the key uses are detailed below.

Efficiency of Electricity Generation

Electrical generation efficiency from biogas has generally been shown to be 34 to 41% and as such, this represents an area for improvement. A current suggested improvement is the use of larger electrical generators and the development of generators at a hub servicing a number of biogas plants.

Upgrading of Biogas

CH_4 is concentrated to 91.5% so it can be fed into natural gas grids.

Removal of CO_2 from biogas means that the CH_4 concentration is equivalent to that of natural gas.

CO_2 can be removed using Pressure Swing Adsorption (PSA) technology by passing the biogas over an activated carbon filter under 5 bar pressure. Alternatively, water scrubbing and membrane technology are available.

H_2S is removed by biological filters or precipitating iron sulphide with an iron salt.

Water can be removed by compressing the biogas, heating it and then reducing pressure so that the gas cools with the water condensing, so it can be removed.

Haldor Topsø from Sweden has produced a Solid Oxide Fuel Cell (SOFC) using electricity and CO_2 to produce CH_4 across a membrane.

Biogas as On Demand Energy

Biogas has the potential to supply on-demand energy to compliment other renewable energy supplies, such as wind and solar energy. Through the storage of biogas it could be available at critical times for electrical generation.

Using Biogas Locally

Using biogas locally can improve efficiency in use.

Ways Heat Energy from Biogas Production Can be Used

Heat from biogas production and electricity generation can be used in a host of ways involving heating and cooling.

Biogas as a Transport Fuel

Biogas is being used to fuel vehicles directly such as cars, buses and tractors. Dual fuel systems may be required such as diesel combined with biogas to overcome the slow refuelling time of biogas.

Three are expected to be four million cars to be running on biogas in Germany by 2020.

Heating for Animal Husbandry

Heating from biogas is being used to improve pig, poultry production and aquaculture.

Heating of Glasshouses

Glasshouses are being heated using biogas.

Drying of Digestate

The drying of digestate using biogas so that it can be used as a fertilizer is currently being practiced.

Converting and Storing Biogas Heat Energy

New technology is being used to convert biogas to heat energy and also to store the heat produced with new and improved technology such as the Rankine Cycle and thermodynamic storage systems.

Nutrient Recovery from Biogas Production

Nutrients to Recover

There is substantial recovery of P, N and K from biogas production possible.

Of the nutrients contained in the digestate:

- 45% of P is contained within the solid fraction. It is expected that in future the cost of P will increase with a decrease in the availability of mined P
- 20% of N is contained within the solid fraction
- Elemental S can be recovered and used as a valuable mineral fertilizer.

The nutrient content of digestate is typically:

- N 5.0 kg/t
- NH_3N 4.0 kg/t
- P 0.9 kg/t
- K 2.8 kg/t

Separation of the Liquid and Solid Fraction of Digestate

The liquid and solid fraction can be separated by screw type separators for example.

Solids can be pelletised and transported if economically viable for the domestic market.

The N can be recovered using a precipitation process using magnesium (Mg) and phosphoric acid (H_3PO_4) to form magnesium ammonium phosphate ($MgNH_4PO_4$). Reverse osmosis is required for this process making it questionable as an economic proposition.

The K is difficult to recover as it is part of the liquid fraction of the digestate.

A screw type separator, similar that used in the food processing industry, is used to separate the solid digestate from the liquid digestate at the conclusion of the AD process in the Laran-Plug Flow Digester.

Microfiltration Technology

Nutrients may be recovered from the liquid substrate using microfiltration and then using reverse osmosis technology to precipitate P as $MgNH_4PO_4$.

Membranes have been found to degrade making this technology unviable. High streaming of the liquid has been shown to use a lot of energy. A rota over the screen is currently being tested to save the cost of pumping across the membrane.

Soil Conditioners

The solids from the digestate are able to be used as a soil conditioner.

The solid fraction of the digestate from the Laran-Plug Flow Digester following separation.

Liquid Digestate as a Nitrogen Fertilizer

The liquid fraction is applied as a liquid fertilizer during summer months by injection methods to avoid the release of NH_3.

Quality Assurance Schemes for Substrates

Sweden, Switzerland and the United Kingdom have introduced substrate quality assurance schemes to ensure that substrates used in AD are safe for use.

Critical factors for safe substrates are:

- Sanitisation to ensure the digestate is safe for animals and the environment
- They are free from inorganic impurities
- They are free from biological (pathological) and chemical pollutants including both organic and inorganic pollutants such as heavy metals[12].

The Application of Liquid Digestate as a Fertilizer

The timing and method of the application of liquid digestate fraction is limited by law in Germany and Denmark to the warmer months of the year to reduce the release of nitrogen into the air.

Composting Compared to AD

It was generally agreed that composting is not as efficient as AD due to loss of energy and also the emissions of nitrous oxide (N_2O) which is a significant GHG.

Deep Litter Waste Management

Generally the Fellow observed that there is a direction to use deep litter for AD as it is needed to increase the energy production from biogas production.

Ligno-cellulose Substrates

Ligno-cellulose substrates can be digested to release an additional 30% energy.

Straw as a Substrate

Straw was generally seen as an important energy source for AD in the future as the energy production from animal slurry is too low.

The long term harvesting and use of straw for AD appears to be possible without impacting negatively on grain yields.

N_2O which is a significant GHG, can have emissions reduced by straw being used in biogas production rather than leaving it in the field.

Pre-treatment strategies for straw are being developed and this can increase the biogas yield by 30-50%.

It is important to have a consistent substrate for high performance biogas production.

Pre-treatments include:

- Steam explosion
- Pre-cooking such as heating the substrate to 160°C for 30 minutes
- Mechanical degradation such as maceration, extrusion or the use of piston compression at 120°C
- Ultrasound
- Bio-enzymes
- H_2 degradation processes.

The use of crop residues is seen as an important way of achieving renewable energy targets for 2020 and 2050 as laid out in the EU Renewable Energy Directive (2009/28/EC), commonly called RED. This includes straw and grass verge.

Research into Breaking Down Ligno-cellulose Molecules

Research is occurring into how to break down ligno-cellulose molecules to increase energy yields.

Fungi may offer a solution to this problem.

Types of Digesters

A CSTR typically process substrate with 10-15% DM content. More than this level of DM in a substrate requires a different approach to the physical handling of the digestate. There were a number of very impressive digesters observed during the tour which are explained below.

Laran-Plug Flow Digesters

These digesters worked very well for high DM substrates.

The feeding rate of the digester is 9-11kg DM /m^3/day which is considered to be relatively high compared to the average rate of 2-4kg DM /m^3/day.

The substrate consisted of a blend of slurry (16% DM) and drier material being made up of 2/3 maize (35% DM) and 1/3 animal manure (50% straw and manure) at a total DM content of 38-40%.

The substrate is crushed as it is fed into the reactor.

Another Plug Flow digester was observed with similar operation and performance.

Slow paddle like stirrers push the digestate along the horizontal reactor tank.

The Laran–Plug Flow Digester visited at Honeneggelsen in Germany was operated by INPUT GmbH. This photo shows the feed hopper on the right with the feed-in entry to the reactor at the centre top at the end of the reactor.

The feed hopper for the Laran-Plug Flow Digester is viewed from the roof of the reactor. It contains maize silage as the substrate which is mixed with animal manure slurry.

Garage Batch Reactors

The Garage Batch reactor is able to handle high rates of solid DM.

Percolate is pumped from a tank underneath the garage section to encourage AD and biogas production.

Digestion is generally stopped at 75-90% degradation to allow for aerobic composting of the digestate following the AD process.

Garage digesters have a higher labour requirement for loading and emptying of solids.

The SMARTFERM garage fermenter system produced by Eggersmann Anlagenbau Smartferm GmbH located at Bad Oeynhausen in Germany. The fermenter is loaded with a front end loader and the deep litter agricultural residue substrate is pictured on the right. The control room is located on the right side of the garage reactor.

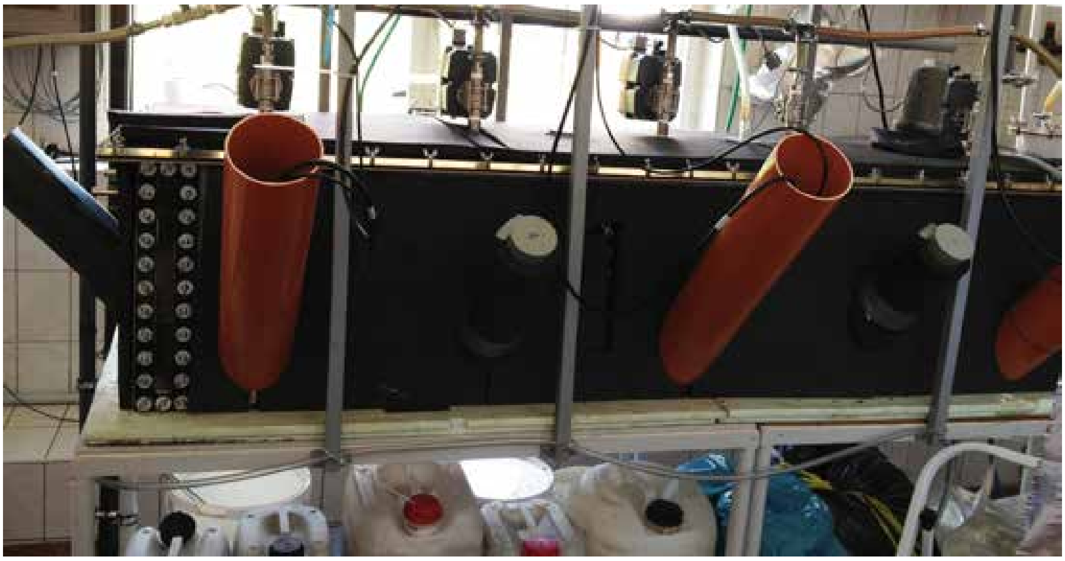
The solid substrate that is digested in the SMARTFERM garage fermenter. The system is able to process deep litter animal residues.

DRANCO FARM Digester

This style of digester is a continuously fed vertical digester capable of handling up to 30% DM. This is reliable and requires no mixing due to percolate being sprayed on top of the digestate creating a natural gravity mixing process. The DM feed rate is 10kg DM/m^3/day and it produces 310l of biogas per kg VS.

Floating Bed Digester

In research this type of digester demonstrates a lot of potential for handling high levels of straw and solid manures. Treatment of the percolate means the environment in the reactor can be potentially modified.



The Leibniz-Institut für Agrartechnik (ATB) in Potsdam is investigating the development of a Floating Bed Digester demonstration unit which is viewed in this photo. The digester is appropriate for digesting deep litter agricultural residues. The substrate is fed into the unit on the left hand side. Sensing and measurement equipment can be seen situated at four locations along the length of the reactor.

Xergi Continuous Feed Chain Crusher

An exciting pre-treatment for straw was observed in Brønderslev in northern Denmark. This was demonstrated by Xergi. It is a high capacity continuous feed chain crusher which has been developed in the last year or so.

The straw was observed to be cut to 15 mm in length and was crushed to provide a homogenous substrate for AD.

Following treatment the substrate resembles porridge like consistency.

The machine is low maintenance with low energy consumption and has the ability to change the quality of the substrate produced.

The production of biogas has been raised by 25% following pre-treatment with the crusher.

The Xergi Chain Crusher was located at the Lunden Biogas Plant, Brønderslev, Denmark.

The deep litter residue prior to pre-treatment through the Xergi Chain Crusher.

The deep litter residue following pre-treatment through the Xergi Chain Crusher. It can be observed that the straw has been crushed and broken by the treatment.

The deep litter residue pre-treated with the Xergi Chain Crusher forms a suspension when added to water as shown in this photo. This creates a homogenous substrate to be fed into the reactor.

The Key Outcomes from the Fellowship for the Fellow

The key outcomes of the Fellowship for the Fellow were:

- Access to networks with biogas production expertise
- Access to intellectual capital on AD and biogas production and the scope of available technology and practices
- The development of an understanding of the potential of biogas production and its benefits and uses
- By attending the 21st European Biomass Conference and Exhibition in Copenhagen and then visiting 11 sites in Germany, Denmark and Belgium, the Fellow was able to evaluate and validate the information provided by the different sources
- Gained first hand access to expertise, sites and technology
- The development of an understanding of the European and global context for AD and biogas production
- The opportunity to create and participate in a critical discourse on AD and biogas production and uses during the period of the tour
- The ability to re-write and update a short course on biogas production and use which the Fellow has edited previously.

Outcomes for Agricultural Industry in Australia

The outcomes for Australian agriculture were:

- Access to new knowledge and technology from Europe for successful design, planning and operation of biogas production units and to prevent failed investments
- An understanding of new directions and the potential for biogas production and use
- Access to networks and expertise on biogas production and use from specialists who have worked in the field for more than 30 years
- The ability to convert what is currently considered to be a low value product into a value added product and resource
- The potential to increase production from increased yields and production from cropping and animal production systems from biogas production
- The potential to lower costs of production
- The ability to operate more environmentally friendly enterprises and increase sustainability of production
- The ability to increase sustainable employment in regional areas with employment being supplied from biogas production units
- The ability to operate a safer and sustainable industry.

7. Knowledge Transfer: Applying the Outcomes

The Plan to Utilise Study Tour Outcomes

It is planned to:

- Forward the report to the key agricultural industry associations
- Deliver seminars to key industry associations
- Develop a revised training program for biogas production and use for delivery to industry
- Attend industry events where a contribution may be made to industry directions on biogas production.

Government Role

- Support the development of a viable technology and clean energy technology
- Promote the development of policies, safe work practices and support training in biogas production and use.

Industry Associations

- Inform members of new technology and ideas to increase productivity.

Knowledge and Skill Dissemination Sessions

The Fellow intends to:

- Present at the Bioenergy Australia Conference to be held in the Hunter Valley in November 2013
- Deliver training programs to industry during 2014
- Deliver sessions to industry association forums in 2014 for the dairy, pork, poultry and beef industries.

8. Recommendations

Skill Deficiencies and Achievable Solutions

That the Fellow conducts forums for each of the agricultural areas of dairy, beef, pork and poultry as well as other areas of agriculture such as cropping to promote the study tour findings and report.

That co-digestion of different agricultural substrates are researched and long term trials to determine the BMP of agricultural residues are established to realize the potential of biogas production from agricultural residues.

That an holistic approach is adopted to determining the viability of establishing cost effective biogas production and use.

That the key findings and conclusions presented in this report are considered for further development of biogas production units, and research and development by industry, government, research and education and training providers.

Government

That Governments at all levels support research into the feasibility of developing biogas production in Australia using agricultural residues.

That the Federal and State governments introduce an approval system for companies to work on biogas facilities.

That Federal and State governments support the development of nationally accredited training for biogas production and use using agricultural residues.

That Federal and State governments provide incentive based schemes to support the development of biogas production and use.

That the Federal government sets targets for the use of agricultural residues for energy production and nutrient recovery, similar to those of European countries such as Germany and Denmark.

That governments at all levels develop policies to promote public awareness, increase investment and gain support for biogas production and use as a sustainable and viable alternative to fossil fuel use.

That the Federal government considers introducing quality assurance schemes for substrates to ensure safe bi-products are produced from biogas production.

Agricultural Industries

That agricultural industries support further research and development into optimizing biogas production in Australia.

That the agricultural industry support and facilitate the conduct of knowledge transfer to their industry about the potential of biogas production and use through supporting:

- Formal training
- Information sessions
- Establishing online knowledge and information services relevant to their industry.

That the agricultural industry considers straw, deep litter and appropriate pre-treatment and post-treatment technology as viable options for biogas production.

8. Recommendations

Professional Associations

That Bioenergy Australia promotes biogas production and use as a viable form of renewable energy.

Education and Training – University, TAFE, Schools

The Fellow to update Sunraysia Institute of TAFE's National Centre for Sustainability short course on 'The Fundamentals of Anaerobic Digestion and Commercial Biogas Production and Use' to include skill deficiencies and the intellectual capital about biogas production identified during the study tour.

That the Fellow will liaise with the relevant Industry Skills Councils about developing accredited training for biogas production and use.

That the Fellow continues to liaise and work with industry groups to ensure training and development programs are appropriate and relevant to industry needs.

The International Specialised Skills Institute

That this report be made freely available online to agricultural industries, government and the community in Australia.

Future Fellowships

Future Fellowships should consider following up the areas identified in this report as future trends and issues for researchers in the Key Findings and Conclusions section, under Overall Impressions, as well as issues in the areas of cost-effective biogas production, energy management, nutrient recovery and deep litter residue management.

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10. Attachments

Attachment One

Pre-visit Questions Document

The following document was emailed to all visit sites approximately four to six weeks prior to the visit to inform hosts about the areas of research and also enable them to prepare for the visit.

This process seemed to assist in planning of the visits and preparation of comprehensive responses.

10. Attachments

International Specialised Skills Institute - 2012 Higher Education and Skills Group Overseas Fellowship

Visit Questions/Issues to be Investigated

Stanley Pietsch

Fellowship Title

Anaerobic Digestion Systems and Deep Litter Waste Management for Rural Primary Industry Enterprises

The context of Stanley's project is firmly grounded on raising the competitiveness and sustainability of Australian agricultural production.

Given the tightness of economic conditions for farmers, Stanley's Fellowship is to focus on cost-effective technology, knowledge and skills for biogas production in regional rural primary enterprises. The aim of this work is to integrate technology into primary enterprises such as:

- Pork production
- Dairies
- Poultry production
- Beef feedlots

Australian Context

The production of Biogas is gathering momentum in agricultural enterprises. In the pork industry lagoons have been the traditional method of disposing of effluent and these are now being covered to harness methane and fertilizers. The Hydraulic Retention Time for these systems can be over 20 days however. The pork industry is also moving towards using dry deep litter systems using straw for example to save water used in wash down systems and this needs to be investigated.

Some of the critical issues identified from discussions with industry are:

- Cost effective technologies and systems to assist in decision making
- Biogas production system start up procedures
- Hydraulic Retention Times
- Safety
- Lower cost investment systems which effective and productive
- Training in skills and knowledge required to operate plants
- Management and culture of micro-organisms
- Making full use of energy and nutrients
- Pre-treatment of substrates
- Trouble shooting and solutions

- Monitoring digestion effectively to maintain an appropriate environment for micro-organisms to be productive
- Currently in general electrical energy is not being fed into the national electrical grid as it is not seen as feasible, which means the energy is being used within an enterprise
- Access to reliable knowledge, expertise and advice

There are some areas of agricultural production that have not yet considered biogas production as a viable option for energy production and nutrient retrieval.

There are four main areas of investigation of this Fellowship which are outlined below along with critical question/issues to be investigated to guide the research.

The research is not limited to these questions however at the expense of identifying critical and important information. I would welcome suggestions and input into this research.

Thanks Stanley Pietsch

16 May 2013

10. Attachments

Cost Effective Systems

a. What do you believe the most cost effective (best practice) anaerobic digestive systems are for agricultural enterprises such as piggeries, poultry and cow industries, particularly in the Australian context?
b. Do you know of effective low up front capital investment systems?
c. Skills and knowledge required for cost effective systems?
d. Future trends in technology development?
e. Future skill/knowledge needs?
f. Major issues for increased adoption of anaerobic digestion?
g. Solutions to adoption of anaerobic digestion technology?

Effective Use of Energy – Enterprise Energy Management

a. Best practice effective energy recovery/capturing strategies or processes?
b. Energy utilisation/transfer/management strategies or processes which are effective for increased primary enterprise production?
c. Skills/knowledge required for effective energy management/utilisation?
d. Future trends in effective energy use?
e. Future skill/knowledge needs for energy management?
f. Major issues for adoption of energy use?
g. Solutions to adoption of energy use technology?

Biogas Production Bi-products

a. Best practice effective bi-product recovery/capturing strategies or processes?
b. What are the main bi-products which are collected as a result of anaerobic digestion and biogas production?
c. How are these bi-products used profitably?
d. Technologies/skills required for collection of bi-products?
e. Future trends in technology development?
f. Future skill/knowledge needs?
g. Major issues for adoption of bi-product production and collection?
h. Solutions to adoption of bi-product use?

Deep Litter (Relatively Dry) Waste Management

a. Best practice technologies for cost effective deep litter waste management using substrates such as straw?
b. Energy production from deep litter waste management?
c. Bi-products from deep litter waste management?
d. Skills required for effective deep litter waste management?
e. Knowledge required for operation of deep litter waste management?
f. Future trends in technology development?
g. Future skill/knowledge needs?
h. Major issues for adoption of deep litter waste management production?
i. Solutions to adoption of bi-product use?
j. Major barriers to adoption of biogas production and solutions?

General Issues

a. Approaches and critical issues to health and safety issues?
b. Drivers for biogas production?
c. Do you know of any other issues I should be aware of that I have not raised please?

Attachment Two

21st European Biomass Conference and Exhibition, Copenhagen, Denmark

Objectives

The focus of attending the 21st European Biomass Conference and Exhibition was to gain an understanding of the European context for biogas production and to network and identify contacts, technologies and skills relevant to the objectives of the Fellow's study tour.

Conference Opening

Plenary Session Scientific Opening

Green Chemistry and Biobased Products: M&G Approach Behind Proesa

Dario Giordano, Chemtex Italia s.p.a., Research, Italy

Outcomes

Key points from the discussion were:

Cost Effective Biogas Production

- There is a need to locate refineries close to source of substantial biomass source. If the biomass density is low this increases the transport costs.

The Bella Center, Copenhagen, Denmark where the 21st European Biomass Conference and Exhibition was held from 3-7 June, 2013

Chaired by Anders Eldrup, Conference General Chairman, Chairman of the Copenhagen Cleantech Cluster

Key points from the discussion were:

- Denmark is aiming to be fossil fuel free by 2050. Currently 85% of energy is fossil fuel
- Denmark is aiming to supply 50% of energy by 2020 from wind
- Biomass is critical to the ability to shift away from coal and other fossil fuels
- Biomass is critical to complement wind and solar energy generation
- Combustion of waste is not the way forward compared to recycling
- New products are needed without using oil
- It is predicted that oil prices will increase as well as there is the problem of pollution
- New sustainable jobs are needed for the young generation from sustainable energy sources.

Attachment Three

21st European Biomass Conference and Exhibition, Copenhagen, Denmark

General Conference Session Summaries

Martin Lidegaard, Danish Minister of Climate, Energy and Building

Key points from the discussion were:

- Martin pointed out that a good infrastructure was needed if Denmark is to achieve renewable energy targets
- There would need to be a biomass to market price established
- Regulatory frameworks for renewable energy is needed with legislation and standardisation
- Investment is needed along with new technology
- Public support is important to obtain as they are the consumers
- Biomass is a complicated area of study and there is a diverse range of views across the 27 countries of the European Union
- Attacks on the use of biomass for energy need to be countered.

Giovanni De Santi, Director of the Institute of Energy and Transport, Joint Research Centre (JRC), European Commission

Key points from the discussion were:

- Bioenergy has scientific based support
- Legislation and standardisation are needed for energy production from biomass
- Employment resulting from biomass processing is a key issue
- Europe has set targets of 20% reduction in GHG emissions by 2020 and 80% - 90% by 2050
- European Union is 80% dependant on fossil fuels currently
- GHG emissions have been reduced by 16.3% compared to a target of 20% by 2020
- Renewable energy has been increased by 12.7% compared to a target of plus 20% by 2020
- It is expected that between 2030 and 2050 biomass as an energy source will increase dramatically
- The JRC has developed two directives
  - » The Renewable Energy Directive (2009/28/EC)
  - » Fuel Quality Directive (2009/28/EC)
- Straw is seen as an important energy source for the future
- The JRC believes that biomass is critical to achieving the 2020 GHG emission reductions.

Location of Biogas Production – Slurry as a Retail Commodity

Mikkel Bojesen, Institute of Food and Resource Economics, University of Copenhagen

Key points from the discussion were:

Cost Effective Biogas Production

- Denmark aims to increase use of animal slurry manure from 8% to 50% by 2020
- This is to meet European Union renewable energy source directive[1].
- By 2013 biogas production must be part of municipal heating plans for Danish municipalities
- Biogas production has environmental and renewable energy potential
- Existing plants will need to increase production and new plants will need to be established to meet targets
- Using a location allocation model this presentation provided a model for optimal location and production capacity of new biogas plants
- Transportation costs can account for a total of 30% of production costs
- There is little research on how to minimise production costs through economic planning. There is a large knowledge gap and a need for decision support
- A location of future biogas plants map was shown.

Energy Use from Biogas Production

- By 2013 biogas production must be part of municipal heating plans for Danish municipalities.

Biomass Conditioning –Degradation of Biomass During the Storage of Woodchips

Sabrina Heinek, alpS GmbH, Austria

Key points from the discussion were:

Cost Effective Biogas Production

- Respirometric tests were used to determine degradation of biomass fuel
- This is the sort of factors that will need to be considered if storing straw for AD
- Losses can be significant in woodchips with 13% loss of biomass lost in dry chips from AD, the loss depending on the temperature and moisture level.

The Biomass Resource Model – Meeting Bioenergy Targets with Reduced Imports

Andrew Welfle, Tyndall Centre, University of Manchester, School Mechanical, Aerospace & Civil Engineering, Unit Kingdom

Key points from the discussion were:

Cost Effective Biogas Production

- The three most reliable sources of biomass in the United Kingdom are agricultural residues, grown biomass and municipal waste

- The highest biomass energy contributor with a food production focus scenario is predicted to be agricultural residues from 2015 to 2030 and grown energy crops from 2030 to 2050. The most abundant biomass is predicted to be agricultural residues
- The highest biomass energy contributor with an energy production focus scenario is predicted to be grown biomass from 2015 to 2020 and from 2030 to 2050 with municipal solid waste from 2020 to 2030. The most abundant biomass is municipal solid waste for the entire period.

When Does Decentralised Production of Biogas and Centralised Upgrading and Injection in the Natural Gas Grid Make Sense

Evert Jan Hengeveld, Hanze Research Centre Energy, The Netherlands

Key points from the discussion were:

Cost Effective Biogas Production

- The presenter argued that by having biogas plants feeding biogas into a centralised hub that it is more efficient to treat the gas centrally so that it can be treated and injected into the natural gas grid
- Centralised hub arrangements of biogas plants were found to have major cost benefits such as:
  - » Saving on transport
  - » Saving on digester costs
  - » Savings on injector costs
- A sensitivity analysis demonstrated that costs benefits can be predicted for transport distances using trucks for transporting biomass.

Modelling of Biomass Potential for Energy and Food Security from Agricultural Land and Forests for Long Term Horizons (2030)

Jan Weger, Silva Tarouca Research Institute for Landscape, Phytoenergy and Biodiversity, Czech Republic

Key points from the discussion were:

Cost Effective Biogas Production

- Overall Europe is still evaluating the cost/benefit/security of bioenergy and technologies to optimise energy production
- In general huge potential exists for increased biogas production and biofuel production
- In Czech Republic straw, cereals and rape can be used effectively for biogas production
- Geographic Information Systems (GIS) technology can be used to model potential yields.

China's Biomass Energy Development Status and Policy Framework

Jingming Li, Director, Renewable Energy Division, Rural Energy and Environment Agency, Ministry of Agriculture, Peoples Republic of China

Key points from the discussion were:

Cost Effective Biogas Production

- Most centres are looking at viable ways to use straw for biogas production
- China has:
  - » 700MT of crop straw and forest waste annually
  - » 3BT livestock and poultry manure per year
- The Chinese Government has invested 4.5B€ over 13 years into biomass development
- Renewable Energy Law, Modified in 2009
  - » States that all grid companies should buy renewable power unconditionally
- China has a National Rural Biogas Development Plan with a target of 44Bm^3 of biogas per year by the end of 2020
- National Rural Biogas Development Plan 2011 -2015 has targets of:
  - » 10M new biogas users
  - » 70,000 small biogas plants
  - » 8,000 middle and large projects
  - » 50,000 village service network
  - » Technology support projects
  - » Experimental projects on high value utilization of biogas
- There are 55 Standards program on biomass energy issued by the Ministry of Agriculture including 36 Standards for biogas production
- China has established a National Biogas Standards Committee (SAC/TC 515) and ISO Biogas Standards Committee (ISO/TC 255)
- There are 39.96M rural household digesters with 14.7Bm^3 of biogas per annum
- There are 80,890 biogas plants of different sizes including 14,000 large and medium sized plants.

Bayernplan: An Innovative Business Concept for Biogas

Michael Schmidt, Bavarian Ministry of Agriculture and Forestry, Munich, Germany

Co-authors: W. Ortinger, R. Schäfer, Bavarian Ministry of Agriculture and Forestry, Munich, Germany

Key points from the discussion were:

- There is a trend away from nuclear power and a move to bioenergy such as biogas production
- Biogas production is to compliment wind/solar energy as it can be produced on demand
- Currently there are 7000 biogas plants in Germany
- It is anticipated that there will be new biogas plants built
- It is expected that there will be co-firing of biogas with fossil fuels.

Concepts for Energy Production from Grass – a Case Study on the Havelland-Region in Germany

Philip Sauter, DBFZ-German Biomass Research Centre, Bioenergy Systems, Germany

Co-authors: A. Brosowski, F. Döhling, Deutsches Biomasseforsceungszentrum, Leipzig, Germany; Y. Lochmann, Leibniz Institute for Agricultural Engineering, Potsdam, Germany; Bosch & Partner GmbH, Berlin, Germany

Key points from the discussion were:

- Grass is no longer used in the Havelland Region of Germany and is available for biogas production
- There is potential to recover P and K
- There is a lot of grass available for processing
- Government subsidies assist with making the use of grass and straw a cheaper fuel than wood or oil (40€/T is paid for grass supply chain and a subsidy is paid at 200€/Ha/year for conservation areas).

Best Practices for Building Sustainable Biomass-to-Biofuel Chains in Southern EU Regions: the Cases of Capitanata (IT) and Thessaly (GR)

Emmanuel Koukios, National Technical University of Athens, School of Chemical Engineering, Greece

Co-authors: L. Karaoglanoglou D., Koullas, National Technical University of Athens, Greece; M. Monteleone, University of Foggia, Italy

Key points from the discussion were:

- The presentation discussed the practices of building sustainable biomass to biofuel chains in Europe
- Need to develop feasibility criteria with broad considerations such as economic, environmental, social, technological and others
- A case study was provided using AD of surplus straw as an example for the two regions of Capitanata in Italy and Thessaly in Greece
- Ten 'hot questions' were designed including soil fertility, alternative uses of straw, GHG emissions reductions, the conversion efficiency of 20-40% and markets for energy produced
- The need to consider a comprehensive list of stakeholders was discussed including farmers, electrical utilities, policy makers and local and national government
- The stakeholders were surveyed to determine the importance of the ten critical criteria in order of importance such as return on investment or environmental concerns
- The priorities of the stakeholders were mapped with the use of preference vectors to decide on criteria
- This provided a systematic approach to decision making with regard to establishing biogas plants
- There have been four straw projects established in Greece.

The Agronomic Management of Straw and Its Energy Use in a Long-Term Sustainability Perspective

Massimo Monteleone, University of Foggia, STAR Agro-energy Group, Italy

Key points from the discussion were:

- The presenter concluded that their study demonstrated that energy production from crop residues can be coupled with optimal grain production and may improve environmental conditions as a result
- N_2O emissions (an important GHG) were shown to be reduced compared to straw being left on the ground
- Soil organic carbon levels were shown not to be reduced
- This is a significant study to show that energy production from crop residues is viable over the long term and does not negatively impact on soil and environmental conditions
- The use of crop residues is seen as an important way of achieving renewable energy targets for 2020 and 2050 as laid out in the EU Renewable Energy Directive (2009/28/EC) commonly called RED.

Optimized Biogas Production by Using the Primary Agricultural Products : Manure and Lignocellulose Crop and Crop Byproduct Biomasses

Jens Bo Helm-Nielsen, Aalborg University, Department of Energy Technology, Denmark

Key points from the discussion were:

- Given the targets to reduce GHG emissions by 2050 there will be a huge demand on biomass for energy production
- Critical biomass supplies to meet this demand are likely to be straw, horse manure, grass verge and grass meadows
- Different pre-treatment strategies for straw such as pre-cooking, steam explosion can increase the energy yield by 50%.

Optimisation of Sensor Technology for Efficient Fermentation of Biogenic Residues and Waste in Biogas Plants

Diana Pfeiffer, DBFZ – German Biomass Research Centre, Bioenergy Systems, Germany

Co-authors: M. Fenske, C. Hälsig, teleBITcom, Teltow, Germany; A. Hörig, S. Pä□ler, M. Schelter, W. Vonau, J. Zösel, Kurt-Schwabe-Institut Meinsberg, Zeigra-Knobelsdorf, Germany; S. Junne, E. Kielhorn, P. Neubauer, Technishe Universität Berlin Germany; A. Richter, GICON Gro□mann Ingenieur Consult, Dresdeb, Germany; P. Zimmermann, TEB Ingenieurbüro Peter Zimmermann, Berlin, Germany

Key points from the discussion were:

- It has been suggested that detailed knowledge of the AD process on an industrial scale is not understood
- The main reason for the lack of understanding of the processes is the absence of sensors and process control instrumentation in the industry
- The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) has funded two projects in the program called 'Promoting Projects to Optimise the Use of Biomass for Energy Production'. This project aimed to investigate the use of multi-sensors and online measurement of process data and how this can be applied to biogas production
- The use of sensors allows the measurement of layering of the digestate and how to combat it

- Lances used for sampling can be retro-fitted to measure acetic acid concentrations for example. The content of acetic acid cannot be measured using surface measurements
- It was shown how the concentration of acetic acid changed with the depth of the reactor when measured across 0.5m layers
- The use of sensors in the AD process could increase the potential yield of the process.

On-line Process Control and Operation of Anaerobic Digesters

Matthias Franke, Fraunhofer UMSICHT, Institute Branch Sulzbach-Rosenberg, Recycling Management, Germany

Co-authors: A.Weger, A. Hornung, Fraunhofer UMSICHT, Institute Branch Sulzbach-Rosenberg, Germany

Key points from the discussion were:

- On-line process control can allow the optimum use of substrate, avoid problems arising and process breakdowns
- H_2 can be used as a key controlling measure (parameter) as the concentration of propionic acid varies directly with the concentration of H_2
- Using the concentration of H_2 of 300ppm as an indicator and the percentage of CH_4 being produced, this data can be used to manage the substrate feeding rate into the reactor to optimise CH_4 yields.

Technical Modifications and Concepts for a Controllable Electricity Production via Biogas Plants in Germany

Georg Karl Häring, Hochschule Ingolstadt, Centre of Excellence for Renewable Energy Research, Germany

Co-authors: S. Bichlmeier, N. Nitzer, UTS Biogastechnick, Hallbergmoos, Germany; V. Hanby, De Montfort University, Leicester, United Kingdom; M.Sonnleither, W. Zörner, Ingolstadt University of Applied Sciences, Germany

Key points from the discussion were:

- It has been identified that renewable energy electrical generation provides a fluctuating supply of electricity with periods of over and under supply
- Biogas provides a means of overcoming these fluctuations through using additional gas storage so that electricity generation can be planned to occur in periods of under supply
- Scenario planning to 2050 indicate that biogas production has the capacity to compensate for under production periods by biogas producers being controllable electricity producers
- Controllable electricity production will also have the capacity to relieve the electricity grid from stress.

Methane Fermentation for Treatment of Nitrogen-rich Resources with Biogas Circulation

Hiroshi Oshibe, Tokyo Gas Co., Fundamental Technology Department, Japan

Co-Authors: N. Osaka, T. Matsui, Tokyo Gas, Kanagawa, Japan; K. Kida, Sichuan University Sichuan, P.R. China

Key points from the discussion were:

- A research project demonstrated that it is possible to successfully strip NH_3 from a biogas reactor by diverting the biogas to a water stripping process and then recirculating the biogas back into the reactor
- The demonstration used milk to be digested using a bench reactor
- This raises the possibility of effectively digesting substrates high in N such as chicken manure without the NH_3 inhibiting AD.

Attachment Four

21st European Biomass Conference and Exhibition, Copenhagen, Denmark

Conference Posters

Rice Straw and Wheat Straw: Potential Feedstocks for the Biobased Economy,

Rob Bakker, Wolter Elbersen en Steef Lips, Wageningen UR Food and Biobased Research, Wageningen, Netherlands

Key points from the poster were:

Cost Effective Biogas Production

- From agricultural production data the total production of rice and wheat straw is 727MT and 583MT per year
- Due to the high C to N content of straw, it needs to be blended with other agricultural residues to make it suitable for biogas production.

There were extensive poster displays at the 21st European Biomass Conference and Exhibition.

Development of Sustainable Heat Markets for Biogas Plants in Europe: Market and Framework Analysis

Bailon Allegue L., Hinge J., Dzene I., Rochas C., Mergner R.,Kulisic B., Maras Abramovic J., Vorisek T., De Fillippi F., Devetta M., Surowiec M., Amann S., Adamescu M., and Wagner I., Danish Technological Institute

Key points from the poster were:

Cost Effective Biogas Production

- Heat from CHP units in Europe is commonly not fully utilized or wasted
- The BIOGASHEAT project targets the sustainable development of the heat market for existing and new biogas plants at a European, national and local level
- The project has produced a detailed framework and market analysis on the use of biogas heat in 9 countries
- A handbook has been developed and there have been examples of good practice of biogas heat use identified
- A strategy paper has been produced for enforcement of national and EU biogas heat use policy
- Work includes business models, entrepreneurial strategies, pre-feasibility studies and business plans tested for real projects
- The biogas market development is influenced by legal and political framework conditions such as:
  - » Feed-in tariffs for electricity sale are a key for market growth
  - » Obligatory measures to use heat have been introduced into Germany
  - » Emerging biogas markets need to consider integrating heating concepts.
- Energy Use from Biogas Production can be used as:
  - » Heat for digestate and sludge drying
  - » Air cooling
  - » Aquaculture and greenhouses
  - » Heating spas, hospitals and public buildings.

Attachment Five

21st European Biomass Conference and Exhibition, Copenhagen, Denmark

Conference Exhibition Displays

Supergen Bioenergy Hub

- Commented that England is trying to replace coal gas with biogas and that they are researching the best ways to do this
- Aston University are looking at increasing the energy yield from biogas production and pyrolysis
- The Renewable Energy Association in England are looking at ways to encourage viable uptake of biogas production in the United Kingdom
- The Supergen Bioenergy Hub can be found at: http://www.supergen-bioenergy.net/.

ECOWEB from Research to Realisation

- This website provides access to a large number of research organisations in Europe linking 7 research organisations which have received funding from the European Union Seventh Framework Program
- ECOWEB provides information on over 3000 European eco-innovations, including technologies, applications, products, processes and other solutions. It aims to link enterprises and networks, in particular SMEs, to encourage an increase in the uptake of EU-funded research for the development of eco-innovations
- This website allows searches by topic and lists all contacts who can be accessed
- The site also provides a weekly newsletter that can be accessed and customised to meet individual needs
- The site can be found at http://www.ecoweb.info.

The Exhibition floor at the 21st European Biomass Conference and Exhibition. There was an impressive gathering of exhibits.

BIOGASHEAT Project

- This project was established to encourage German farmers to collect heat from electrical generation using biogas and to use the heat profitably within their enterprise to increase production
- There has been little adoption of biogas production in Eastern Europe in countries such as Austria, Croatia, Czech Republic, Denmark, Germany, Italy, Latvia, Poland and Romania
- The BIOGASHEAT Project was established to assist capacity building through training farmers. A training manual was established to assist this process
- The uses for heat from biogas plants are:
  - » Direct heat use
  - » The use of satellite CHP's requiring piping of biogas
  - » Replacement of natural gas following upgrading biomethane and injecting it into the natural gas grid
  - » Drying of wood chips, cereals and digestate
  - » Upgrading biogas to biomethane
  - » Heating of piggeries and chicken sheds
  - » Cooling for fresh food such as dairy products using absorption chillers
  - » Aquaculture
  - » Greenhouse heating and cooling using vapour-compression chillers or absorption chillers
  - » Transport in Compressed Natural Gas Vehicles as biomethane.

An increasingly important aspect of biogas is the good storability of biogas and biomethane.

All of these options are explained in the Sustainable Heat Use of Biogas Plants – A Handbook as part of the BIOGASHEAT project[10].

Other highlights from this handbook are:

- The Handbook provides heat production estimations and methodologies for calculations to determine the heat use by anaerobic digesters
- A comparison of the efficiency of gas electrical generator engines and their characteristics and efficiency, such as the Gas-Otto engine compared to the Gas-Pilot Injection engine for CHP production
- The use of waste heat from CHP units as a critical economic and environmental factor for performance of biogas plants
- District heating systems and their efficiencies
- Heat transport in containers using phase change material (PCM) whereby a substance stores heat by changing from a solid to a liquid. Heat can be retrieved by reversing the physical state of the material from a liquid to a solid. This technology although not widely used shows potential for the future
- The use of new technology such as thermodynamic storage systems utilizing Zeoliths which are micro-porous, aluminosilicate minerals which have a large surface area. This enables water vapour

passed through the material to be adsorbed with the release of heat. These can be used for drying purposes as well. Research is being conducted at the Fraunhofer Institute in Germany on 750l demonstration scale model. The system can store three to four times the heat to that of water[11]

- The use of the Rankine Cycle and the Organic Rankine Cycle using water and organic fluid respectively to convert heat energy from biogas combustion to mechanical and electricity generation. The Organic Rankine Cycle can operate at lower temperatures down to 70-80°C compared to 100°C for water
- The upgrading of biogas methane from 45%-70% to more than 95% using:
  - » Adsorption technology using pressure swing adsorption (PSA)
  - » Absorption technology using water scrubbing, organic physical scrubbing and chemical scrubbing
  - » Permeation technology using high pressure membrane technology and low pressure membrane separation
  - » This enables supplementation of natural gas grids with biomethane[10]
- The use of compressed biomethane for transport in compressed natural gas vehicles which occurs in Sweden. A current drawback exists of only being able to drive short distances. This may require the use of dual fuel systems such as diesel and compressed biomethane.

Attachment Six

Tour Visits and Interviews

Clausthaler Umwelttechnik-Institut GmbH, (CUTEC Institute), Clausthal-Zellerfeld, Germany

Contacts

Hinnerk Boorman, Physical and Biological Processes

Prof. Michael Sievers, Head of the Department, Physical and Biological Processes

Objectives

The Fellow wanted to establish the general context of biogas production in Germany and how this related to the four study tour objectives.

Outcomes

Key points from the discussion were:

Context

- Germany has approximately 7000 biogas plants currently
- CUTEC was established in 1990 to provide research for companies
- CUTEC Institute's main focus is applied technology research and development
- Projects consist of European and other international projects such as in Nigeria
- Typically there are 3 digesters in each normal biogas plant, one for easily digested material, one for slower digested material and one for storage. The storage provides digestate when it is required for spreading as a fertilizer.

Cost Effective Biogas Production

- Farms need biogas production to support their income
- Maize is grown as an energy crop. However, it competes with wheat production
- There is a food/energy production debate
- Sugar beet is being grown as an alternative energy crop and provides a 'disease break' for other crops
- The cost of transport of biomass is a key cost to account for in biogas production
- 48% of biogas energy comes from maize
- To achieve an effective analysis it is necessary to consider a whole of supply chain approach for biogas production
- Typically there is a 30 day Hydraulic Retention Time (HRT) in German biogas plants and Organic Load Rates of 2-4 kg DM /m^3/day
- Ligno-cellulose material can be digested to provide a potential 30% of additional energy and this represents a significant opportunity for improvement. It is a question of comparing the cost of

accessing the additional energy with the additional energy yield. Strategies such as H_2 degradation processes, mechanical degradation, ultrasound treatment of substrates, chemical processing and the use of bio-enzymes are all options to consider

- In determining the cost-effectiveness of biogas production, an holistic view needs to be taken into account, the whole system needs to be included in the analysis. Systems are best developed for specific situations to meet specific needs and to fit into the specific context being considered. There are no general rules to apply. Research and development need to be completed for specific situations. Lagoon digesters may be the best solution but there may also be ways to improve the lagoon digester performance
- Anaerobic digestive system designs need to account for how micro-organisms live and ensure that they can perform under optimal conditions
- Anaerobic digestive system designs need to also consider the impact on the environment. For example, maize grown as an energy crop is not good for soil improvement
- Another consideration for cost effectiveness is storage of the substrate so that energy is not lost during storage. As much as 20% of the CH_4 can be lost during storage. The time of harvesting agricultural residues can be important to optimise energy yields
- Different pre-treatment technology can increase energy yields such as disintegration processes where the substrate is passed through a quick change in pressure. To liquefy the ligno-cellulose, the sludge is then heated to 160˚C for 30 minutes
- The input systems for AD are important to create the appropriate balance of nutrients for micro-organisms
- Split systems are a positive as hydrolysis occurs at pH 5.2 – 6.5 whereas optimal CH_4 production occurs at pH 6.7. By providing optimal conditions for micro-organism growth, CH_4 production can be increased. If too much substrate is fed that is easily digestible the pH will drop. Feeding of anaerobic digesters needs to be tightly controlled for optimum performance and monitoring systems for pH for example need to be in place
- High-tech equipment is being used to measure CH_4 production over time accurately. New heat bank equipment is being used for laboratory anaerobic digestive trials instead of water baths. These provide a more stable environment for more reliable results
- Chemical, engineering, biological and agricultural expertise are required to take an holistic understanding of AD systems
- Trials of anaerobic digestive systems need to be conducted over at least three equivalent HRT or at least 400 days as it takes this long for problems in the AD process to emerge. Expensive capital outlay projects requires that processes and research trial data is reliable. The research equipment can be controlled remotely.

Biogas production trials are conducted at CUTEC Institute in Clausthal-Zellerfeld, Germany. This photo shows the sophisticated equipment used in trials.

Nutrient Recovery from Biogas Production

- There is a risk of cadmium and uranium contaminants contained in P fertilizers from Morocco
- Residual non-digested ligno-cellulose material can be incinerated for energy but this requires energy for drying, and alternatively the ligno-cellulose material can be used to improve soil structure
- Nutrients may be recovered from the liquid substrate using microfiltration and then using reverse osmosis technology to precipitate P as magnesium ammonium phosphate (MgAP). Membranes have been found to degrade making this technology unviable. Ceramic membranes last longer. High streaming of the liquid has been shown to use a lot of energy. A rota over the screen is currently being tested to save the cost of pumping across the membrane.

Energy Use from Biogas Production

- Typically anaerobic digestive systems use 6-10% of electricity to run the plant and 15 to 30% to heat the fermenter
- Electrical generation efficiency has been shown to be 34 to 41% and as such, this represents an area for improvement. A current suggested improvement is the use of larger electrical generators through the development of generators at a hub
- In Sweden biogas is being upgraded to increase the energy yield by decreasing the concentration of CO_2 so that the CH_4 concentration is equivalent to natural gas

- It may be more efficient to only dry the biogas and use it closer to its source such as heating a school
- Effective storage of bioenergy is important such as elevating water to height so that as energy is required water is released to generate electrical energy.

Deep Litter Residue Management

- There are a number of systems which can be used depending on the moisture content of the substrate. Wet fermenters can be used with less than or equal to 50% DM as long as there is no straw as this forms layers and makes the systems inoperable. With greater than 50% DM Back Flow digesters may be used. Batch systems can be used but this represents old technology
- CUTEC Institute is researching how ligno-cellulose molecules can be broken up and digested to increase energy yields using pre-treatment technology.

Trials of substrates for biogas production are conducted over a period of up to 400 days at CUTEC Institute in these larger reactors. The reactors can be controlled remotely using online process control.

INPUT - Ingenieure GmbH, Sehnde, Germany

Contact:

Holger Funke, Operations Manager

Objectives

The aim of this visit was to observe two plants of contemporary technology using the ‘Laran –Plug Flow Digester’. The Honeneggelsen plant was using deep litter residue including straw as a substrate in this system. The plant at Königslutter was used to digest crop residues from cereal crops.

The Laran–Plug Flow Digester visited at Honeneggelsen in Germany was operated by INPUT GmbH. This photo shows the feed hopper on the right with the feed-in entry to the reactor at the centre top at the end of the reactor.

10. Attachments

Honeneggelsen Site

Outcomes

Key points from the discussion were:

- The substrate consists of a blend of slurry (16% DM) and drier material being made up of 2/3 maize (35% DM) and 1/3 animal manure (50% straw and manure).
- Substrates sourced include cattle deep litter and chicken deep litter as well as pig slurry manure

The feed hopper for the Laran-Plug Flow Digester is viewed from the roof of the reactor. It contains maize silage as the substrate which is mixed with animal manure slurry.

- Maize is stored as silage from September/October and used during the year to provide a continual energy source
- The feeding rate of the digester is 9-11kg DM /m^3/day which is considered to be relatively high compared to the average rate of 2-4kg DM /m^3/day
- All DM is weighed in and out of the digester accurately
- The Plug Flow Digester allows flexible input of substrates including straw as substrate is fed in one end and slowly pushed to the other
- The substrate is pre-treated by being crushed and the maize is cut with six cutters
- Substrate is stirred by large slowly rotating stirrers (one rotation per minute with a diameter of 7.5m). These resemble paddles which mix the substrate from the bottom of the digester to the top. There are four stirrers which operate alternatively to avoid them hitting each other. Each paddle rotates three times in a clockwise direction followed by a rotation in the reverse direction. The slow turning

of the substrate means that a lot of small bubbles are released to the surface as opposed to a large bubble of biogas being released if no stirrers were present

This view shows the four motors on the side of the Laran-Plug Flow Digester used to turn the large horizontal paddle like stirrers inside the reactor.

- The dimensions of the digester is 30m long by 10m wide and 8m high
- The Plug Flow Digester is heated with tubes in the walls of the digester and operates at a thermophilic temperature of 50°C
- Sensors in the digester measure temperature, pH and the pressure in the digester
- One of the advantages of the Plug Flow Digester is that hydrolysis occurs at the start of the digester in favourable conditions at a lower pH
- Methanogenisis occurs more at the end of the digester
- The HRT of the digester is 30 days
- A gutter in the bottom of the digester collects stones and rocks for example, to stop the material going through the screw pump once the digestate is pumped from the digester to remove solids
- The digester produces 300m^3/hour of biogas which powers a 850KW/h generator
- The DM content of the resulting digestate output is 11%
- Following the digestate being passed through the screw pump the DM content of the solid fraction is 24%. The liquid from the screw pump is transferred to a third tank where it undergoes further

fermentation

A screw type separator, similar that used in the food processing industry, is used to separate the solid digestate from the liquid digestate at the conclusion of the AD process in the Laran-Plug Flow Digester.

- Ultrasound device mounted at the top of the digester measures the depth of digestate in the digester
- Gas flow safety valve is located on the top of the reactor

The biogas take off for the Laran-Plug Flow Digester is seen on the right in the foreground with an emergency gas release valve seen in the background, located on the roof of the reactor.

- H_2S is removed using a biological filter reducing the concentration from 300-400ppm to 0ppm

A bio-filter using microorganisms is used for the Laran-Plug Flow Digester to remove H_2S from the biogas prior to the biogas being piped to the CHP unit. The bio-filter is the vertical tank in the background of this photo.

- The storage tank is heated to 40°C. The digestate needs to be able to be stored in the storage tank for 180 days to comply with legislated time limits on when the digestate can be applied to paddocks. It is supplied to farmers as a liquid fertilizer from February to the end of summer

The dome in this photo is the biogas storage tank located at the end of the Laran-Plug Flow Digester. It was a double layer cover held rigid by compressed air between the two layers of the cover to create a stable cover in windy conditions.

- The digestate is applied in the warmer months when crops are actively growing and can use the N immediately in the growing season. This is controlled by legislation to reduce N pollution
- Solids from the digestate can be applied to paddocks during the winter time more as a soil conditioner

The solid fraction of the digestate from the Laran-Plug Flow Digester following separation.

- The plant is monitored and controlled by using computer systems which provide continual process performance information
- It is more cost efficient to use electricity from the grid to operate the plant compared to using electricity generated by the plant. This is because the payment for electricity fed into the grid is higher than the cost of using electricity from the grid.

Deep Litter Residue Management

- The Plug Flow Digester is able to treat high levels of deep litter residue and avoid physical problems normally associated with digesting this material.

Maize silage is stored on-site at Honeneggelsen. This is typical of the way the maize silage is stored in Germany ready for biogas production.

Königslutter Site

- This plant is identical to the plant at Honeneggelsen
- The substrate used is pig manure slurry, rye, triticale, sorghum and maize without any animal manure being used
- The substrate is fed in at 38% – 40% DM
- The digester produces 642m^3/hour of biogas which is fed into the natural gas grid following purification
- CH_4 gas is put into the natural gas grid at a rate of 381m^3/hour
- The plant operates at 54°C in the thermophilic range
- 1.7% of the biogas is used for operation of the gas treatment process
- Digestate is recirculated in the digester to increase energy yields.

Gas Treatment for Feeding into the Natural Gas Grid

- The biogas is treated using chemical removal of H_2S
- CO_2 is removed by increasing the gas to 5 bar pressure and then passing the gas over an activated carbon filter
- H_2O is removed by compressing the gas and heating it, then reducing the pressure and cooling it so that the water condenses. The gas it heated again prior to being transferred to the natural gas grid
- Accurate measurements of pH, temperature, CO_2, H_2O and H_2S are taken and recorded continuously
- The gas is fed into the natural gas grid at 91.5% CH_4

Eggersmann Anlagenbau GmbH, Bad Oeynhausen, Germany

Contacts

Marco Hillbrand, Project Manager, Sales, Bad Oeynhausen

Jens Jüngel, Sales Manager, Area Manager North America

Eike Horn, Operations Manager, Bad Oeynhausen

SMARTFERM 'Garage' Batch Fermenter

Outcomes

Key points from the discussion were:

Cost Effective Biogas Production

- Municipal waste and all manures are processed except chicken manure which is considered to have too high N content
- The 'garage' digester consists of four sheds in series, sharing common walls located above an underground fermentation tank

The SMARTFERM garage fermenter system produced by Eggersmann Anlagenbau Smartferm GmbH located at Bad Oeynhausen in Germany. The fermenter is loaded with a front end loader and the deep litter agricultural residue substrate is pictured on the right. The control room is located on the right side of the garage reactor.

- The underground fermentation tank contains percolate which is pumped into each garage while they are digesting

A view inside the SMARTFERM garage fermenter showing the sprinkler system near the roof used to spray percolate over the digestate. It is pumped from the fermentation tank underneath the garage fermenter.

- A CHP unit produces electricity which is fed into the electrical grid, while the heat is used to dry painting of equipment. The efficiency of the CHP is the production of 40% electricity and 40% heat. The use of the heat has resulted in reduced use of natural gas to operate the business
- The plant is monitored at distance via online, but not managed online, as this is considered too dangerous. For example, it is too dangerous to start a pump up at distance
- Temperature, pressure, pH and biogas production and flow are all constantly measured and monitored. The composition of the biogas produced is broken down into H_2S, CO_2 CH_4 and H_2O vapour for analysis and evaluation
- All production data is stored electronically
- Parameters may be changed automatically or manually
- Heat is used to heat the percolate in a heat exchanger so that the percolate is heated prior to being pumped back into the garage
- A small biogas plant costs approximately 1M€
- The ‘garage’ digester is not sensitive to contamination. However, it is important to remove such items as batteries and oil filters

10. Attachments

- The plant has been operating for one and a half years
- If wet material is added liquid can be drawn off the percolate to ensure that the level of the percolate is safe
- There are pressure release valves on top of each garage
- Large scale units operate with 15,000 to 20,000T of substrate per year
- California is using the garage systems for food waste and New Zealand for municipal waste
- It takes from 6 to 24 hours to heat the substrate to 40°C to commence AD
- Capacity of each 'garage' is $95m^3$
- A 100KW/h electrical generator is run off the biogas produced
- The plants are easy to install, easy to operate and follow up service and trouble-shooting services are available
- The percolate tank has a trough to allow solids to settle and be removed prior to be being pumped
- The percolate is allowed to drain from the garage overnight prior to the emptying of the garage compartment
- The garage unit is environmentally friendly as it does not release odours into the atmosphere
- Residues are used as substrates and do not compete for food production, but in fact assist food production by returning nutrients and organic matter to the soil.

The solid substrate that is digested in the SMARTFERM garage fermenter. The system is able to process deep litter animal residues.

Nutrient Recovery from Biogas Production

- The digestion is intentionally stopped at 75 – 90% degradation so that there is material to compost
- There are three methods of composting:
  - » Open windrow
  - » Covered aerobic composting using a gauze to cover the compost
  - » In vessel composting which is favoured environmentally as you can capture gas emissions. It takes 28 days compared to 12 weeks for composting to be complete
- Compost is valued at 5€/T. If the compost is bagged and retailed it is worth more
- The composting process helps to control pathogens by the temperature increase of the composting material
- In this case it was considered more economical to treat straw by composting and returning it to the soil as a fertilizer/soil conditioner to increase the soil humus content.

Deep Litter Residue Management

- No pre-treatment is required as the substrate is loaded directly into the garage
- The digestate is composted off site
- Pathogens in the digestate are killed by thermophilic temperatures
- Horse manure and cow manure are used in the digester
- Air is sucked in at the back of the garage to stop odours escaping
- The fresher the substrate the more gas that is produced as any degradation of the substrate is avoided
- HRT of 21 days for each section of the ‘garage’ digester
- The digesters operate at 7.2-7.4pH
- It takes 9 – 16 days to circulate the percolate through the system
- Having four separate garages and a HRT time of 20 days means that a garage is filled or emptied every four to five days in a rotational sequence
- When the digester is filled, the garage is closed and air is sucked out of the digester to eliminate oxygen. The doors have inflatable seals to ensure that they are airtight
- Larger units are built from concrete
- The units have pipe work all pre-fabricated prior to shipping and the walls are insulated
- Smaller units are pre-fabricated and are bolted together. The garage digester operates at thermophilic temperatures and are self-heating using aerobic digestion initially to increase temperatures to 50°C
- At the end of the digestion process it takes 20 minutes to 2 hours to vent off biogas to make it safe to open the unit and remove the digestate
- The percolate is held in the underground tank
- The percentage of DM handled is 30% and is ideal for horse, cow and pig manures with straw.

DBFZ Deutsches Biomasseforschungszentrum GmbH (German Biomass Research Centre (DBFZ)), Leipzig, Germany

Contacts

Dr. Britt Schumacher, Department Biochemical Conversion

Dr. Walter Stinner, Department Biochemical Conversion

Objectives

The purpose of this visit was to focus on the research facilities used for AD and to investigate responses to the four tour objectives.

Outcomes

Key points from the discussion were:

Cost Effective Biogas Production

- The Research Centre has an operating Plug Flow Digester capable of processing high DM content material. It is a high grade stainless steel tank laid on its side

The maize silage used as the substrate in the plug flow style reactor at the German Biomass Research Centre in Leipzig, Germany.

- The DM feed rate is greater than 11 kg DM /m^3/day which was considered to be a high rate
- Strong paddles are used to stir the digestate and push it from the entry end to the exit end of the digester. They are strong enough to process municipal waste
- The substrate fed into the digester is a mixture of dry and slurry manure. This results in a 20% DM substrate being fed into the reactor
- The viscosity of the substrate varies directly with the temperature and the amount of floating material such as straw
- A concrete storage digester which is located beside the plug flow digester has stirrers mounted on the outside of the tank for ease of maintenance
- Manure storages are covered but not gas tight
- The energy production from substrates varies directly with the water content (or DM content). That is, the higher the water content the less energy that will be produced. Biogas production is complex due to variation in substrates and systems available
- Research is occurring into viable technology to break the bonds between cellulose and lignin molecules in crop residues and it appears to be only a matter of time for a viable solution to be found. Fungi may offer a solution to breaking the ligno-cellulose molecules and these were currently being investigated. A combination of strategies may also work such as thermal pressure hydrolysis.

The feed hopper for the maize silage at the German Biomass Research Centre.

10. Attachments

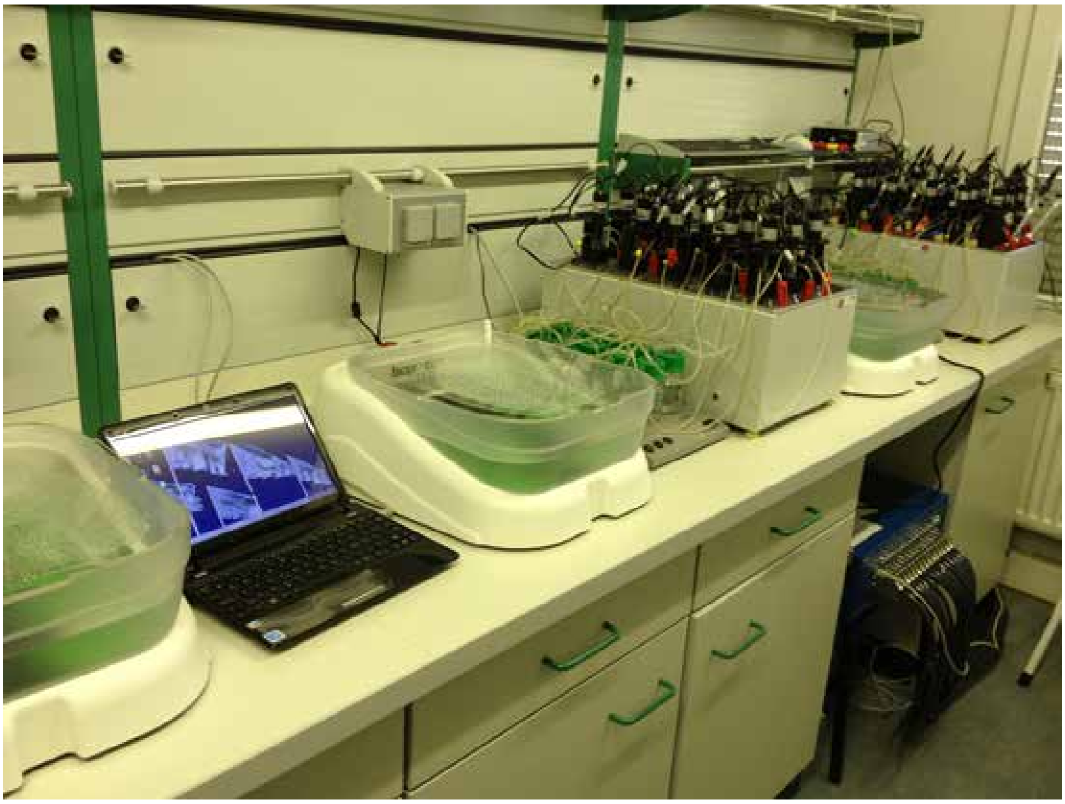
Determining Appropriate Biogas Plant Systems to Build

- The hosts considered the feasibility, design and operation of biogas plants needs to be a case by case analysis considering an holistic range of variables specific to the context
- In analysing the viability or feasibility of a biogas plant an holistic approach needs to be taken to include all the relevant variables and drivers, many of which are site specific. Some of the variables which need to be considered are the energy needs and the cost of alternative energy sources, what the drivers are for installing a biogas plant, and, what the site specific challenges are for biogas production
- It was suggested that in deciding what type of digester to install, it is important to start with the type of substrate to be used first and then design the digester. It is important to consider changes in substrate that are likely to occur, such as seasonal changes. It is advisable to consider one or two possible designs and adapt them to the situation. Pre-treatments and post-treatments need to be considered also. It is advisable to keep the systems as simple as possible. The issue of pathogens and vermin such as rats, mice and birds needs to be considered. There is also a risk of the transfer of pathogens from other sites such as from slaughter house residues threatening biosecurity of a site. There is also a risk of salmonella bacteria and viruses which affect wheat and other crops for example. This poses a risk for the use of the digestate to be used as a fertilizer. Pathogens can be controlled by heating the digestate to 70°C for one hour duration
- The Plug Flow Digester is efficient from a labour perspective with only a small amount of work required each day
- The garage style digesters are low capital investment but relatively labour intensive digesters requiring one days labour per week to be spent loading and unloading the substrate and digestate
- The garage style digesters have safety concerns with respect to H_2S being released. There is a need for the garage digester to be kept airtight and also ensure that they are well ventilated prior to emptying at the completion of the AD process
- A Wet Sprinkler System can operate effectively as a Batch Digester where fibre length is a risk. It is difficult to get sediment out of the Wet Sprinkler System and it is better to use the Plug Flow Digester in this situation
- A Sauter Lagoon reactor provides a low cost investment biogas plant for liquid and solid substrates.

Future Trends

- Energy efficient substrate pre-treatment is an important area for research and development
- Emission control systems for batch style digesters like the garage digesters for example
- There is a need for robust technology, consideration of substrate combinations, additives to reactors and to supply digesters with micro and macro elements
- There needs to be a focus on the reduction in energy consumption of biogas plants and integrated energy management systems to make them more efficient
- There needs to be microbiological parameters identified which are measured for biogas production monitoring:
  - » To understanding the microbiological process in AD
  - » To maintain AD stability through using early warning of process disturbances
  - » Development of on-line measurement techniques
- Increase the range of substrates used by being able to employ different microorganisms
- The use of fungi for pre-treatment of lingo-cellulose material has potential

- The use of specialist cellulolytic microorganisms from (extreme) environmental habitats to increase biogas production could offer benefits
- The diversification of substrates particularly the ligno-cellulose material



Biogas research experiments are conducted at the German Biomass Research Centre under controlled conditions in the laboratory. This photo shows the small reactors and equipment used to measure biogas production.

Nutrient Recovery from Biogas Production

- A lot of technology is too expensive to concentrate the digestate. It is possible to separate the liquid phase from the solids. It is also possible to micro-filtrate the liquid and use reverse osmosis to extract nutrients
- There are technical issues to consider such as heavy metals in municipal waste which can make recovering nutrients problematic
- The domestic fertilizer market is small and highly competitive, the solid digestate is valued at 10-15€/T
- The digestate is stored for fertilizer until it can be spread on fields
- The digestate from agricultural biogas plants is used as a bio-fertilizer in agriculture
- Municipal digestate is also used as a fertilizer
- Solid separated part of digestate is pelletized and sold as a fertilizer. Liquid fertilizer is also used
- Drying of the digestate can cause a loss of minerals and can cause emissions

Energy Use from Biogas Production

- Solutions will be site specific and dependant on enterprise
- Transport and machine fuelled by biogas
- Electrical and heat production
- Cooling and refrigeration
- Storable energy.

External motors are fitted to the CSTR at the German Biomass Research Centre. Being located on the outside of the reactor the motor is not at risk of being subject to corrosion and harsh conditions that exist inside the reactor.

Deep Litter Residue Management

- Research is continuing with Canadian researchers into Plug Flow digesters
- Plug Flow Digesters can handle a higher level of DM up to 20% if no straw or grass is included
- Straw length is a critical issue for processing in AD. Straw from cattle and poultry litter is long whereas in litter produced by pigs, the straw is short due to pigs chewing the straw
- Straw and can be extruded to make it more accessible to AD
- Using aeration to heat a garage style digester is not favoured as easily digestible material may be decomposed aerobically with a loss of energy. Pre-heating with percolate was considered to be more likely to be efficient
- A sprinkler digester where the percolate is sprayed from the top of the digester may work more effectively for deep litter waste. Channels in the deep litter however, may mean that not all the substrate is processed effectively. The CH_4 may not be released.

- In garage style digesters different mixes of substrates could be investigated to assist with making the structure of the digestate more open to allow the percolate to penetrate and biogas to escape. Mixing wood chips with deep litter waste has been researched for this purpose
- Extrusion and cutting of straw are additional technologies that assist digestion of straw.

Chicken Litter

- Issues which need to be considered for systems for chicken or poultry manure are:
  - » Higher production of free NH_3
  - » The building up of sediments in a reactor making transferring or pumping of the digestate difficult
  - » Feathers can pose a physical problem
  - » Special solutions are required.

Trends

- The future trend is to focus on optimization of ligno-cellulose degradation and the pre-treatment of deep litter residues.

Future Knowledge and Skill Needs

- Technology options
- Microbiological management
- Measurement technologies
- Safety training for toxic gases and biogas.

Biogas trials at the German Biomass Research Centre are viewed in this photo utilising larger reactor containers and accurate gas production measurement equipment in the laboratory.

Barriers to Adoption of Deep Litter Residue Processing

- It was considered by the hosts that hydraulic challenges pose the main concern

Training

- Knowledge and skills of operator need to be at a high level
- Training is provided by IBBK, GIZ or Biogas Fachverband e.V in Germany
- Training on inoculum is important
- Use of measuring devices for energy produced
- Management of hydraulic systems (pumps, tubes, stirring systems).

Health and Safety Issues

- CO_2 and H_2S are toxic gases so that aeration and warning systems are needed
- Biogas can burn or explode.

Biogas Production and Hygiene

- Hygiene is increased with food source for vectors like insects, rodents, birds being removed
- Pathogens are killed during the digestion process.

Capacity building for different stakeholder groups requires work in:

- Policy development
- Approving authorities
- Scientists working in various areas
- Companies for plant erection
- Technical staff for operation and plant maintenance.

ATB, Leibniz Institute for Agricultural Engineering Potsdam, Germany

Contacts

Prof. Bernd Linke, Department Bioengineering

Prof. Thomas Amon, Department of Veterinary, Freie University, Berlin

Dr. Philipp Grundmann, Resource Economics, Technology and Substance Cycles

Objectives

The purpose of this visit was to investigate research projects which have been performed and to gain insights from the contacts on the project objectives.

Outcomes

Key points from the discussion were:

Cost Effective Biogas Production

- There are different technologies for AD which are appropriate depending on substrate characteristics. For example, if the substrate is liquid or solid
- There is a wealth of advanced information available with respect to the biogas and energy yields of different crops and agricultural residues in general. In particular, there is a publication by IEA Bioenergy called 'Biogas from Crop Digestion' which provides a full description of the this data[13]
- The Fellow was extremely fortunate to be provided a CD containing 16 key references from this visit which provided valuable background reading and have enabled key issues involving biogas production and use to be identified and validated. Key concepts have been able to be documented as a result of reviewing these documents
- Another major reference which has been produced to guide the biogas industry has been the publication of the 'Biogas Handbook – Science, production and applications' by the IEA Energy[14]
- It was considered that the average cost of producing energy from biogas production is 3000€/kWh. A Plug Flow Digester in Minnesota, USA is a bit more expensive costing 3,500€/kWh[8]
- In Germany the HRT for 10-15% DM systems generally takes 30 to 50 days to digest. The digestate is then stored for 150 days in which 5-10% additional CH_4 is produced
- 'Dry AD' is being practiced in Belgium by a company called OWO. The feeding rate is 10kg DM/m^3/day. This is a reliable and robust system with 20-30% DM substrate input. This is made up of maize (20 -30% DM) pig and cow manure (15-20% DM varying with the amount of straw). The system operates using gravity to mix the percolate as the percolate is pumped into the top of the digester and flows down through the tank. Germany and China are operating this type of system as well
- It was stressed that for new substrates it is necessary to test the AD process in a 1–2 m^3 digester. It is necessary to conduct the trial for at least two HRT periods to determine if the system works
- There are two ways AD can be inhibited:
  - » High organic acid levels causing a low pH
  - » Free NH_3 in high pH conditions
- Some of the factors influencing the cost effectiveness of biogas plants are[7]:
  - » The size of the plant being established

- Plants built to produce less than 100kWel from the AD of agricultural residues like liquid manure, involves specific investment costs of 3,000 to 5,000€ per kW of installed electrical capacity
- Larger wet fermentation plants can cost 2,500€
- Standardised designs could cost less but may not operate to optimum efficiency
- Plants specifically designed for a farm may cost more to construct but operate more efficiently and productively
  - » The operating costs of the plant should also be considered. The most important of these are:
  - » Maintenance and repair costs
  - » Substrate costs in some cases (up to 50% in some cases)
  - » The costs for maintenance and repairs of CHPs can be minimised by electronic engine control and regulation, especially to account for variations in the quality and quantity of biogas produced from changes in substrates for example
  - » The daily work hours required to operate a plant. This can vary substantially depending on the plant
  - » Insurance costs
  - » Laboratory tests

Nutrient Recovery from Biogas Production

- Some farmers in Germany use separation of digestate producing solids which are spread onto paddocks and the liquid which is spread on paddocks during the warmer months of the year
- One option is to separate of the solids from the liquid fraction of the digestate using a screw type separator. This produces:
  - » 45% of P in the solids which is valuable and viable to transport
  - » 20% of N in solids
- Solids can be pelletised into a fertilizer and be sold on the domestic market
- The slurry is not permitted to be spread during the winter months. It can be applied to the soil surface post sowing of crops and to pasture
- N can be recovered from the digestate using precipitation, using magnesium and phosphoric acid to produce magnesium ammonium phosphorous ($MgNH_4P$). This process requires reverse osmosis
- There has been significant improvements in soil structure observed from the application of solids from the digestate and the nutrients are in a form readily available for plants to take up
- Artificial ammonium sulphate ($(NH_4)_2SO_4$) can be produced from biogas production by using sulphuric acid to combine with NH_3 so that $(NH_4)_2SO_4$ precipitates
- The efficiency of a CHP unit is typically 40%. There needs to be more efficient use of the 40% energy which is produced as heat. Some companies in West Germany are drying digestate so that it can be transported
- In terms of N emission from livestock the allowable amount is equivalent to one cattle head unit per hectare. With current livestock rates there are 3-4 cattle head equivalents per hectare in West Germany. So there is an excess of N available
- Only 5% of animal manure is being used in Germany in biogas plants. This represents a huge potential for energy and nutrient recovery

- Energy crops are subsidised 6-7ct/kWh. The German government aims is increase the use of animal slurry and minimise the use of maize to the following levels:
  - » 60% animal slurry
  - » 40% maize
- An innovative trial being conducted involves using magnetic granules which methanogens attach. The granules can be extracted from a reactor with a magnet and concentrated along with the bacteria. The bacteria can then be re-injected into the system.

Quality Management of Digestate

- The quality of digestate to be used as a fertilizer is an important issue. It is raised in a number of comprehensive references which are too involved to go into detail in this study. A brief summary of some of the critical issues is presented below
- The quality of the digestate is dependent on the quality of the substrate and the process of AD[12]
- Sweden, Switzerland and the United Kingdom have introduced substrate quality assurance schemes to ensure that substrates used in AD are safe for use
- Critical factors for safe substrates are[12]:
  - » Sanitisation to ensure the digestate is safe for animals and the environment
  - » The digestate to be free from inorganic impurities
  - » The digestate to be free from biological (pathological) and chemical pollutants including both organic and inorganic pollutants such as heavy metals
  - » The Danish experience shows that pasteurisation can be achieved at both thermophilic and mesophilic AD temperatures if the digestate is maintained within the reactor for a specific minimum amount of time termed the minimum guaranteed retention time (MGRT)[12]
  - » HRTs combined with temperatures and other parameters such as pH, redox potential and NH_3 are all involved in the effectiveness of sanitation

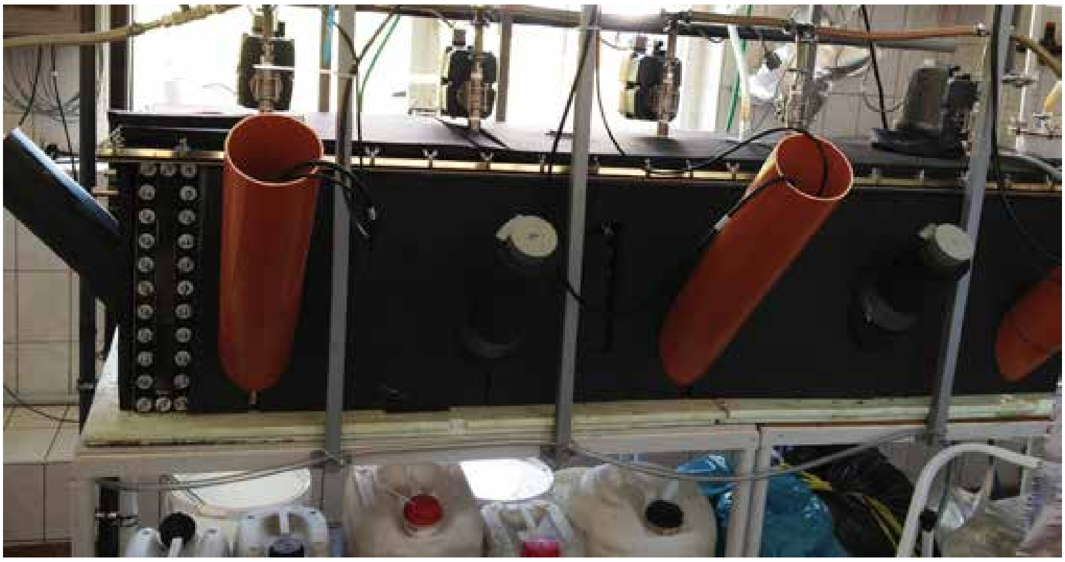
Energy Use from Biogas Production

- Upgrading biogas so that it can be fed directly into the natural gas grid or piped and used directly as biogas is viable. This is achieved by lowering the percentage of CO_2
- It is expected that 4 million cars will be running on biogas in Germany by 2020
- Upgrading technology for biogas is developing quickly. Membrane technology is being used in Sweden to directly fill vehicles such as cars and fleet vehicles. Tractors are also being directly filled with biogas
- There is an issue with manufacturers' warranties being nullified by using biogas to power some equipment.

Deep Litter Residue Management

- Pigs seem to be happier on straw and they reduce the length of the straw so that it is not too difficult to process in AD systems
- A CSTR typically has 10-15% DM content. Any substrate greater than 15% DM in the generally means that an alternative method to pumping the substrate is required for AD processing
- Poultry manure is high in N and produces NH_3 during AD which needs to be removed to avoid the pH rising too high for AD

- Bernd Linke showed the Fellow a demonstration Floating Bed digester which has been designed by the ATB which was approximately one metre in length. The operation of the Floating Bed digester relies on the floatation of the deep litter. Deep litter is fed into a horizontal tank at one end. The ascent of the solids is due to the adhering biogas bubbles and this subsequently results in the separation of the solid and liquid components, with a floating bed of solids on the top of the biomass and the liquid at the bottom of the digester



The Leibniz-Institut für Agrartechnik (ATB) in Potsdam is investigating the development of a Floating Bed Digester demonstration unit which is viewed in this photo. The digester is appropriate for digesting deep litter agricultural residues. The substrate is fed into the unit on the left hand side. Sensing and measurement equipment can be seen situated at four locations along the length of the reactor.

- Percolate from the bottom of the tank is sprayed on top of the floating layer for 2-3 days per week. This creates a self-mixing system which assists to mix chemicals and micro-organisms through the digestate without inhibiting methanogeneration

This way, optimal conditions can be set in the floating bed digester at high organic loading rates. If the N content of the feed does not exceed a critical concentration, a high performance thermophilic process is applicable. A significant advantage of the Floating Bed digester is that the percolate is almost free of solids and can be treated separately.

The percolate can also be syphoned off to allow removal of free NH_3 or organic acids. This provides excellent control over the AD process not provided by other systems. This system is ideal for chicken manure for example, as there is high level of free NH_3 in the manure[9].

The Floating Bed Digester demonstration unit is viewed in this photo showing the viewing window and the floating layer of straw is sitting on top of the percolate. The percolate is sprayed over the top of the straw to create a self-mixing reactor.

Trends

The following trends and key areas for further work were seen to be:

- Pre-treatment of substrate feed
- AD process control
- Characterisation of microbial community in AD
- Upgrading of digestate and biogas
- The development of two phase AD systems for better process control and nutrient recovery from liquid phase (for solid biomass).

Upgrading and Utilisation of Biogas

Removal of H_2S

It is critical to remove the H_2S from biogas to avoid its' corrosive properties using a process called desulphurisation.

This is able to be achieved by two main methods:

- A chemical process is used by adding an iron salt to the digester so that iron sulphide precipitates.
- Alternatively, a biological process utilises aerobic micro-organisms which oxidize the H_2S to elementary S. This is achieved by pumping a small amount of air into the digester or it is performed separately to the digester in in cylindrical tank. Biogas is passed through the tank filled with microbes and support material.

Elemental S can be recovered from the de-sulphuring tank and can be used as a valuable mineral fertilizer[9].

Removal of CO_2 from Biogas for Gas Grid Injection or Vehicle Fuel

Before biogas can be injected into the natural gas grid, or used as a vehicle fuel it needs to be upgraded by removing H_2S and CO_2.

There are a number of technologies available for this process:

- PSA technology, where CO_2 is separated from the biogas by adsorption onto the surface of activated carbon or zeolites under increased pressure
- Water scrubbing of biogas where the higher solubility of CO_2 compared to CH_4 is used to progressively remove CO_2 from the biogas at lower temperatures. Multiple tanks allow sequential CO_2 removal or regeneration of the activated carbon or zeolites
- Membrane technology is also being used employing small tubes coated with a polymer. The CO_2 diffuses through the membrane quicker than the CH_4. The CH_4 concentration achieved is 97%-99% with CO_2 less than 1%[9].

Future skill and knowledge needs

- A better understanding of the AD process leading to improved process control and optimising the productivity from technology for AD.

Major benefits for increased adoption of AD

- Producing energy from renewable sources

- Improved sanitation and odour control of organic wastes
- Reducing the need for use of artificial fertilisers
- Providing income and source diversification for rural businesses
- Creating local employment
- Reducing GHG emissions
- Reducing our carbon footprint due to recycling.

Danish Biogas Association, Copenhagen, Denmark

Bruno Sander Nielsen, Head of Secretariat

Objectives

The purpose of this visit was to establish an overview of biogas production in Denmark with respect to the objectives of the project and to identify additional possibilities of relevant places to visit.

Outcomes

Key points from the discussion were:

Context

The Agriculture and Food Council was established in Denmark in 1997. During the mid-1980's to 1990's there were about 20 centralised biogas plants established in Denmark. This was a result of the oil crisis which occurred in the 1970's. In the mid-1980's legislation was passed to protect streams, lakes and the sea from high levels of N from livestock production. Legislation set a maximum density of 2.3 cattle per hectare and 1.7 pigs per hectare.

As a result of this legislation it was also necessary to store liquid fertilizer from biogas production from 6 to 9 months so that the fertilizer could be spread in spring so that crops could use the N immediately and reduce the risk of it entering into the environment.

During the 1990's farmers built joint biogas plants to serve from 15 to 150 farmers located in a distance up to 20km from the plant. They have typically burnt the digestate solid faction to produce heat following separation of the liquid and solid faction of the digestate.

Denmark has also been incinerating household waste to produce hot water and electricity.

Cost Effective Biogas Production

- Currently there are 23 centralised biogas plants in Denmark and 60 farm scale biogas plants
- Denmark is focussing on using agricultural residues to supply the biomass for the biogas plants and not use energy crops which compete with food and fibre production. Denmark is legislating to reduce the level of maize that can be used for biogas so that its' use is eliminated by 2020. The targets that have been set are:
  - » 2015-2017 maximum of 25% maize or energy crop
  - » 2018 12% of energy crops
  - » 2020 5% of energy crop can be used for biogas production

- Currently, most of the manure in Denmark is not used for biogas production and this offers enormous potential for the future. Currently there is 7% (3 MT/annum) used with a target of 50% of animal manure to be used by 2020
- Another complimentary activity to biogas production is that Denmark is set to double the area of land allocated to organic farming. This will require nutrients to be available which are organic. That is, nutrients produced as a bi-product from biogas production for example
- It is critical to have trials of biogas production compared to predictions of biogas production for different situations. Otherwise investments could be wasted and used poorly
- In Denmark 18 out of 23 biogas plants are owned by farmers
- Using manure compared to maize for biogas production is a benefit to the environment
- Unless incentives are provided by government it is likely that there will not be investment into biogas production
- Incineration means that heat is produced, not electricity or gas is produced. There is a loss of N from the soil although P can be recovered from ashes
- Advantages of biogas production:
  - » Reduces CHG emissions
  - » Increases nutrient recycling and transportation to deficient areas, free of weeds and pathogens
  - » Protects aquatic environments from nutrient pollution
  - » Lowers odours produced by agriculture
  - » Recovers energy
  - » Provides sustainable agriculture
  - » Increases energy supply security
  - » Provides heat and power transportation
  - » Utilises a wide variety of organic waste
  - » Reduces leaching of N
  - » Biogas is not more expensive to produce then diesel or natural gas or ethanol
  - » Improved relations with neighbours
- In Denmark incentives are required to encourage equal gas and electricity production
- Trends in biogas production in Denmark are:
  - » Development of farm scale and centralised plants
  - » Focus on power to gas
  - » Conventional and organic residues.

Nutrient Recovery from Biogas Production

- It is believed that there is 60-80 years of P supplies left in the world. Iraq has increased this prediction to 200 years. However, it is believed P will increase in price as it becomes scarce. There is also concern with contamination of P from cadmium (Ca) and heavy metals. Denmark is putting legislation into place to limit the levels of Ca and heavy metals in fertilizers
- Denmark is also concerned about the level of N being returned to the soil from the growth of legumous pastures including clover and alfalfa which fix N from the symbiotic relationship with rhizobial bacteria. It is estimated that cows can only consume 20% of the clover grown. If the clover

is ploughed into the ground this is likely to result in high levels of nitrous oxides being released to the atmosphere which are 300 times more powerful as a GHG compared to CO_2. Harvesting the clover and using it in biogas plants could be a good solution to solve this problem and produce organic fertilizer at the same time

- Biogas production increases utilisation of nutrients
- Nutrient content of a digestate is typically:
  - » N 5.0 kg/t
  - » NH_3N 4.0 kg/t
  - » P 0.9 kg/t
  - » K 2.8 kg/t

Energy Use from Biogas Production

- Haldor Topsø from Sweden has produced a Solid Oxide Fuel Cell (SOFC) using electricity and CO_2 to produce CH_4 across a membrane
- Biogas as a flexible fuel and can be used in the following ways:
  - » Decentralised co-generation
  - » Distribution in the gas grid (biogas mixed with natural gas)
  - » Individual or district heating
  - » Process fuel in industry
  - » Transportation fuel
  - » Engines, boilers and fuel cells
  - » Complimentary power to wind and wave power production.

Deep Litter Residue Management

- There are great benefits from deep litter residue in terms of energy production and also as a fertilizer and soil conditioner
- Pig and cattle slurry usually has a DM content of 4% and 7-9% respectively. It is preferred to have a DM content of 10-11% for biogas production to increase energy yields. This can be achieved by adding maize, industrial waste or deep litter to the biogas production process.

Aikan Solum Gruppen, Gislinge, Denmark

Contact:

Morten Brøgger Kristensen, Chief Technology Officer

Objectives

The objectives of this visit were to investigate the technology used to process solid municipal waste by AD to produce biogas.

Outcomes

Key points from the discussion were:

Context

Aikan and Solum are two public companies in Denmark. This site used to incinerate the waste but has successfully operated AD of municipal waste in a garage style reactor system for about 10 years. It is intended to expand the site in 2013.

Cost Effective Biogas Production

- Processing of municipal waste which is solid
- Produces 70% CH_4 which could be higher if the AD temperature was increased
- The plant operates by completing:
    - » 2-3 weeks AD at 30-40°C
    - » 3-4 weeks aerobic composting in boxes at 70°C
- Separation of solids from the liquid digestate is being investigated. The slurry is stored for 150 days to ensure degasification is complete. There is 9 months storage capacity for the slurry

- The plant processes 35,000t of municipal waste per year
- In 2014, it is planned to build a plant with a group of 16 farmers involved on Jutland using straw, manure and red clover as substrates with the aim of producing compost and fertilizer

The loading of the garage digester system at Gislinge, Denmark operated by Aikan Solum Gruppen. The floor of the garage is covered with a layer of woody material for drainage. The substrate can be seen at the rear of the garage.

Nutrient Recovery from Biogas Production

- The slurry is returned to paddocks as it is too expensive to transport the slurry to other sites.

Deep Litter Waste Management

- Organic farmers are testing straw in biogas plants
- Organic waste, solid agricultural residues

The substrate used in the garage digester at Gislinge, Denmark. This system is not sensitive to larger objects and in this case contamination by plastic residues.

Sanitation

In Denmark it is a requirement to complete sanitation by treating the digestate with conditions of:

1. 55°C to 65°C for 2 weeks in controlled composting
2. Subjecting it to 70°C for one hour

10. Attachments

The digestate taken from the garage digester at Gislinge, Denmark. This digestate can be used as a soil conditioner or garden mulch for example.

Aarhus University, Blichers Allé 20, DK-8830 Tjele

Contact:

Henrik Møller, Senior Scientist, Department of Engineering

Objectives

The focus of this visit was to investigate the latest research and development occurring in Denmark into biogas production from deep litter residue material.

Outcomes

Key points from the discussion were:

Cost Effective Biogas Production

- Aarhus University is working on a research project using hydrogenotrophic methanogens to convert CO_2 to CH_4 by combining it with H_2. This has the potential to produce 40% more CH_4 from biogas production
- Another research area is to use electricity from wind power to produce H_2, to inturn produce CH_4. This provides the potential to store wind power as CH_4
- Purification of biogas can be achieved by compressing biogas into water so that the gases dissolve into solution. Decompression means that CO_2 is released prior to CH_4 gas so it can be removed first
- The biogas plant at Aarhus University's research facility produces 625kW/h of electricity

10. Attachments

The reactor at Foulum which is fed substrates at the top of the reactor. The daily gas production is approximately 57,000m^3 per day with a HRT of 14 days.

- A safety authority ensures that a safe workplace exists for biogas production. Authorities have to approve the design of biogas plants. There is an emergency plan required to be kept and displayed on site. Key risks identified are:
  - » Gas leaks
  - » Slurry collapse
  - » Awareness of explosion zones

- Safety precautions taken include:
  - » Gas meters and alarms
  - » Ensure areas are vented prior to entry
  - » Tools are approved for use near gas facilities (spark reduction)
  - » Two persons are required to work in enclosed tanks or areas
  - » Approved companies carry out repairs or conduct maintenance
  - » Training occurs on the job.

Deep Litter Residue Management

Straw Pre-treatments

Extrusion

- Two parallel intermeshing large screws cut and grind straw so that more of the material is exposed to bacteria for AD

The deep litter residue used as a substrate for biogas production at the Foulum Campus of Aarhus University, Foulum, Denmark.

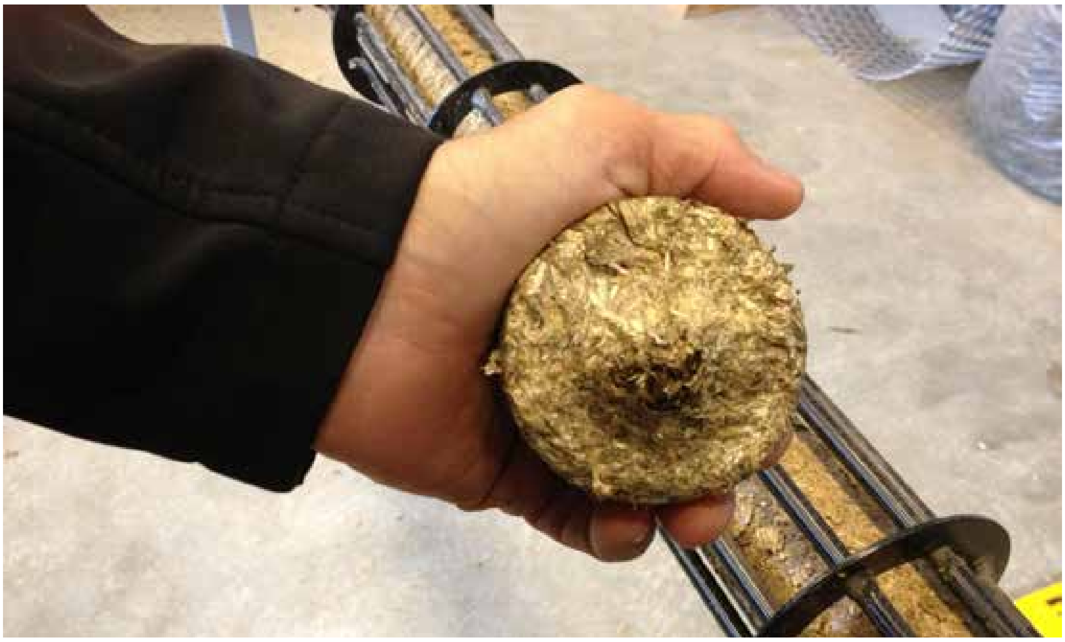
Straw is extruded through this machine at the Foulum Plant of Aarhus University, Denmark. The extruder is fed substrate from a bio-mixer consisting of straw or hay mixed with deep litter or silage to produce a DM of approximately 55%. The straw passes through two large interlocking screws of the extruder where it is compressed and crushed prior to being fed into the digester.

Piston

- This equipment operates by compressing cut dry straw with a piston at high pressure and 120°C. The lignin melts at this temperature

Research is being conducted by Aarhus University at Foulum into the pre-treatment of straw using a briquette press which utilises a piston to compress and heat the straw up to 120°C. This process melts the ligno-cellulose molecules in the straw. The piston equipment is pictured in this photo which has a capacity of 1 ton of straw per hour. The briquette press is fed straw which has been passed through a hammer mill and shredder. The substrate has a DM of approximately 85%.

This photo shows the cylinder of compressed straw being produced by the briquette press.



A block of the compressed straw, which feels hot when held in the hand after processing.

Biochemical Methane Potential

- The BMP of solid manure is higher compared to slurry manure
- Cattle manure is 20% DM
- Chicken manure is 60% DM
- It is necessary to mix straw with animal slurry to increase the BMP of a substrate

The reactor at Foulum used to conduct more extensive trials of biogas production.

Free Ammonia a Problem with Deep Litter

- Free NH_3 is a problem with AD of deep litter as this exceeds regulations for release of NH_3 to the environment
- It has been shown that 20% of the substrate mixture can be chicken litter without causing concerns with NH_3 levels. This means that chicken litter could be used for biogas production a lot more than previously thought to increase the BMP of substrates being used.

AD of Straw

- Without pre-treatment 45% of straw can be digested
- With pre-treatment 60-70% of straw can be digested
- Straw was considered to be viable to digest

- The problem with straw is that it floats in a digester so that it is difficult to mix with manure
- Garage style digesters can be used to digest straw.

AgroTech, Agro Food Park 15, Skejby, Aarhus North, Denmark

Contacts

Tørkild Søndergaard Birkmose, Senior Consultant

Kurt Hjort-Gregersen, Senior Consultant

Objectives

To research the project objectives with respect to biogas production in Denmark. Tørkild and Kurt have the roles of advising organisations which service farmers.

Outcomes

Key points from the discussion were:

Cost Effective Biogas Production

- Biogas plants have been established collecting biomass from a 20km radius
- It is viable to transport deep litter longer distances (up to 200km) because of its energy content compared to slurry manure (20km)
- Trucks need to be used to transport digestate for spreading on fields if distances are greater than a 100m or so. Otherwise tractors can be used
- Denmark prides itself in using biogas production to use a low value agricultural residue and turning it into a high value product.

Comparison of Biogas Plant Systems

- Heated lagoons with better mixing provide a low cost alternative. Sand traps can be installed to remove solid objects like stones from the substrate
- Garage style digesters are labour intensive with loading and emptying of solids.

High Energy Substrates

- High energy substrates are required to increase viability of biogas production. The use of slaughter house waste or food waste can achieve this. Hygiene issues need to be considered though.

Environmental Concerns

- Odour from biogas plants needs to be controlled well in the future.

Nutrient Recovery from Biogas Production

- N is a limiting nutrient in Denmark and its availability needs to be increased
- There is focus on recycling N in Denmark
- Composting is not as energy efficient as AD and also has emissions issues with N_2O which is a significant GHG

- Slurry is applied at 25-30t/Ha rate
- Biogas plants in high manure areas have nutrients to export
- Solids in digestate can be separated using a screw press and transported up to 100km. Liquid digestate is more appropriate to be used locally
- K is difficult to extract because it is dissolved in the digestate
- The liquid fraction of the digestate is high in N and K
- P is held in the solid fraction of the digestate
- South Zealand has critically low P and organic matter soils
- Soils in Denmark are temperamental to moisture level and the ease of cultivation. Adding organic matter (solid fraction of digestate) can significantly improve the structure of these soils
- Selling dried and pelletised chicken manure is a future option
- Biogas production is perceived as a viable means of reducing losses of N to the environment.

Energy Use from Biogas Production

- District heating is supplied by biogas plants
- Electricity is fed into the national electrical grid from biogas electrical generation
- Vehicles can operate on biogas including buses such as the Swedish transport system
- Tractors could operate on biogas if the time to fill with gas could be reduced. Tractors could switch between diesel and biogas.

Producing and Selling Heat

- Selling heat is efficient compared to generating electricity.

Deep Litter Residue Management

- Kurt and Tørkild attended a seminar the day before the Fellow's visit which demonstrated a new technology to pre-treat deep litter. They explained it was an exciting development by a company named Xergi. A visit was subsequently organised for the Fellow later in the week
- There is need to have deep litter fed into the biogas plant to increase energy yields
- Xergi has developed a chain technology to pre-treat deep litter residue which operates continuously as opposed to a unit which operates on batches of litter
- The 'Lunden' plant has operated at Brønderslev since 1984 and was the first biogas plant constructed in Denmark. The benefits of the pre-treatment are to:
    - » Change the straw so that is easier to handle and stir rather than floating in long pieces
    - » Increase the energy yield from crushed fibres
    - » Increase the DM input into the biogas plant
    - » Deep litter is worthless to farmers in Denmark and needs to be converted into useable and valuable products
- Chicken manure is starting to be used in biogas plants to obtain additional energy. Up to 20% of the substrate for biogas can be chicken manure without creating problems with NH_3
- The deep litter AD systems are considered to be better than liquid systems in terms of energy production and soil improvement products.

Xergi Chain Crusher at 'Lunden' Biogas Plant, Brønderslev, Denmark

Contacts:

Michael K. Hansen, Sales Manager

Kirsten Birke Lund, Agricultural Consultant

Henrik Kjeldgaard Hansen, Development Engineer

Objectives

The objective of this visit is to investigate the operation of the Xergi Chain Crusher which is used to pre-treat deep litter residue such as cattle manure and straw.

Context

The Lunden Biogas Plant was the first and biggest biogas plant built in Denmark in 1986. It is small compared to modern biogas plants. Xergi design and build biogas plants to the 'turnkey' stage. They have built plants in Belgium, Greece, Holland, Poland, Sweden and the United States of America.

Outcomes

Key points from the discussion were:

Cost Effective Biogas Production

- A key issue in designing a biogas plant is to estimate the BMP and the HRT
- In Denmark they are starting to pay for biomass. Pig manure slurry is a low energy substrate
- To be effective a consistent substrate is required to feed biogas plants. The substrate needs to have the right physical characteristics e.g. not long straw

Shredder with Automatic Feeding

The advantages of using the crusher are:

- Access to plenty of biomass with high gas potential is essential with the capability to use more than one substrate
- Uniform and stable feeding results in stable gas production
- Effective shredding of biomass so the homogeneous biomass is produced with high density to avoid floating layers and less mixing required
- Homogeneous biomass means increased pumpability with reduced risk of clogging of pumps and pipes
- Homogeneous biomass with high density means less agitation is required in pre-treatment tanks and during processing results in less energy used for processing
- The reduced requirements for agitation presents an opportunity to increase the DM in the reactor so that more gas is produced
- Shredding means that all types of biomass with BMP can be used
- The shredder was able to run with continuous automatic feeding.

The Xergi Chain Crusher was located at the Lunden Biogas Plant, Brønderslev, Denmark.

Deep Litter Residue Management

- There is a trend to increase the amount of deep litter being processed in biogas plants but this means dealing with a floating layer of straw and a long HRT to complete AD of the substrate
- A pressure boiler can be used to pre-treat straw but this uses a lot of energy
- What is needed is a pre-treatment technology which is:
  - » Low operating energy consumption per tonne of biomass
  - » Easy to repair and maintain with low maintenance costs
  - » Where the motor is operating at the optimum
  - » Capable of handling a variety of substrates
  - » Is a continuous feed
- Trials with more than 600t of substrate shredded and digested demonstrates that biogas production is increased by 25%
- 20t of deep litter was mixed with 90t of animal slurry per day. The substrate resembled a ‘porridge’ consistency.

The deep litter residue prior to pre-treatment through the Xergi Chain Crusher.

- There are three adjustments of the Xergi Chain Crusher:
  - » The screw auger speed (variable speed auger)
  - » The slurry feed in rate
  - » The deep litter feed in rate
- The straw is cut and crushed by the Xergi Chain Crusher to a length of approximately 15mm

The deep litter residue following pre-treatment through the Xergi Chain Crusher. It can be observed that the straw has been crushed and broken by the treatment.

- The Xergi Chain Crusher uses a 55 kW electric motor operating at 1500RPM
- The shredder is made of 2 chains with hammers in 15 mm cutting steel attached at each end
- The life of chains is equivalent to the processing of 400t of substrate with the hammers being able to process 600t of substrate with the chains spinning at 300km/hour
- The shredder is a Hardox 400 lined with rubber which provides less mechanical damage and reduced wear
- The feed-in auger has a 400 mm diameter and a 5.5kW motor with variable speed which is altered according to the load on the crusher
- The feed-out auger uses a 3 kW motor with variable speed controlled based on the load on the shredder and required substrate fibre size i.e. the substrate stays in crusher longer to produce a shorter fibre length

- It has been found that feeding in animal slurry to the Chain Crusher at the same time as the deep litter has increased the output of the crusher by 90% without using any more energy

The deep litter residue pre-treated with the Xergi Chain Crusher forms a suspension when added to water as shown in this photo. This creates a homogenous substrate to be fed into the reactor.

- The control system is a Siemens PLC with touch screen interface
- Shredder programs are pre-programmed recipes for shredding of different substrate types
- Motor drives:
  - » Main motor, soft starter
  - » Feed-in: variable frequency converter
  - » Feed-out: variable frequency converter
  - » Slurry dosing: variable frequency converter
- The safety of the crusher is assured, with all hatches and doors which can be opened without tools, being equipped with safety switches
- The crusher mounts are adjustable for easy setup and doors are able to be opened quickly and easily for access and maintenance.

Organic Waste Systems, Gent, Belgium

Contact:

Bruno Mattheeuws, Public Relations Manager

Objectives

The focus of this visit was to follow up a biogas plant design that was identified during the visit to the ATB in Potsdam in Germany which was able to process deep litter residues effectively and efficiently. A visit was subsequently organised by the Fellow.

Outcomes

Context

There are some 40 to 45 biogas plants in Flanders, all built since an incentive scheme was put in place in 2002. OWS has a focus on household waste organics.

Key points from the discussion were:

Cost Effective Biogas Production

- OWS has developed a DRANCO biogas plant which is a vertical cylindrical steel tank
- The basis of DRANCO system is a continuously fed vertical digester operating at thermophilic temperatures with sludge recycling. At an organic loading rate of 10 kg/m^3/day, the CH_4 yield from biogas crops amounts to 310 l per kg VS in a 1,000 m^3 digester[9].
- The digester needs more than 5% DM to make it viable to operate
- It is critical to have no odour and high levels of hygiene in a public waste system
- It is also critical to have high levels of security and safety in the design of the plants as the company cannot afford to have any mishaps to damage the reputation of biogas production in a competitive environment
- OWS is high technology equipment compared to lagoon style digesters for example
- There are approximately 260 plants treating municipal waste in Europe with 10 to 15 plants being constructed per year
- It is difficult for most pre-treatment technologies to pay off economically
- The OWS digesters work by gravity so that there are no stirrers to break. The digestate is pumped from the base to the top of the digester. This means there is low maintenance
- Lagoon digesters collect stones and hard objects over time requiring shut down of the plant
- The HRT of the DRANCO digester is 20 to 30 days and the digesters operate thermophilically
- The air from the digester is burnt to reduce odours

Laboratory and Testing Services

- A large part of OWS's business is biodegradation, composting and entoxicity services which are provided
- Short term testing of substrates for BMP occurs over 3-4 weeks
- Longer term testing of substrates for BMP occurs over 3-4 months. This is much preferred to provide more accurate feedback and is often recommended to customers
- The longer testing allows the inoculum to change from the original microbial population to a new population suited to new substrate environment. This means there is a complete change in microbial population in the digestate as they adapt to the new food source
- It is critical to have a representative sample for accurate testing.

Nutrient Recovery from Biogas Production

- The solid digestate is used as a soil fertilizer and is valued at approximately 5€/t

Deep Litter Waste Management

Plug Flow Digester

- A plug flow digester is formed by lying the tank on its side
- Chicken, pig and cow manure are digested in these digesters
- The long term focus for biomass for AD will be waste and agricultural residues such as manure and straw compared to using maize