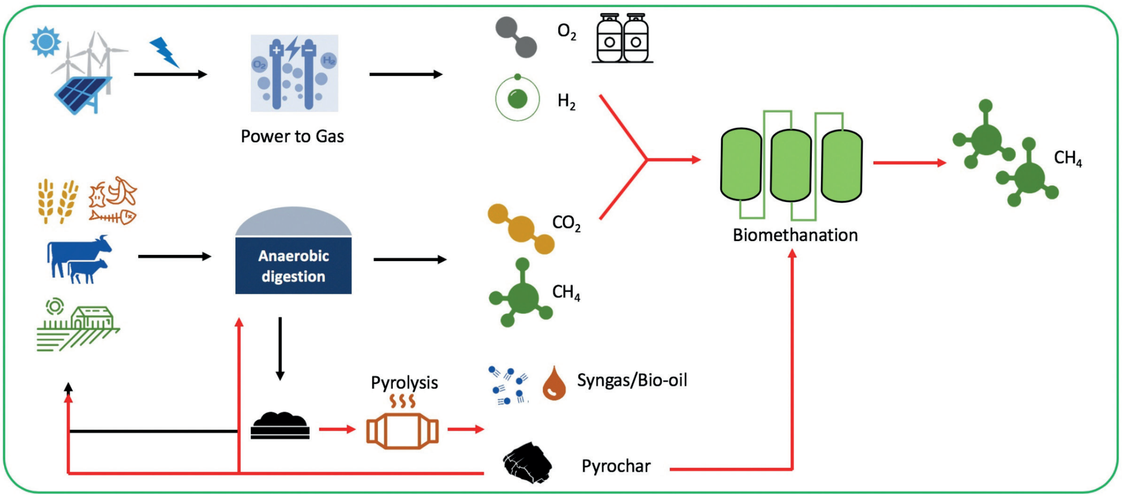
Drivers for Successful and Sustainable Biogas Projects:

International Perspectives

Report of a symposium held on March 26, 2020

IEA Bioenergy: Task 37

May 2020



Drivers for Successful and Sustainable Biogas Projects:

International Perspectives
Report of a symposium held on March 26, 2020

Maria Wellisch (Agriculture and Agri-Food Canada), **Jennifer Green** (Canadian Biogas Association), **Bernadette McCabe**, (University of Southern Queensland, Australia), **Saija Rasi** (Natural Resources Institute Finland (Luke), Finland), **Wouter Siemens**, (Netherlands Enterprise Agency (RVO), **Jonas Ammenberg** (Linköping University, Sweden), **Jan Liebetrau**, (Rytec, Germany), **Guenther Bochmann** (University of Natural Resources and Life Science Vienna, Austria), **Jerry D. Murphy** (MaREI Centre, University College Cork, Ireland)

Edited by

Jennifer **Green**, Maria **Wellisch**, Paulina **Szlachta** and Jerry D. **Murphy**

Citation

Wellisch, M., **Green**, J., **McCabe**, B., **Rasi**, S., **Siemens**, W., **Ammenberg**, J., **Liebetrau**, J., **Bochmann**, G., **Murphy**, J.D. (2020). Drivers for Successful and Sustainable Biogas Projects: International Perspectives – Report of a symposium held on March 26, 2020.
Green, J., **Wellisch**, M., **Szlachta**, P., **Murphy**, J.D. (Ed.) IEA Bioenergy Task 37, 2020: 5

Acknowledgements

This work was made possible with funding from IEA Bioenergy Task 37, and the support of Agriculture and Agri-Food Canada and the Canadian Biogas Association

ISBN: 978-1-910154-74-8 (eBook electronic edition)

Cover photo: Graphic by Richen Lin MaREI centre, UCC, Ireland

Published by IEA Bioenergy

Overview

On March 26th, 2020, speakers representing the IEA Bioenergy Task 37 group shared their work and expertise in seven distinct presentations. These experts shared their biogas and renewable natural gas (RNG) experiences in well-developed biogas sectors on a variety of topics, from feedstock, policy, technology issues, to the circular economy. Symposium participants had the opportunity to learn about the history of, and lessons learned in, the biogas-renewable natural gas-green gas industry in specific countries as well as future perspectives for the development of this industry. This symposium (which was held online due to the covid-19 pandemic) was made possible by the International Energy Agency (IEA) Bioenergy Task 37 Group and was hosted by the Canadian Biogas Association (https://www.biogasassociation.ca) and Agriculture and Agri-Food Canada.

The following document provides a summary of the ideas, presentations, and lessons that presenters shared with the wider biogas community via this symposium. The Canadian Biogas Association is grateful to the IEA Bioenergy Task 37 group, to the seven presenters, and to the audience of over 200 participants who contributed to the success of the Symposium.

Table of Contents

Foreword

The drivers for successful and sustainable anaerobic digestion projects are country and context specific. The challenge that such projects face - in all countries - is how to make anaerobic digestion projects financially viable. We know from countries that have biogas plants that supportive policies are required in a number of areas, including waste management, renewable energy and climate change mitigation. To make these projects work, financial assistance, such as capital grants and multi-year power purchase agreements with a significant premium, is needed to attract the necessary investment.

As a member of IEA Bioenergy Task 37, Canada is privileged to learn from the experiences of other countries who have longer established biogas industries. In turn, Canada can share the lessons it has learned from the different provinces on the conditions that will enable the development of anaerobic digestion in a context of low energy prices and low population density (i.e. high land per capita).

In this symposium we heard from seven IEA Bioenergy Task 37 Member countries – Australia, Finland, The Netherlands, Sweden, Germany, Austria and Ireland. Collectively they painted a picture of how the right combination of feedstocks, technologies and policies are required for a successful and sustainable project. The solutions are not "one size" fits all, but country specific. The final presentation by the Task Leader, Professor Jerry Murphy, presents both today's benefits of anaerobic digestion being a negative emission solution and future opportunities for biogas production to be part of a country's clean energy supply and a source of renewable biofertiliser, making agriculture even more circular.

Un grand merci is extended to Canadian Biogas Association who organized this symposium in Toronto, and then – when travel was no longer possible due to the COVID-19 pandemic – quickly turned around and converted the event into a three-hour online symposium. The dedication of Jennifer Green, Paulina Szlachta, and all of the Task 37 country representatives who stayed up to deliver their presentations - outside of normal work hours - is to be commended.

Best Wishes, Bien à vous,
Maria Wellisch Agriculture and Agri-Food Canada, Bioeconomy Policy
Task 37 National Task Leader for Canada (2019-2021 Triennium)

Acknowledgements

Biogas production, which creates alternatives to fossil fuel-based consumption also contributes to GHG emissions reductions through the capture of methane converting biogas to renewable energy. Biogas also offers a waste management solution to support organic waste diversion and landfill gas capture.

The Canadian Biogas Association (CBA) is a not-for-profit, member driven organization whose mission is to advance the development of the biogas and renewable natural gas (RNG) industry across Canada. The CBA is the national, collective voice of the biogas/RNG sector and is committed to its vision of developing the biogas/RNG industry to its fullest potential through capturing and processing organic materials to maximize the utility and value within that material.

The CBA's 130 members span the entire value chain of the sector and consist of: biogas/RNG owners and operators – comprised of farmers, municipalities and private sector; biogas/RNG technology developers and product suppliers; utilities; waste management companies, consultants and regional representatives. The organization serves its members by advocating for effective measures to support growth in Canada; providing information and resources through education and outreach activities; creating networks within the biogas/RNG sector; facilitating the exchange of information to key stakeholders on biogas related policy/regulation; and, undertaking initiatives to support credible data and research.

Our work as an association is to serve as the collective voice of the industry and to support the growth of biogas and RNG in Canada. In providing education and outreach opportunities such as this Symposium we hope to facilitate the exchange of information, foster connections between those in the industry, and ultimately grow this critically important sector to its fullest potential. Through learning about biogas projects, policies, and landscapes in countries such as Australia, Finland, The Netherlands, Sweden, Germany, Austria and Ireland, we have had a unique opportunity to understand biogas development from different perspectives and therefore the chance to improve our own understanding. I would like to thank the International Energy Agency (IEA) Bioenergy Task 37 Group members for all of their efforts in delivering these presentations for both the Symposium and this report, Jerry Murphy (Task 37 Group Leader) for his leadership and for this opportunity to collaborate, and for the support of the Agriculture and Agri-Food Canada's Maria Wellisch, who was the conduit between the CBA and the Task 37 Group – collectively together making this Symposium possible.

Jennifer Green, *Executive Director, Canadian Biogas Association*

1. Summary of Presentations

The symposium was organized according to four themes: feedstocks, policy, technology and the anaerobic digestion system as a whole. Each theme is summarized below. Full speaker synopses are available in Appendix A with speaker profiles in Appendix B. Please see the Task 37 website for access to the powerpoint presentations and full recording of the symposium at:
http://task37.ieabioenergy.com/workshops.html

1.1 WHERE IT ALL BEGINS – FEEDSTOCK

Successful biogas and RNG facilities rely on a secure supply of feedstock. Reflecting on past, present and future practices – what feedstocks work and what don't – this session provided participants a unique perspective of how to move forward for a sustainable future. The speakers discussed the importance of feedstock for determining the success of biogas projects and emphasized the need for a combination of steady, secure supplies of feedstock that is matched with the right treatment and conversion technologies. The second presentation showed how feedstock type can result in a trade-off between biogas production and sustainability criteria. That is some feedstock combinations will produce the maximum amount of biogas, but not be able to meet the EU recast Renewable Energy Directive (RED II) sustainability criteria.

1.1.1 Agro-Industrial Wastes Matching technology with feedstock

Prof. Bernadette McCabe

National Centre for Engineering in Agriculture, University of Southern Queensland, Australia

Successful biogas plants and RNG facilities rely on a combination of steady, secure supply of feedstock that is matched with appropriate pre-treatment methods and conversion technology. This synopsis positions this aspect in the context of the Australian intensive livestock and food processing industry to illustrate the importance of matching technology with agro-industrial feedstock. It provides an overview of waste management practices and its influence on quantity and quality of feedstock in piggery, dairy, milk processing, feedlot, and red meat processing sectors and the current adoption of anaerobic digestion technology to capture methane. Digester technologies such as low rate covered anaerobic lagoons and high rate continuous stirred tank reactors are compared and contrasted in light of feedstock characteristics for each of the industries.
See full synopsis in Appendix A.

1.1.2 Sustainability of grass biomethane according to RED II

Dr. Saija Raisa

Natural Resources Institute Finland (Luke)

The EU recast Renewable Energy Directive (RED II) establishes a new binding renewable energy target for the EU for 2030 and sets emissions reduction targets for a range of biofuel and bioenergy systems depending on end use of energy. This work presents the examples of greenhouse gas emissions from cases where grass is used as raw material for biogas production in Finland. When using only grass silage as substrate for biogas production and the grass is cultivated for energy purposes, the GHG emission reduction thresholds set by RED II are not easy to achieve. The reduction thresholds can be achieved if grass is cultivated as part of a crop rotation or co-digested with manure.
See full synopsis in Appendix A.

1.2 POLICY LANDSCAPE FOR BIOGAS – RENEWABLE NATURAL GAS – GREEN GAS

Setting the right policy framework is an important driver for biogas/RNG/green gas markets. Participants learned about what policy drivers have propelled biogas/RNG/green gas in other jurisdictions to strike the right environmental and economic balance and examples where policies may have contradicted or counteracted each other. The symposium featured in-depth information regarding the history of green gas development and current status of green gas policy in The Netherlands and in Sweden and which economic and political instruments are helping to develop this sector in these nations, as well as issues and challenges these nations face when trying to implement the right policy frameworks to support biogas/RNG.

1.2.1 The Development of a New Green Gas Roadmap in the Netherlands

Mr. Wouter Siemers

Netherlands Enterprise Agency (RVO)

In the first roadmap for green gas published in 2014, the target green gas availability for 2030 was 3 billion m^3. With the benefit of hind sight this perspective was far too optimistic. The short-term forecasted growth to 1 billion m^3 for 2020 is not expected to be reached. In 2018 the government started the negotiations on the climate agreement, in which green gas is expected to have an important role in getting households and industries off natural gas through use of 2 billion m^3 of green gas in 2030. The parties of the climate agreement decided on making a new roadmap, in which the path towards production acceleration should be paved to 2030. Therefore, the Ministry of Economic Affairs and Climate Policy formed a Roadmap center group with parties of industry, trade associations, government and the Netherlands Enterprise Agency (RVO). Since August 2019 the group has held meetings to form this roadmap. Further information was presented about the project, the negotiations and the results.

See full synopsis in Appendix A.

1.2.2 Sweden Roadmap

Dr. Jonas Ammenberg

Dept of Management and Engineering, Linköping University, Sweden

In 2018, there were 280 biogas plants in Sweden producing about 2 TWh, mainly from bio-waste (such as food waste) in co-digestion plants and at waste-water treatments plants (WWTPs). A large share (63%) of the biogas is upgraded and used as transportation fuel, which makes Sweden relatively unique internationally. The upgraded biogas has mainly been used in buses, cars and light lorries, but recently there has also been a focus on production of liquefied biogas (LBG), for use in heavy lorries. In 2018 Sweden imported 1.6 TWh of biogas.

In Sweden, biogas production from anaerobic digestion could be 5 to 10 times larger by 2030. However, development depends on the policies of the EU and of Sweden. The presentation addresses existing policy, a large inquiry into market conditions for the Swedish biomethane sector, and some recent developments regarding biogas solutions.

See full synopsis in Appendix A.

1.3 TECHNOLOGY – FRIEND OR FOE?

Biogas/RNG projects are complex systems that require balancing a host of technical elements (biological, mechanical, electrical). In an ever-changing technological landscape, adaptation can prove challenging and costly and critical components of biogas production (analysis, plant procedures, operations, economics, and efficiencies) are all dependent on the ability to adapt to new technologies. Jan Liebetrau described the work undertaken in Germany to determine the efficiency of digester operation, in particular the parameters that could be used to assess biogas production. Günther Bochmann reviewed the different types of anaerobic digesters in use today to treat different feedstock types. The presentations dealt with the evolution of biogas systems and technologies, and the process to monitor and maximise efficiency and sustainability through matching feedstock with technology.

1.3.1 Efficiency of the biogas process - results of a monitoring program

Dr. Jan Liebetrau

Rytec, Germany

Sixty one biogas plants in Germany were monitored over a one year period. Operational data, process parameters and also economic data were evaluated to describe the state of the art of the biogas sector in Germany. Determining the efficiency of the biological process was a main objective of the project. The use of four different methods for the analysis of efficiency, combined with interlaboratory tests to ensure a high quality of data, was carried out to determine a better evaluation method and a detailed comparison of the 61 biogas plants. The presentation discussed the project findings, starting with a general description of the state of the art in Germany and preliminary results of the efficiency evaluation and economic assessment.

See full synopsis in Appendix A.

1.3.2 Digester Types

Dr. Günther Bochmann

University of Natural Resources and Life Science, Vienna, Institute for Environmental Biotechnology, Austria

There are a wide range of anaerobic digestion system designs primarily due to different feedstock types and applications in specific environments. Feedstock characteristics influence the type of digester options. Continuous stirred tank reactors (CSTR) systems are the most common type of digester used in Europe, and have a high investment cost. In some countries, covered lagoons are preferable due to their lower investment costs. However, the lower investment costs often translates into systems with lower performance efficiency. It is important to note that not all feedstocks are good substrates for anaerobic digestion. The presentation provided an overview and explanation of the different technologies.

See full synopsis in Appendix A.

1.4 CIRCULAR ECONOMY AND DIGESTATE

Managing all aspects of a biogas/RNG project – biogas/RNG/digestate – is mission critical for individual facilities and industry growth. End-markets are imperative to driving successful biogas/RNG development. Limiting greenhouse gas emissions is the driver for this work which operates within the concept that the world needs negative emission technologies and that carbon neutral emissions are no longer sufficient in maintaining temperature rise below 1.5°C. Speaker Jerry Murphy spoke about a novel integrated system incorporating state of the art technologies in biogas, pyrolysis and power to gas systems which if optimized can generate a negative emission technology system.

1.4.1 Advanced gaseous biofuel produced by integrating biological, thermo-chemical and power to gas systems in a circular cascading bioenergy system

Prof. Jerry Murphy

MaREI Centre, Environmental Research Institute, University College Cork, Ireland

A model is proposed integrating biological, thermo-chemical and power to gas systems. The proposed system treats wastes and uses surplus electricity from variable renewable electricity to produce oxygen and hydrogen, returning an economic incentive through sale of oxygen and using hydrogen to upgrade biogas to biomethane, increasing the methane output by 70%. Digestate is pyrolyzed producing bio-oil, syngas and pyrochar. Pyrochar is used as a conductive material which via direct interspecies electron transfer (DIET) increases biogas production and reduces the size and cost of the digester. This pyrochar will eventually be applied to land increasing the soil organic carbon content and serving as a negative emission technology.

See full synopsis in Appendix A.

Appendix A: Speaker Synopses

Agro-industrial waste: The importance of matching technology with feedstock

Bernadette K McCabe, Stephan Tait and Peter Harris

Centre for Agricultural Engineering, University of Southern Queensland

Successful biogas plants and RNG facilities rely on a combination of steady, secure supply of feedstock that is matched with appropriate pre-treatment methods and conversion technology. This synopsis positions this aspect in the context of the Australian intensive livestock and food processing industry to illustrate the importance of matching technology with agro-industrial feedstock.

Waste management practices and influence on quantity and quality of feedstock

The Australian agricultural sector is dominated by the piggery, dairy, milk processing, feedlot, and red meat processing (RMP) sectors. These sectors produce large quantities of solid and liquid wastes which have become a significant cost burden for operators. Waste management is diverse, with each industry varying in waste type, composition, collection methods and handling.

Australian piggeries produce two different types of wastes dependent on the style of piggery: Slatted floors and deep litter sheds. Slatted floor sheds are designed for manure to pass through the slatted flooring and accumulate on a concrete slab underneath. Water flushed across the concrete slab collects deposited manure and transports it to an anaerobic lagoon located adjacent to the shed. Deep litter sheds utilise bedding consisting of either rice husk, wheat straw, barley straw or saw dust and do not have slatted floors. Instead, manure, urine and spilt feed mix with straw bedding which must be manually removed from sheds, is first stockpiled and then composted before being applied to land as fertiliser rich in organic matter.

The primary waste produced in the Australian dairy industry is manure. Manure is collectable from the milking sheds, and water used to wash down these areas may collect spilt milk which has a high organic load. Effluent is typically treated onsite using anaerobic digestion (AD) prior to irrigation onto agricultural land. Alternatively, manure may be scraped and collected semi-dry or dry, composted, and spread onto agricultural land to supplement synthetic fertiliser use.

Australian feedlots produce large quantities of manure. However, due to a holding time of around 90 days, manure deposited on the clay pen surface dries, loses volatile organics and becomes compacted into a hard surface which may be several centimetres thick. Manure is typically scraped from the pen surface using one of two methods. Wheel loaders harvest manure down to the soil and gravel underlay to produce a rough pen surface finish. While this method collects more manure, there is typically significant contamination with rocks and soil. By comparison, graders provide good depth control and produce a smooth pen finish by maintaining a manure interface layer. While a smoother surface and manure with less contamination is recovered, the method yields a lower quantity of manure. Harvested manure is ground into a finer product and typically stockpiled and actively or passively composted to reduce bulk, concentrate nutrients, reduce pathogens and seeds, and improve handling properties. Stockpiled manure is then sold as fertiliser to the farming community.

Australian slaughterhouse waste can be divided into two main categories – solid and liquid. Solid waste consists primarily of paunch and fly ash. These two components are typically mixed and composted on-site to stabilise the material prior to application to nearby land. The liquid waste streams are heavily contaminated and nutrient rich, consisting primarily of blood, fat, manure, urine, and paunch. Primary pre-treatment in the form of screens recover much of the large particulate solids while dissolved air flotation is common for the recovery of fats for rendering. The remaining wastewater is typically treated in anaerobic lagoons, with covered anaerobic lagoons (CALs) becoming more popular. Following CAL treatment, common wastewater disposal is through land application, disposal to sewer for subsequent processing by wastewater treatment plants, or into waterways.

Current biogas recovery and future opportunities

AD has received considerable interest from these industries as a means to reduce waste discharge to sewers, waterways, landfill and land application, to reduce on-site energy costs, and improve public perception by reducing noxious odour emissions. While each of these industries produces significant quantities of solid and liquid wastes, industry-specific practices and the nature of the wastes produced can significantly influence the decision-making process behind waste treatment technology adoption.

In piggeries, CALs are common and well established. Several factors lend themselves to the high adoption of AD in piggeries. In Australia, land availability is high and while the area footprint of a CAL is high, the low costs associated with CAL installation and operation are attractive (IEA Bioenergy Task 37 Case Story, 2018). Piggeries are typically located outside of populated areas, minimizing the nuisance of odour production. Pig manure is highly degradable, with a low fraction of recalcitrant materials. Methane recovery potential from pig manure is typically 300 m^3 CH_4/t volatile solids (VS) (Nasir, Mohd Ghazi, & Omar, 2012). Slatted floor sheds allow for easy waste collection of waste.

Capturing methane in dairies using CAL technology is currently underutilized in Australia. While dairy manure has a typical methane yield around 200 m^3 CH_4/t VS, manure collection has historically been difficult due to time spent at pasture. In more recent times cows are held longer on feed pads, improving manure collectability and supply of a quality feedstock to CALs which could see an increase in the adoption of this technology.

The processing of milk also generates significant quantities of nutrient-rich liquid and solid waste with quantities and composition dependent on the product in question. Of particular interest is whey – the liquid remaining after milk fat and casein separation from whole milk. Whey has been considered a major environmental problem for dairy processing, because of its high organic load of lactose (Fernandez-Gutierrez et al., 2017; Panesar & Kennedy, 2012). However, because of this high organic strength, whey has also been investigated as a substrate for the production of a range of bio-products, including lactic acid, 2,3-butanediol as feedstock for methyl-ethyl-ketone or 2-butene production, ethanol, single-cell protein (predominantly as yeast), enzymes, citric acid and biogas. The high carbohydrate and protein content in cheese whey lends itself well to AD, with methane yields of 350 m^3 CH_4/t of chemical oxygen demand (Carvalho, Prazeres, & Rivas, 2013). However, high salinity in the wastewater may result in inhibition to the AD process.

Red meat processing (RMP) wastewater in Australia is a good candidate for AD as the high-strength liquid waste is highly digestible under ideal conditions. Prior to AD, liquid waste streams are screened of major solid contaminants prior to entering AD systems. Small suspended particulates and dissolved waste can be easily transported to AD technology located on-site. Dissolved air flotation technology is commonly used on-site at RMP facilities to remove the majority of suspended fat in wastewater streams, though recovery is not 100%. From this point, the waste is typically treated using AD, and although highly variable, improved methane yields result when using mesophilic continuous stirred-tank reactors (Schmidt et al. (2018)). CALs are preferred by processors for several reasons: low capital and ongoing costs, ability to resist shock loading, land is available for a large area footprint, reduced odour emissions with covers in place. While CALS in RMP facilities currently receive a degree of fat which impacts the stability of digestion infrastructure, the industry is aiming to enhance recovery of fat for processing into tallow.

While AD has been investigated for use in Australian feedlots (Figure 1), the impracticalities have inhibited adoption. Firstly, collection of manure can only occur at the end of a 90-120 day cycle in which cattle are removed from the pen and the manure layer is scraped, resulting in the significant loss of volatile solids from the manure in this time. While the potential for methane production is around 200 m^3 CH_4/t VS from fresh manure, this decreases substantially over a 3-month period.

Waste aggregation opportunities for co-digestion

Opportunities for waste aggregation and industry benefit through co-digestion are numerous, albeit under-explored in Australia. Each of the described industries contain unique wastes with unique challenges that could benefit from co-digestion (McCabe et al 2019). In Australia, distance and the transporting of waste is a major challenge to co-digestion. Programs including the Australian Renewable Energy Mapping Infrastructure (AREMI) and Australian Biomass for Bioenergy Assessment (ABBA) aim to deliver tools that will aid researchers and industry to identify and take advantage of co-digestion opportunities coupled with new R & D projects (such as https://research.qut.edu.au/biorefining/projects/wastes-to-profits/). For those enterprises isolated from other feedstock producers, new digester technologies and pre-treatment developments are aiming to improve the cost-effectiveness of implementing AD technology for waste treatment.

Presentation available at: http://task37.ieabioenergy.com/workshops.html

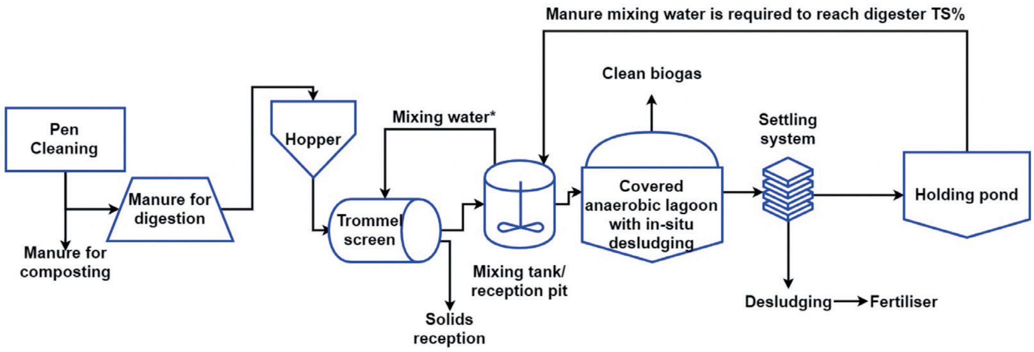


Figure 1: Flow chart incorporating key elements of a proposed biogas system suitable for feedlots (MLA, 2017).

References

Carvalho, F., Prazeres, A. R., & Rivas, J. (2013). Cheese whey wastewater: Characterization and treatment. Science of The Total Environment, 445-446, 385-396. DOI:https://doi.org/10.1016/j.scitotenv.2012.12.038

Fernandez-Gutierrez, D., Veillette, M., Giroir-Fendler, A., Ramirez, A., Faucheux, N., & Heitz, M. (2017). Biovalorization of saccharides derived from industrial wastes such as whey: a review. Reviews in Environmental Science and Bio-Technology, 16(1), 147-174. DOI:10.1007/s11157-016-9417-7

MLA. (2017). Tips & Tools: Feasibility of using feedlot manure for biogas production. In M. a. L. Australia (Ed.): Meat and Livestock Australia.

McCabe, B. K., Tait, S., Marchuk, S., Lee, S., Antille, D. L., Eberhard, J., Baillie, C. P. (2019). Identification and analysis of organic waste produced from Australian intensive livestock industries: opportunities for aggregation and treatment via co-digestion. ASABE Paper No.: 1900170. St. Joseph, MI.: 2019 ASABE Annual International Meeting, American Society of Agricultural and Biological Engineers. DOI: 10.13031/aim.201900170.

Nasir, I. M., Mohd Ghazi, T. I., & Omar, R. (2012). Anaerobic digestion technology in livestock manure treatment for biogas production: A review. Engineering in Life Sciences, 12(3), 258-269. DOI:10.1002/elsc.201100150

Panesar, P. S., & Kennedy, J. F. (2012). Biotechnological approaches for the value addition of whey. Critical Reviews in Biotechnology, 32(4), 327-348. DOI:10.3109/07388551.2011.640624

Profitable on-farm biogas in the Australian pork sector, February 2018. Available from: (http://task37.ieabioenergy.com/case-stories.html)

Schmidt, T., McCabe, B. K., Harris, P. W., & Lee, S. (2018). Effect of trace element addition and increasing organic loading rates on the anaerobic digestion of cattle slaughterhouse wastewater. Bioresource Technology, 264, 51-57. DIO:https://doi.org/10.1016/j.biortech.2018.05.050

Sustainability of grass biomethane according to REDII

Saija Rasi

Natural Resources Institute, Finland

Alongside electric vehicles (EVs), biomethane has been seen as an interesting option to reduce the use of fossil fuels in transport in Finland. This is due to the inherent long distance travel associated with natural gas vehicles (NGVs) as compared to EVs and the possibility to replace fossil fuels in heavy duty vehicles (a sector not ideally suited to electrification). The goal to reduce greenhouse gas (GHG) emissions were also set at European level in 2008 when all EU Member States agreed to raise the share of energy consumption from renewable sources to 20% and to reduce CO_2 emissions by 20% by the year 2020. In Finland these targets were achieved and more ambitious targets for the transport sector were set, such as to increase the share of renewable transport fuels to 40% by 2030. Different targets were also set for different type of renewable energy vehicles. As gas is seen as one piece in the puzzle, the target is to have 50,000 gas driven passenger cars (or NGVs) by 2030. There were about 5600 NGV cars in use by the end of 2018 (Winquist et al 2019).

To reach these targets, new substrates for biogas production are needed. In Finland, biogas production relies strongly on waste- and side-streams and only a small fraction of energy crops (mainly grass silage) is used. All together, there were 63 biogas plants in Finland in 2017 (landfills not included) (Fig 2).

Manure is seen as a possible substrate for biogas production but relatively low methane potential can create economic barriers to biogas facilities so other co-substrates are needed to increase energy production. Perennial grass swards fit well to the Finnish growing conditions as the grasses start growing early in the spring when solar radiation is abundant and soil water levels are good. In addition to feed production, grasses are grown as perennial green fallows and in buffer zones. Silage production is closely connected to milk production and the additional biomass generated from more efficient grass production would be available on areas where milk production is high. Green fallows are located quite evenly around the country in relation to overall field area (Rasi, 2016).

The recast Renewable Energy Directive (RED II; Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources) for the years 2021-2030 was released in December 2018. The final agreement includes a transport sub-target that Member States must require fuel suppliers to supply a minimum of 14% of the energy consumed in road and rail transport by 2030 as renewable energy. New targets are expanded also to consider solid and gaseous biofuels, in addition to liquid fuels. The RED II defines a series of sustainability and GHG emission criteria that fuels used in transport must comply with to be counted towards the overall 14% target and to be eligible for financial support by public authorities. For example for installations starting in early 2021 or later, the emission reduction requirement for biogas used in transport will be 65% compared to fossil fuel. The aim of this work was to see if grass or clover silage grown in Finnish conditions, is sustainable from the perspective of the REDII directive.

The life cycle assessment (LCA) was used to calculate the climate impact of grass cultivation as well as emissions from the production of biomethane. The calculation was done according to REDII and IPCC (2006) rules, International Standards for Life Cycle Assessment (ISO 2006a, ISO 2006b) and applying the system constraints and others assumptions. Five scenarios were set, to compare the emissions from differ-

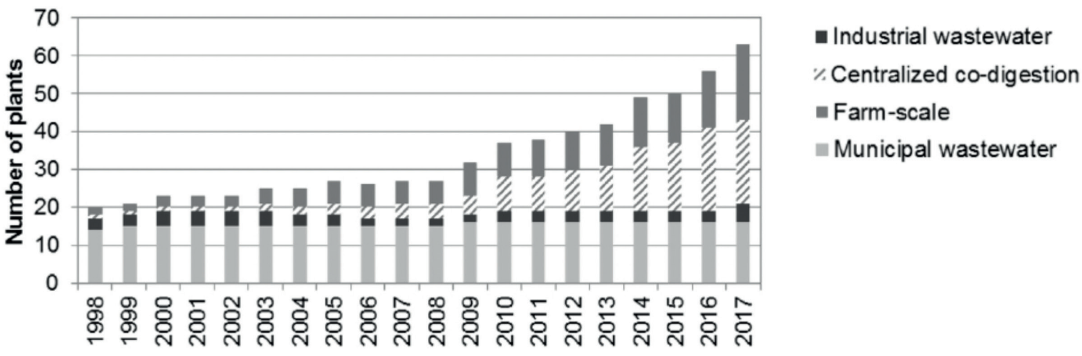


Figure 2. Number of biogas plants in Finland in 2017 (Winquist et al 2019).

ent substrates at biogas facilities. All scenarios had the same energy output (about 5.2 MW). Scenarios were:

1) Biogas plant using only grass silage from mineral soil as substrate;
2) Biogas plant using only grass silage from organic soil as substrate;
3) Biogas plant using only clover silage from mineral soil as substrate;
4) Biogas plant using only grass silage from green manuring as substrate;
5) Biogas plant using grass silage from mineral soil as co-substrate (20%) with manure (80%).

The results show that when using only grass silage as a mono-substrate for biogas production and the grass is cultivated specifically for energy purposes, the emission reduction targets set in REDII are not easy to achieve (Table 1). It was noted in particular that the emissions from organic soils are high, when the benefits of grassland on organic land are not taken into account. According to REDII, biogas facilities using manure as a co-substrate can include for negative emissions (-45 gCO_2eq/MJ) in calculations for emissions saved from raw manure management. Due to this, using grass as co-substrate with manure gives relatively high emission reductions. For example with clover, about 20% of manure in feed will reduce the emissions sufficiently to achieve sustainability criteria (data nor shown). If grass is cultivated for other purpose, such as for green manuring, and the cultivation phase can be excluded from emission calculations, the emission reductions can be achieved.

Table 1. Emission reductions of biogas production compared to fossil fuel

Scenario	Total emissions before manure bonus (gCO2eq/MJ)	**Total emissions after manure bonus* (gCO2eq/MJ)**	Emission reduction (%)
Grass silage (mineral soil)	47		50
Grass silage (organic soil)	106		-13
Clover silage (mineral soil)	37		61
Grass silage from green manuring	20		79
Grass silage + manure	30	4	96

* - 45 gCO_2eq/MJ_{manure}

Presentation available at: http://task37.ieabioenergy.com/workshops.html

References

EU. Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources vol. 2018. http://data.europa.eu/eli/dir/2018/2001/oj

IPCC. Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, Forestry and Other Land Use. Intergovernmental panel on climate change. 2006.

Rasi (ed). Biorefineries in decentralized environment. Natural resources and bioeconomy studies 70/2016. Available on-line: http://urn.fi/URN:ISBN:978-952-326-334-5

Winquist, E., Rikkonen, P., Pyysiäinen, J. & Varho, V. Is biogas an energy or a sustainability product? – Business opportunities in the Finnish biogas branch. J Clean Prod, 2019, 233:1344-1354.

The Development of a New Green Gas Roadmap in the Netherlands

Wouter Siemers

Senior Advisor - National Energy Prospective (KEV), Netherlands Enterprise Agency (RVO)

The first roadmap for green gas in The Netherlands, published in July 2014, set a goal of 3 billion m^3 of green gas to be available by 2030. The term green gas was interpreted to include the entire range of gaseous energy carriers – biogas and natural gas quality green gas, and included for longer-term production of hydrogen via power to gas systems. This goal was very optimistic as the short-term forecasted growth of green gas of 1 billion m^3 by 2020 was considered to be tough to reach. In the years that followed, actual biogas production remained far below the granted production subsidies. One of the reasons for this was that the competition for substrates (such as food waste) grew and digester feedstocks became very expensive, increasing biogas production costs.

In 2018 the Dutch government started negotiations on a new national climate agreement, establishing greenhouse gas reduction targets for the different sectors of the economy. Under this agreement, the built environment is targeted to reduce its greenhouse gas emissions by 3.4 Million tonnes CO_2e by 2030 which translates into disconnecting 1.5 million houses from natural gas. Green gas is expected to have an important role in reducing the natural gas consumption of households and industry by substituting 70 PJ of natural gas with 2 billion m^3 green gas by 2030.

To achieve this new goal, it was decided to develop a new green gas roadmap that would describe the path to accelerate production to 2030. The Ministry of Economic Affairs and Climate Policy formed a Roadmap core group and several steering committees that include representation from industry, trade associations, government and RVO (Netherlands Enterprise Agency). Starting in August 2019, these groups have been holding two weekly meetings to develop this new roadmap. In November 2019, a conference was held with stakeholders to discuss the proposed approach.

Some of the elements of the new Roadmap include:

1) developing a more professional and organized biogas production industry;
2) scaling up production;
3) promoting innovation and complementarity with the innovation roadmap for hydrogen; and
4) repurposing of the existing natural gas infrastructure.

Incentives will be needed to reach the 70 PJ target for green gas by 2030. A subsidy system (SDE) for green gas production is currently in place. It has the advantage of providing certainty for producers, however, in its current form, it does not encourage adoption of innovative solutions. Complimentary measures, such as renewable gas mandates and energy taxation, have therefore been proposed. In April 2020, The Ministry of Economic Affairs and Climate Policy will submit these proposed measures to Parliament for decision-making on how to best realize the 70 PJ green gas goal by 2030.

Presentation available at: http://task37.ieabioenergy.com/workshops.html

The Swedish biogas roadmap

Jonas Ammenberg and Marcus Gustafsson

Swedish Biogas Research Center, Linköping University, Sweden

In Sweden, biogas has been produced from sewage sludge at wastewater treatment plants (WWTPs) since the 1930s. During the 1970-80s, biogas production started within the manufacturing industry and agricultural sector, and biogas from landfills was collected. From the mid-1990s, co-digestion plants were introduced, producing biogas from different types of feedstock like waste from households, slaughterhouses, catering establishments and food processing industries. Municipalities have played a central role in biogas development in Sweden, for example as owners or part-owners of a large share of the existing biogas plants.

In 2018, there were 280 biogas plants in Sweden, producing about 2 TWh (of which ca 140 GWh from landfills). For a long time, WWTPs have been the largest source of biogas (35%), but lately the production from co-digestion plants has grown and advanced as the major source (47%). In an international comparison, Sweden has a low share of biogas production within the agricultural sector – only a 3% share from farm-based plants in the statistics. However, some agricultural feedstock is transported to urban co-digestion plants and larger farm-based plants are categorized as co-digestion plants. Still, the agricultural share is relatively low, just not as low as the statistics may indicate.

A large share (63% as of 2018) of the produced biogas is upgraded and mainly used as transportation fuel. This makes Sweden relatively unique internationally. The number of gas filling stations has grown from less than 20 in the year 2000 to about 200 (public) stations by the of year 2019 (plus 60 non-public stations). The upgraded biogas has mainly been used in buses, cars and light lorries, but recently there has been a focus on production of liquefied biogas (LBG) to be used by heavy lorries and for other purposes.

In 2018 Sweden imported 1.6 TWh of biogas from Denmark. This gas, which has availed of double subsidies (production support in Denmark and tax exceptions in Sweden), has resulted in biogas with very competitive prices – on the same level as natural gas for heating/industry – and thus resulted in increased use of biogas.

Studies suggest that the Swedish biogas production could be 5-10 times larger from anaerobic digestion, by 2030. In addition, there is a great potential to gasify forestry residues. However, the development will, amongst other things, depend on policy at EU and Swedish level. The presentation deals with the existing policy situation, but also addresses market conditions within the Swedish biomethane sector and recent developments on innovative biogas solutions.

Presentation available at: http://task37.ieabioenergy.com/workshops.html

Efficiency of the biogas process – results of a monitoring program

Jan Liebetrau, *Rytec, Germany*,
Tino Barchmann, Marcel Pohl, Velina Denysenko, Erik Fischer, Josephine Hofmann, Markus Lenhart, Jan Postel, *(DBFZ Deutsches Biomasseforschungszentrum)*,
Torsten Mächtig, Christian Moschner,
(Kompetenzzentrum Erneuerbare Energien und Klimaschutz Schleswig-Holstein),
Benedikt Hülsemann, Lijun Zhou, Hans Oechsner, Hans-Joachim Nägele,
(Landesanstalt für Agrartechnik und Bioenergie),
Matthias Effenberger, Rainer Kissel, Robert Kliche, Gabriel Streicher,
(Bayerische Landesanstalt für Landwirtschaft)

1. Background

The German biogas sector developed quickly since 2005 (Figure 3). With the amendments of the renewable source Act in 2012, 2014 and 2017 the construction of new plants was brought to a stop mainly due to substantial reduction of tariffs for the electricity produced.

In 2018 about 8,980 biogas production plants including upgrading plants for biomethane were in operation. Currently the main activity in the sector is the increase of installed capacity (without increase of the annual electric output) due to reconfiguration of facilities for flexible operation.

Two plant concepts are not affected by the tariff reduction; as such an increase of small scale manure based plants (up to 75 kW_{el} installed capacity) is still underway and a few biowaste digestions plants have also been commissioned. With the approaching end of the 20 year period of guaranteed feed in tariffs for many plant operators a decision has to be made as to how to proceed further – either to find viable concepts or to shut down operation.

Besides the tariff reduction the system has been changed from a fixed tariff for a delivered energy amount to a auction system in 2017. Additionally a cap for the capacity available for the auction was installed (200 MW until 2022). Beyond 2022 no decision has been made about the available capacity as of yet. The low maximum bidding prices (in 2020 for existing plants this was 16.39 ct/kWh_{el}) is likely the major reason for the low number of submissions to the auction; another reason stated relates to legal hurdles/effort of the auction process and increasing (and changing) legal requirements to the plant operation in regards of safety and emission protection. Unfortunately the authorities show little urgency to define clear perspectives for the future of the sector. Due to the lack of these perspectives or roadmaps the sector may face a severe reduction in the coming years.

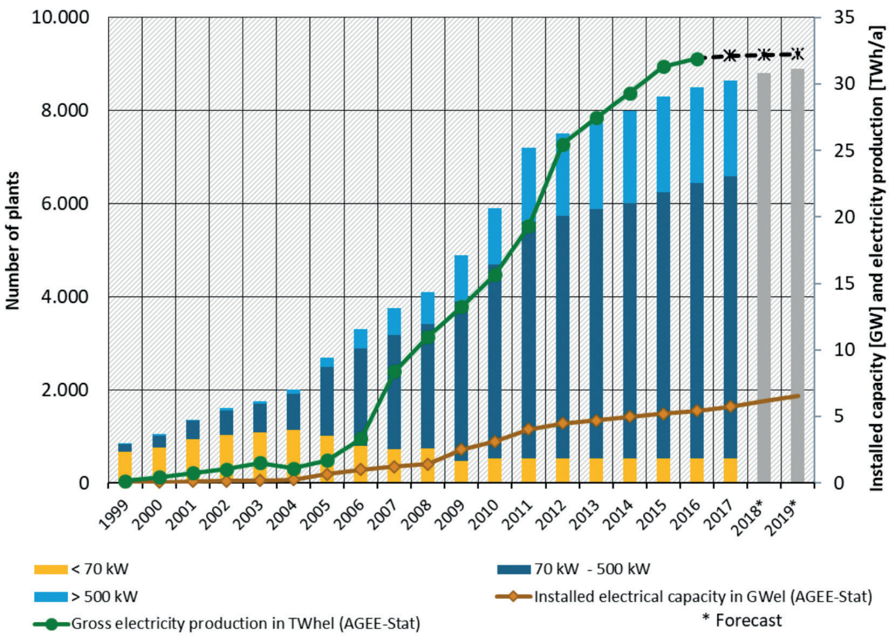


Figure 3: Development of number of plants and installed capacity in Germany (1)

2. Efficiency

Efficiency of the biological process is a major criterion to evaluate the performance of the biogas process. It should be evaluated based on the amount of available substrate and the collected biogas. Assuming steady state in the process, the evaluation starts with a mass balance of the input and output. A material balance is usually used to obtain more precise data of the relevant materials (including for the organic or degradable fraction of the input mass). Mass from a material balance then can be used to perform an energy balance.

The analysis of the overall performance of the plant requires additional information to evaluate the performance and reliability/availability of the equipment (hours/year). At the end a proper basis for a normative-actual comparison has to be selected and the comparison has to be undertaken. A precise balance requires precise data and here the evaluation of the biogas process has to deal with a variety of uncertainties. Starting with the characterisation of the substrate – the determination of the gas potential is a critical issue. Firstly, this requires representative sampling and secondly a reliable method for the determination is challenging. Furthermore, the measurements on site of a biogas plant are often not very precise. Determination of masses of feedstock fed to the digester and the amount of gas produced (including for losses of gas during storage and transport, low reliability of gas flow measurement and unknown efficiency of CHP) are usually compromised with uncertainty. In order to get some better insight into the process, a monitoring program (project duration 01.12.2015 – 30.11.2019) aiming at the evaluation of 60 biogas plants in Germany was initiated and focused on the efficiency of the biological process and economic situation of the plants.

In order to cover all regions in Germany, 4 partners were involved who analysed 15 plants each. The partner institutions were:

- Deutsches Biomasseforschungszentrum (DBFZ) (Coordinator);
- Landesanstalt für Agrartechnik und Bioenergie;
- Kompetenzzentrum Erneuerbare Energien und Klimaschutz Schleswig-Holstein;
- Bayerische Landesanstalt für Landwirtschaft.

The project was funded by the Ministry of Food and Agriculture in Germany through the funding body of the Ministry, the Fachagentur für Nachwachsende Rohstoffe (FNR). Each partner realised two periods of measurements over one year each. Different methods were applied in order to identify advantages and drawbacks of the methods. Transparent data acquisition and evaluation was the basis for the project and ring tests for the major analyses were conducted to minimize deviation between the results.

As one result of the evaluation a comparison of substrate methane potential and obtained yield was carried out (Figure 4).

Figure 4: Overview comparison of 4 methods for methane potential determination and obtained yield

For the calculation of the potential several methods were applied as can be seen in figure 5. VS was chosen as the denominator for potential and yield since it is a well known reference value and the error of the method is well known.

In the following the methods will be characterized.

Potential Standard KTBL: The methane potential (or in this case more precise the yield to be expected) was calculated based on standard values published from the KTBL in Germany. These values have been used for many years as “the” reference in Germany.

Potential FVS: The potential of energy crops is calculated based on a regression to feed value analysis (4 samples for each substrate a year) of the substrate (mainly raw fiber). The method includes a stoichiometric value for the methane potential. The regression models for the degree of degradation are based on feeding tests with sheep. Therefore, for manures and waste materials, where such tests have not been conducted, standard gas yield from KTBL have been used. The method is based on development and publications from Prof. Dr. Friedrich Weißbach.

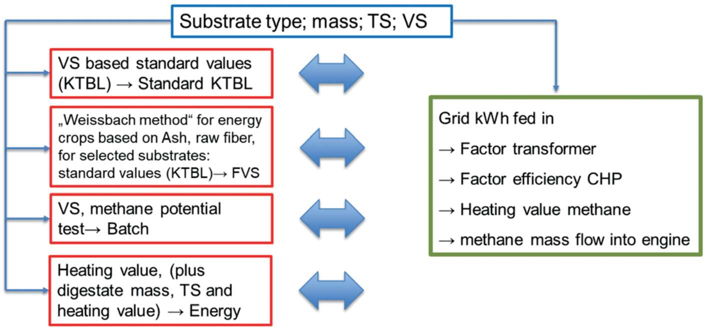


Figure 5: Comparison of different methods for methane potential analysis for 60 biogas plants

Potential Batch tests: Each substrate was tested (once) in a standard batch test according to VDI 4630.

Potential Energy: heating value of dried substrate was determined and the gas potential was calculated. Based on analysis of the digestate a non-degradable part was determined and subtracted.

Yield: Under the assumption that the fed in electricity is a representative value on site, the gas amount sent to the CHP was back calculated from the electric meter.

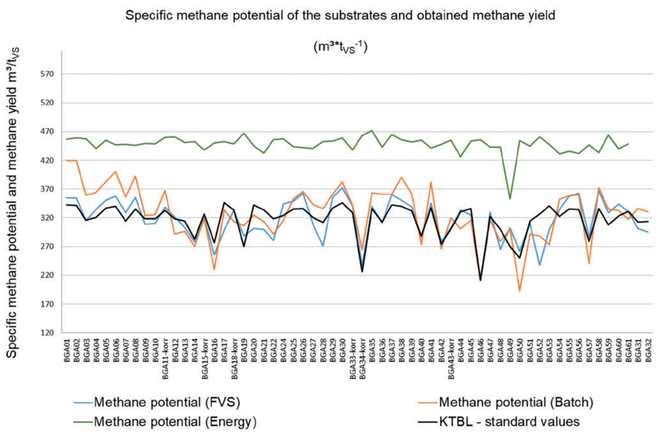


Figure 6: Comparison of different methods for methane potential analysis for 60 biogas plants

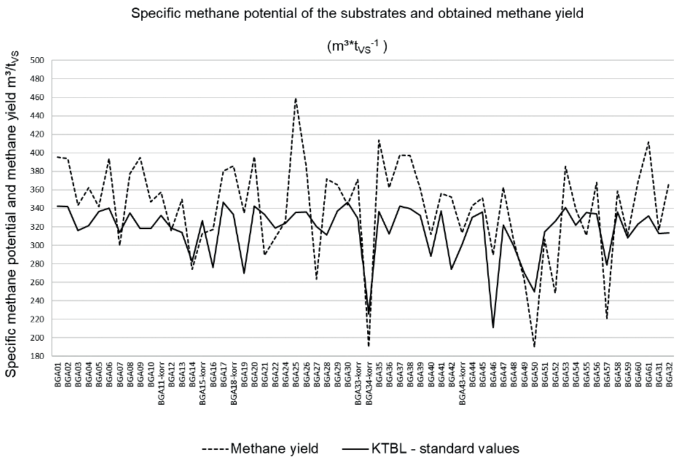


Figure 7: Comparison of yield and KTBL value

The comparison of the obtained potentials shows a similar trend for the three methods KTBL, FVS and Batch. The Energy method has much higher values and does not respond to substrate changes in the same way as the other methods (Figure 6). Deviation between the three similar methods can be substantial, likely due to non representative sampling and differences in the method itself. Batch tests for instance had in one lab a tendency to be higher than in others, similar issues where identified with the raw fiber determination.

In order to compare the potentials with the yield, the standard KTBL was compared to the yields (Figure 7). The yields tend to be higher than the potential. This holds true for three of the methods except the energy method for obvious reasons. KTBL values are known to slightly underestimate gas yields obtained in full scale. However, looking at the gas yields itself show that some numbers are not plausible. Assuming a substrate rich in carbohydrates based on stoichiometric calculations a maximum methane yield of 420 m³/tVS is conceivable. Subtracting losses and microbial activity in best cases a value of 400 m³/tVS could be possible. Some of the plants are close to or even higher than that. In that case, it is likely that the mass fed to the system has been systematically underestimated. More gas produced is related to a small amount of substrate which results in high yields. The plant looks very efficient, but the reason is likely a measurement error. Other reasons for the deviation can be again non representative samples. For gas potential there is unfortunately no way of evaluating this precisely or to measure a “true” value. Due to this uncertainty and the inconsistencies within the masses an overall evaluation of all plants is not possible. Plants have to be evaluated in detail in order to identify the reasons for the error. Then a more detailed look into the efficiency is possible.

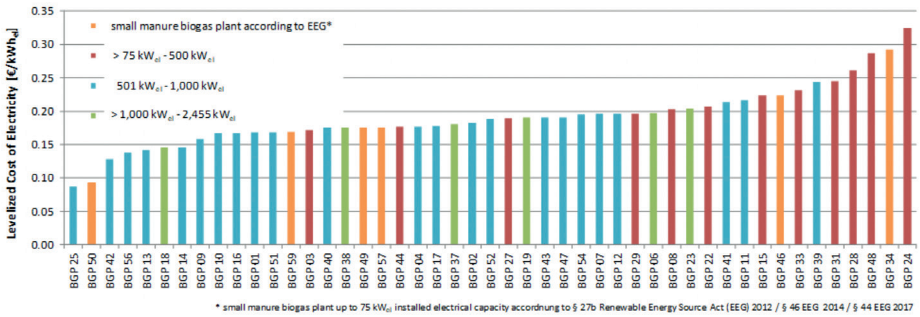


Figure 8: Production costs at German biogas facilities

3. Economics

The economy of the facilities has been evaluated in detail as well. Costs have been documented where possible and structured. Since some of the plants are part of larger entities within a farming business or milk/meat production a clean separation of finances was not always possible, others were not able or refused to deliver certain data. Economic evaluation was based on a one year assessment. When looking at such a short period potential reinvestments have a large impact on the perceived situation, which might not be the case when looking at other time frames. One of the major outcomes of the economic evaluation are the production costs outlined in figure 8.

The costs differ from plant to plant. Looking at other parameter such as operational hours, expensive substrates, breakdown times or high reinvestments it became apparent that not a single parameter regulates the overall costs, the result is a combination of many of them. Plant operators have to keep an eye on all of the inputs to reduce costs at the plants. Looking at the cost (average LCOE: 0.189 €/kWh_{el}) and comparing this to the above stated present maximum bid in the tendering system of 0.1639 €/kWh_{el} for existing biogas plants (§ 39 EEG 2017) it is obvious that only a minority of plants will be able to operate under these conditions profitably.

4. Conclusion

The German biogas sector is one of the largest in the world. The development of the industry has slowed down significantly due to reduced tariffs. Future perspectives are under discussion but nothing has been fixed yet. The introduced project BMP 3 analysed the performance of 60 plants with a focus on the efficiency of the biological process and the economy of the plants. Major findings so far include:

- Mass balance of the plants represents a critical input to the assessment;
- The actual mode of operation and key inputs to the AD facilities are often poorly measured;
- Analytical (lab) errors are insignificant in comparison to errors made on site/during sampling;
- Different methods for potential analysis can result in large deviations;
- In particular input masses seem to be questionable.

Based on these findings the recommendations for the plants for an efficiency check are proposed as follows. Firstly a quick screening of the plant should be evaluated based on standard values to identify uncertainties and check plausibility of the mass and energy balance. In case of accurate and consistent data, this screening should be followed up with a more detailed, precise analysis such as batch tests or a FVS analysis.

The economic analysis revealed that even without a plausible mass balance some plants have proven to be cost efficient. A large variation in production costs was found; it is expected that the auction system will level out this variation in future operating systems. No clear correlation of a single parameter to facilitate a profitable business was identified. Most plants have production costs higher than future tariffs will allow, but investigated plants have a positive balance due to high tariffs which have been guaranteed in the past.

Acknowledgement

Thanks to all participants of the project and contributions to the project. The project was funded by the Ministry of Food and Agriculture in Germany through the funding body of the ministry, the Fachagentur für Nachwachsende Rohstoffe (FNR).

Presentation available at: http://task37.ieabioenergy.com/workshops.html

References

(1) DBFZ, 2019. Database: Distribution of biogas plants by plant size on the basis of the DBFZ plant database; installed plant capacity and electricity generation according to AGEE-Stat 2/2019 (UBA 2019), *DBFZ forecast (modified according to Lenz et al. 2019)

Digester types

Günther Bochmann

University of Natural Resources and Life Sciences, BOKU, Vienna, Austria

Introduction

Anaerobic digestion shows a huge variety of applications due to feedstock, a variety of different digester types and the application in specific environments. Feedstock characteristics define the application of the different types of digesters. For the classical biogas production Continuously Stirred Tank Reactors (CSTRs) are used in Europe with high investment costs. In some countries covered lagoons are preferably due to low investment costs. These low investment costs may be accompanied with a lack of performance efficiency. Furthermore, it needs to be mentioned that not all substrates are applicable to treat in these reactors. The presentation gives an overview and explanation of the different technologies.

Digester types

CSTR (Continuously stirred tank reactor)

To treat high solid content residues a CSTR (continuously stirred tank reactor) is a standard installed system (Figure 9). The digester contains a stirring (mixing) device and inlet and outlet of liquid and solid products. Depending on the feedstock and its properties different mixing devices can be installed. Mixing prevents floating and sinking layers. The CSTR shows high process stability but geometry, mixing and retention time leads to an effective retention time which is lower than the theoretical average retention time. This is influenced by mixing the digester content continuously or semi-continuously (Lindmark et al., 2014; Barchmann et al., 2016).

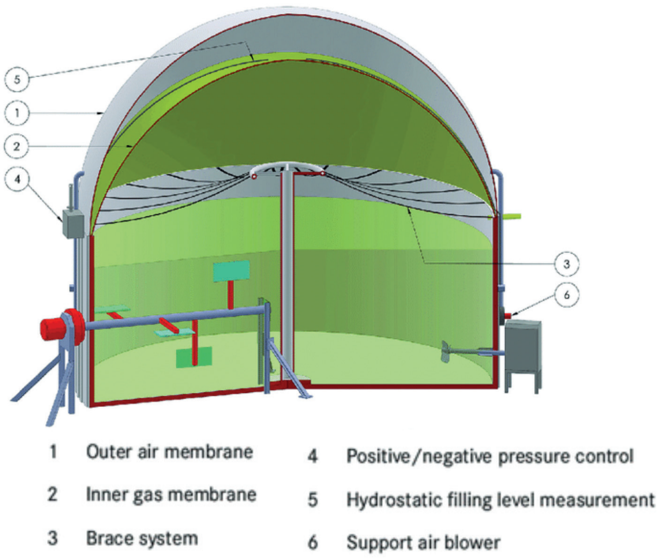


Figure 9: Section of a CSTR

Plug flow digester

The plug flow digester belongs to the tubular reactors and is a type of anaerobic digester which requires feedstock with a high dry matter content. The digester is a horizontal performing system and fed on one side of the digester. The feedstock moves through the digester as a "plug" and leaves the digester on the other side. This plug requires a high dry matter content. Higher concentrations of water destroy the plug process and thereby effect the performance of this system. The digester is longer than it is wide and has a central mixer (stirrer). The plug flow digester guarantees a specific retention time (Adebayo et al., 2014).

UASB (Upflow anaerobic sludge blanket)

Upflow digestion systems are represented prominently with the UASB (Upflow Anaerobic Sludge Blanket) system (Figure 10). This digester type is used for high strength industrial wastewater treatment such as from breweries. A blanket of granular flocs containing an assortment of anaerobic microorganisms are suspended in the digester. Due to gravity and separation processes granules can be kept in the digester. The treated wastewater should not contain any particles and have a maximum concentration of 3 % Total Suspended Solids (TSS) (Lim and Kim, 2014; Anijiofor et al., 2017).

Covered lagoons

A covered lagoon is a simple system for anaerobic digestion. In general, it is an unstirred basin with a plastic layer avoiding seepage of the liquid out of the lagoon. The basin is covered by a membrane to collect the gas and reduce fugitive emissions. This system is not applicable for all feedstocks; the system has a low process stability and lower specific gas production but it is cheaper in terms of investment costs. The mainly used feedstock is manure. If the inert particuate matter in the feedstock is high, these inerts accumulate and build "islands". After years of operation this can lead to a reduction of retention time in the digester and thus, reduced performance and efficiency of the digester. Stirred covered lagoons are available, which can overcome this limitation and increase the digestion performance.

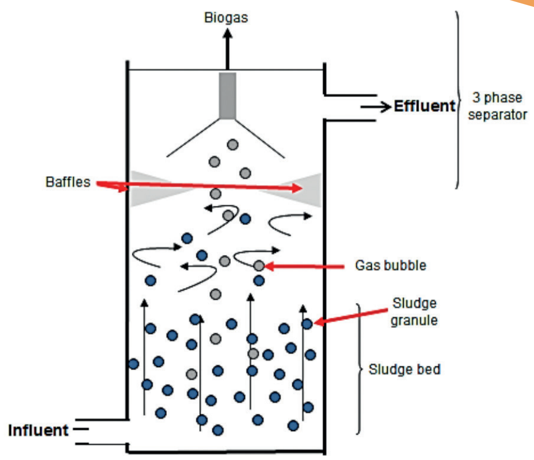


Figure 10: Concept of an UASB (Anijiofor et al., 2017)

Specific developments

Within the past few years several specific digester types were developed. Two examples "Pfefferkorn" digester and Dranco Digester will be presented. The first one is a digester with a hydraulic stirring system. Two digesters connected at the bottom are equipped with pressure valves on the top. By a specific pressure valve regulation, the levels in the tanks vary depending on the gas production and thus a mixing effect in the digesters occurs. The feedstock is mainly liquid and easier to degrade.

The Dranco digester is, like the plug flow digestion, a dry digestion system. But this system is a vertical digester fed from the top with withdrawal of digestate on the bottom of the digester. The feedstock moves slowly down the digester; digestate may be recirculated to the top and mixed with feedstock for futher pathways through the digestion system.

Anaerobic digestion systems for biomethanation

Biomethanation is a rather new field of anaerobic digestion for providing biomethane as a sustainable natural gas. H_2 and CO_2 are injected into the system and converted into methane by the methanogenic archaea. Hydrogen is provided from an electrolyser and CO_2 from various sources such as within the biogas itself, or from external sources such as CO_2 from fermentation processes (such as alcohol industry), or from CO_2 capture from exhaust gases. Both gases are injected in an external "ex-situ" digester, which is the so called biomethanation reactor. So far there are two systems which are seen as preferably: a fully mixed reactor; and a trickle bed reactor. So far, only a few reactor systems are in operation and these are mainly used for research and demonstration purposes (Rachbauer et al., 2016).

Presentation available at: http://task37.ieabioenergy.com/workshops.html

References

Adebayo, A. O. et al. (2014) 'Design , Construction and Testing of a Plug Flow Digester for Converting Agricultural Residues to Biogas', International Research Journal on Engineering, 2(4), pp. 52–60.

Anijiofor, S. et al. (2017) 'Aerobic and Anaerobic Sewage Biodegradable Processes: The Gap Analysis', International Journal of Research in Environmental Science, 3(3). doi: 10.20431/2454-9444.0303002.

Barchmann, T. et al. (2016) 'Expanding the flexibility of biogas plants – substrate management , schedule synthesis and economic assessment', Agricultural Engineering, 71(December), pp. 233–251. doi: 10.15150/lt.2016.3146.

Lim, S. J. and Kim, T. H. (2014) 'Applicability and trends of anaerobic granular sludge treatment processes', Biomass and Bioenergy. Elsevier Ltd, 60, pp. 189–202. doi: 10.1016/j.biombioe.2013.11.011.

Lindmark, J. et al. (2014) 'Effects of mixing on the result of anaerobic digestion: Review', Renewable and Sustainable Energy Reviews. Elsevier, 40, pp. 1030–1047. doi: 10.1016/j.rser.2014.07.182.

Rachbauer, L. et al. (2016) 'Biological biogas upgrading capacity of a hydrogenotrophic community in a trickle-bed reactor', Applied Energy, 180. doi: 10.1016/j.apenergy.2016.07.109.

Advanced gaseous biofuel produced by integrating biological, thermo-chemical and power to gas systems in a circular cascading bioenergy system

Jerry D Murphy, Richard O'Shea, Richen Lin, Chen Deng, David Wall
University College Cork, Ireland

Gas as an energy vector

According to the IEA World Energy Outlook (2019) "in Europe and the United States gas infrastructures delivers between 50 and 100% more energy on average to the end-consumers than electricity grids". Furthermore natural gas is used in the provision of electricity via combined cycle gas turbines as a dispatchable source of electricity, which facilitates intermittent renewable electricity sources such as from wind turbines and solar PV. Gas is used in many countries for home heating; this may change with electrification. Industrial use of natural gas is dominated by the production of steam for use in food processing, in evaporation processes for the production of alcohol, milk formula and other dairy processes, and in other industrial sectors requiring high temperature heat such as glass production and ceramic. While possible, it is hard to see these sectors fully electrified. It is postulated that heavy commercial vehicles are not ideally suited to electrification and biomethane (or hydrogen) in compressed or liquified form may play a significant role. As such over the next 30 years (up to 2050) gas as an energy vector will still have a significant role to play in energy systems. This begs the question of how we can meet our 2050 GHG targets while using gas as an energy vector.

Green renewable gas

Biological systems which produce biogas have a significant role to play in circular bioeconomy systems (Fagerström et al., 2018). They may be used in treating wastes, minimising fugitive methane emissions (such as occur from open slurry tanks), ameliorating smells, reducing contamination of waterways and wells, producing biofertilizer (reducing fossil based fertiliser consumption), and generating renewable methane and a concentrated stream of biogenic CO_2 for further use. A waste to biogas system can often be deemed GHG negative on a circular economy basis as fugitive emissions of CH_4 (with a global warming potential 24 times that of CO_2) are replaced with tail pipe emissions of CO_2 (Liebetrau et al., 2017). However the extent of the sustainable biogas market is limited. The IEA World Energy Outlook (2019) suggests that "20% of annual natural gas demand globally could be produced today in a sustainable manner."

Thermo-chemical systems which employ gasification may produce biomethane through methanisation of the produced syngas and removal of CO_2 (Wall et al., 2019). There are very few such gasification/methanisation systems in commercial operation as of now. Pyrolysis systems generate bio-oils, gas and pyrochar, the compositions and proportions of which depend on operating conditions.

Power to gas systems produce electro-fuels. The primary electro-fuel is hydrogen produced from electrolysis of water, but this may be further processed to methane through reaction with CO_2 (Wall et al., 2018 (described in Equation 1)). The initial gaseous energy vector can be further refined to ammonia or liquid fuels. The resource of power to gas can be very significant with full decarbonisation of electricity. Ireland, for example has a target of 70% renewable electricity by 2030. Assuming for simplicity that this were all met by wind turbines and that the capacity factor of the proposed turbines is 40% then peak production would be equivalent to 175% of average demand. This can be exacerbated by peak production occurring at periods of low demand such as on warm summer nights. Hydrogen production is a way of capturing the potential over supply of electricity. This is serendipitous in that electricity whole sale prices drop when production is high and fossil fuel electricity is ramped down. This could result in relatively cheap and decarbonised electricity being used to make hydrogen (McDonagh et al., 2017).

Advanced gaseous biofuel produced by integrating biological, thermo-chemical and power to gas systems in a circular cascading bioenergy system

A model is proposed as per Figure 11 integrating biological, thermo-chemical and power to gas systems. An issue with biogas systems, in particularly large centralised systems is the digestate produced and the extent of agriculture land that is required to sustainably process the nutrients in the digestate. To overcome this barrier, in the proposed system digestate will be pyrolyzed producing pyrochar, bio-oil and syn-gas.

Lin et al (2019) suggested that graphene (a conductive material) led to an increase in peak biomethane production rate from glycine by 28% through direct interspecies electron transfer (DIET). Graphene is expensive. In our model pyrochar takes the place of graphene and is used to enhance the performance of the anaerobic digestion system. An added circular economy benefit of this is that the pyrochar will eventually be applied to agricultural land adding to the soil organic carbon. This is proposed as a negative emission technology by the European Academies Science Advisory Council (2018).

It is proposed that the hydrogen produced from surplus renewable electricity will be used to upgrade biogas to biomethane. This is envisaged in an ex-situ system (Volklein et al., 2019) whereby hydrogen from electrolysis is reacted with CO_2 in the biogas via the activity of hydrogenotrophic methanogenic archaea in a separate vessel producing renewable methane as per Equation 1

$$4H_2 + CO_2 = CH_4 + 2H_2O \quad \Delta G^0 = -165 \text{ kJ/mol} \qquad \textit{(Equation 1)}$$

A difficulty in biological methanation systems is the solubility of hydrogen and ensuring contact between hydrogenotrophic methanogenic archaea and hydrogen in solution. It is envisaged that conductive pyrochar can enhance this process.

Output from proposed system

The proposed system treats wastes, reduces fugitive methane emissions, uses surplus electricity to produce oxygen and hydrogen, facilitates intermittent renewable electricity, returns an economic incentive through sale of oxygen and uses hydrogen to upgrade biogas to biomethane. Biomethanation not only upgrades biogas to biomethane but converts the CO_2 in the biogas to CH_4, typically increasing the methane output by 70% (Rusmanis et al., 2019). Digestate is pyrolyzed producing bio-oil, syngas and pyrochar. Pyrochar may be used as a conductive material which via DIET increases both the biogas production rate and the quantity of biogas produced, reducing the required size and cost of the digester. This pyrochar will eventually go to land increasing the soil carbon content and serve as a negative emission technology.

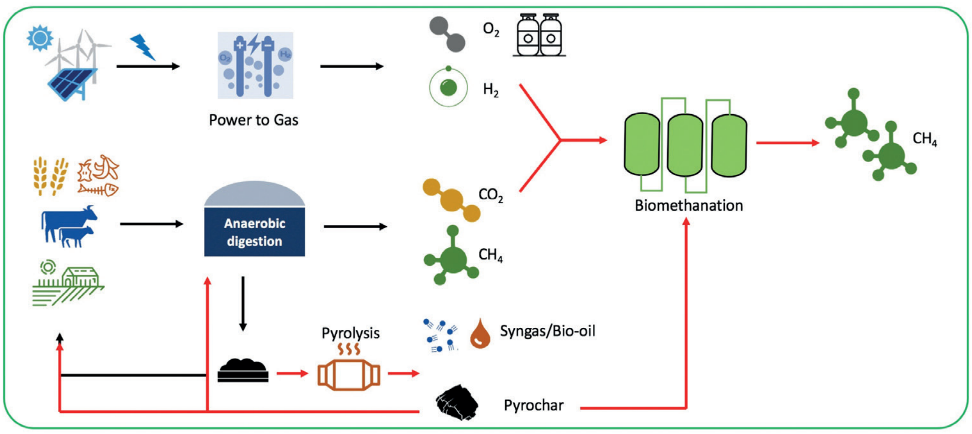


Figure 11 Advanced gaseous biofuel produced by integrating biological, thermo-chemical and power to gas systems in a circular cascading bioenergy system

The Bevtof Biogas plant in Denmark processes 600,000 t of slurries, straw and residues into 21 million m^3 of biomethane (Sønderjysk Biogas Bevtoft, 2018). Use of power to gas at this facility along with pyrolysis could increase the yield by over 70% and reduce the land area required to process the digestate.

This model may be replicated where ever waste treatment is required producing advanced biofuel in the form of biomethane from wastes and electro-fuel in the form of renewable methane from electricity, whilst generating numerous circular economy benefits.

For context Denmark proposes a 100% green gas system by 2035 through digestion of primarily residues and may exceed forecasted natural gas consumption using power to gas systems (Greening the gas grid in Denmark, 2019).

Presentation available at: http://task37.ieabioenergy.com/workshops.html

References

International Energy Agency World Energy Outlook (2019) Available In: https://www.iea.org/reports/world-energy-outlook-2019

Fagerström, A., Al Seadi, T., Rasi, S., Briseid, T, (2018). The role of Anaerobic Digestion and Biogas in the Circular Economy. Murphy, J.D. (Ed.) IEA Bioenergy Task 37, 2018: 8

Liebetrau, J., Reinelt, T., Agostini, A., Linke, B. (2017) Methane emissions from biogas plants Methods for measurement, results and effect on greenhouse gas balance of electricity produced. Murphy, J.D. (Ed.) IEA Bioenergy Task 37, 2017:12

Wall, D., Dumont M., Murphy, J.D. (2018) Green Gas: facilitating a future green gas grid through the production of renewable gas. Murphy, J.D. (Ed.) IEA Bioenergy Task 37, 2018:2

McDonagh, S., Deane, J.P., Rajendran, K., Murphy, J.D. (2019) Are electrofuels a sustainable transport fuel? Analysis of the effect of controls on carbon, curtailment, and cost of hydrogen. Applied Energy 247: 716-730.

Lin, R., Cheng, J., Cheng, J., Xia, A., Lens, P., Jackson, S., Dobson, A., Murphy, J.D. (2019) Graphene Facilitates Biomethane Production from Protein-Derived Glycine in Anaerobic Digestion iScience, 10,21, 158 – 170

European Academies Science Advisory Council (2018) Negative emission technologies. What role in meeting Paris Agreement targets? Available in: https://easac.eu/publications/details/easac-net/

Voelklein, M.A., Rusmanis, D., Murphy, J.D. (2019) Biological methanation: Strategies for in-situ and ex-situ upgrading in anaerobic digestion. Applied Energy 235, 1061 – 1071.

Rusmanis, D. O'Shea, R., Wall, D.M., Murphy, J.D. (2019) Biological hydrogen methanation systems – an overview of design and efficiency. Bioengineered, 10, 604 – 634

SØNDERJYSK BIOGAS BEVTOFT: Hi-tech Danish biogas installation a key player in rural development, March 2018 Available In: (http://task37.ieabioenergy.com/case-stories.html)

GREENING THE GAS GRID IN DENMARK, February 2019. Available In: (http://task37.ieabioenergy.com/case-stories.html)

Appendix B - Speaker Biographies

Bernadette McCabe

National Centre for Engineering in Agriculture, University of Southern Queensland, Australia:

Professor Bernadette McCabe is a principal scientist at the University of Southern Queensland's (USQ) Centre for Agricultural Engineering (CAE) and is the Research Program Team Leader for Energy and Bioresource Recycling. Bernadette is Australia's National Team Leader for the International Energy Agency (IEA) Bioenergy program Task 37: Energy from Biogas and is a member of the Australian Research Council (ARC) College of Experts.

Bernadette has a background in agricultural biotechnology and has over 20 years' experience as an academic and researcher. Her research investigates technologies to enable intensive Australian farming and food-processing industries to turn their commercial waste into a valuable commodity. She works with these industries to be more profitable by using organic waste to produce biogas, clean recycled water and biofertiliser. Her research has been applied to the livestock and cropping sectors (both on and off farm) and water utilities.

Saija Raisa

Natural Resources Institute Finland (Luke):

Saija Rasi, PhD, is a senior scientist at Natural Resources Institute Finland. Her research focuses on biogas and biorefinery systems including studies on biomass availability, production of value-added bio-based products and energy, nutrient recycling, sustainability issues including GHG and energy balances, as well as economic issues. She is the Finnish representative in IEA Bioenergy Task 37: Energy from Biogas.

Wouter Siemers

Netherlands Enterprise Agency:

Wouter Siemers is an expert in green gas and biogas at the Netherlands Enterprise Agency (RVO). Since 2017 he has worked as senior advisor for the National Energy Prospective (NEV now KEV). In 2019 he joined the IEA Bioenergy Task 37 Energy from Biogas.

He has broad experience in governmental environment policy and implementation. He began work in 1993 for a federal environmental agency where he was responsible for environmental permits for the industry in the Port of Rotterdam. After 5 years he started working for NOVEM (former RVO.) Here his task was to give subsidies to SME's for innovative solutions with environmental impact. He also worked for the Green Finance Programme, which gives green loans (with lower interest) to innovative green projects. In 2012 Wouter started working on bioenergy and bioeconomy. He studied Mechanical Engineering at Delft Technical University

Jonas Ammenberg

IEI – Dept of Management and Engineering, Linköping University, Sweden:

Jonas Ammenberg is Associate Professor at the division of Environmental Technology and Management, Linköping University. He is a founder of, and research area leader within, the Swedish Biogas Research Center (BRC), focusing on sustainability systems analysis and decision support, conducting studies on the resource efficiency of different biogas solutions with a broad systems perspective. He represents Sweden in the international working group IEA Bioenergy Task 37, which assesses biogas and anaerobic digestion.

Jonas is head of the Industrial and Urban Symbiosis unit, studying cooperation among local and regional actors that enable more productive utilization of available resources, such as how symbiotic processes can create business value, improve environmental performance and lead to circular economy, enhance innovation capacity and strengthen regional sustainability. Industrial and urban symbiosis is a good platform for systems-oriented research on biofuels and biogas.

Another area of interest is corporate sustainability, including studies on how companies view and manage sustainability issues. Jonas has written the book "Miljömanagement" (eng. Corporate Environmental Management), which is used at several Swedish universities. Jonas is the vice chairman of Environmental and Sustainability Auditors in Sweden.

Jan Liebetrau

Rytec, Germany:

Dr.-Ing. Jan Liebetrau is head of the Department Consulting and Research at the Rytec GMBH. After obtaining a Diploma in Civil Engineering Jan Liebetrau received his PhD at the Bauhaus-Universität Weimar on the topic "Control System for the anaerobic treatment of organic waste". From 2006 to 2007 he was visiting scientist at the Alberta Research Council, Canada, working on a project "Integrated Manure Utilization System" (IMUS). From 2008 to 2019 he worked for DBFZ in Leipzig (German biomass research centre). Since the beginning of 2020 he is working for Rytec GMBH. Jan Liebetrau's main expertise lies in process control of anaerobic digestion processes, emissions from biogas plants and management of research activities.

Günther Bochmann

University of Natural Resources and Life Science, Vienna,
Institute for Environmental Biotechnology, Austria:

Dr. Günther Bochmann has been a working group leader since 2010 at the BOKU University of Natural Resources and Life Sciences in Tulln, Austria. In the field of anaerobic digestion he works on pre-treatment, nitrogen rich feedstock, organic residues from the food and beverage industry. He first studied brewing and beverage technology at the Technical University of Munich, which is where his interest in wastes and breweries comes from. He first worked closely with anaerobic digestion when he set up and operated a pilot biogas plant in a rum distillery in Belize. He continues to cooperates with the biogas field in Central, South America and Asia. Aside from biogas, he also works on biorefinery concepts with food and beverage wastes, including using other microbial processes such as ABE fermentation, biomethanation and nitrogen fixation. He also works on microbial removal of H_2S and CO_2 from biogas, as well as biorefinery concepts fixing CO_2. He represents Austria in the IEA Bioenergy Task 37.

Jerry Murphy

MaREI Centre, Environmental Research Institute, University College Cork, Ireland:

Professor Jerry Murphy is Professor of Civil Engineering in University College Cork, the 12th person to hold the post since 1849. He was awarded the Engineers Ireland Excellence Award (2015) for best paper/presentation, The Marine Industry Award for Excellence in Marine Research (2017), an adjunct professorship in University of Southern Queensland (2018), a fellowship of the Irish Academy of Engineers (2019). He is Director of the SFI-funded MaREI Centre for Energy, Climate and Marine, which includes for 200 researchers, 50 industry partners and 12 third level institutes. He is a leading authority on advanced fuels and the circular economy with more than 150 peer review journal papers (h-Index of 52). He has supervised 31 postgraduates and currently has a team of 15 researchers.

Professor Murphy leads the Biogas Task of the International Energy Agency Bioenergy and has authored/edited numerous IEA Bioenergy reports and provided expert evidence to the IEA and the European Commission.

IEA Bioenergy
Technology Collaboration Programme

Further Information
IEA Bioenergy Website
www.ieabioenergy.com

Contact us:
www.ieabioenergy.com/contact-us/