Measure 42: Biorefinery (as nutrient recovery)

Category
Other nutrient cycle and system changes

Overview
According the International Energy Agency (IEA), biorefinery is sustainable processing of biomass into a spectrum of marketable products and energy (de Jong and Jungmeier 2015). Currently a widely adopted method of biorefining is production of methane as a renewable energy source from waste or green biomass in anaerobic digestion (AD) plants. A further step in this process would be to produce higher-value products to improve the profitability of biorefineries and to reduce greenhouse gas emissions more cost-effectively.

Mitigation summary

Effect on GHG categories*	Rating	Notes
Enteric CH4		
Manure CH4		
Manure N2O		
Soil N2O: applied N	+	Green biorefinery reducing organic N fertiliser
Soil N2O: grazing		
Energy CO2: fieldwork		
Energy CO2: other	-	Replacing fossil energy
CO2 liming and urea		
CO2 sequestration below ground	+	Reducing carbon input to soil
CO2 sequestration above ground		
Pre-farm emissions		
Post-farm emissions		
Substitution of higher C products	-	Replacing other products with high fossil energy use
Production increases by more than the emissions		
Confidence in mitigation effect	Moderate	
Cost-effectiveness**	Low/High	Grey biorefinery potentially profitable. Green biorefinery currently not cost efficient
Confidence in cost-effectiveness	Moderate	

* ”-“ GHG reduction, “+”: GHG increase, “ ”: no significant effect
** low: =< £0/tCO_2e, moderate: £0/tCO_2e< >SCC, high: >SCC

Related measures and potential synergies

Measure	**Impact on other measures**
22 Anaerobic digestion	Potential uptake reduced
23 Methanisation, methane capture and combustion	Potential uptake reduced

Inclusion in other marginal abatement cost curves

UK 2008	UK 2010	UK 2015	Ireland 2012	France 2013	France 2019
No	No	No	No	No	?

What does the measure entail?

Two types of biorefineries are considered here, namely utilization of food waste as feedstock ("grey biorefinery"), and use of green biomass as feedstock in a "green biorefinery" (Table 1). The options for outputs are either energy generation only (from methane and hydrogen produced), or combination of energy generation and production of biomaterials (volatile fatty acids (VFA) from food waste, protein for non-ruminant livestock feeding from green biomass). The net reductions/increase in greenhouse gas emissions were obtained as a sum of additional emissions arising from the biorefinery process and emission savings as a result of replacing alternative products (fossil fuels, synthetically produced acetic acid and butyric acid, soya bean meal and synthetic fertilisers).

Table 1. Biorefinery options considered here.

Type of biorefinery	Option	Input	Outputs
Grey	AD	1 t DM food waste	0.28 t Methane, 0.03 t N, 0.01 t P, 0.01 t K
Grey	AD + dark fermentation	1 t DM food waste	0.20 t Methane, 0.03 t Hydrogen, 0.03 t N, 0.01 t P, 0.01 t K
Grey	AD + dark fermentation + VFA purification	1 t DM food waste	0.24 t Butyric acid, 0.15 t Acetic acid, 0.06 t Methane, 0.03 t Hydrogen, 0.03 t N, 0.01 t P, 0.01 t K
Green	AD	1 t DM clover grass	0.31 t Methane, 0.02 t N, 0.01 t P, 0.01 t K
Green	AD + protein extraction	1 t DM clover grass	0.04 t Protein, 0.25 t Methane, 0.01 t N, 0.01 t P, 0.01 t K

Abatement rate

The abatement rates calculated for different options of management of food waste in biorefinery are presented in Table 2 and the different options for green biorefinery in Table 3. Two alternative food waste management options, namely landfill and composting are also presented. The yields of the grey biorefinery outputs were obtained from Scenario C2 in Bastidas-Oyanedel and Schmidt (2018), after checking the consistency of the energy balance of this scenario (Moscoviz et al. 2018). The GHGE emissions associated with synthetic production of acetic acid were 3.3 t CO_2e/ t acetic acid (Atasoy et al. 2018). No data on the GHGE of synthetic butyric acid could be found. Therefore, the potential abatement is based on the same figure as for acetic acid, which was used as a conservative estimate, or alternatively on a figure for a similar product 1-butanol, with much higher GHG emissions (Bonk et al. 2015). For energy use and protein yield in green biorefinery, the baseline scenario of Corona et al. (2018) was used.

Table 2 Greenhouse gas emissions (GHGE) per t DM of food waste in different management options. Negative sign indicates net reduction of emissions as a result of replacement of alternative products.

Option	GHGE, t CO_2e/ t DM food waste	Source
AD	-0.80	This study
AD + dark fermentation	-0.86	This study
Reduction of emission compared to AD	**-0.05**	This study
AD + dark fermentation + VFA purification	-1.35 … -2.98	This study
Reduction of emission compared to AD	**-0.55 … -2.18**	This study
Landfill	1.99	Styles et al. (2016)
Composting	0.66	Styles et al. (2016)

Table 3 Greenhouse gas emissions (GHGE) per t DM of grass in two different green biorefinery options. Negative sign indicates net reduction of emissions as a result of replacement of alternative products.

Option	GHGE, t CO_2e/ t DM grass	Source
AD	-0.41	This study
AD + protein extraction	-0.49	This study
Reduction of emission compared to AD	**-0.08**	This study

Cost-effectiveness

The cost effectiveness of different biorefinery options were compared. This comparison is based on 1) the outputs of energy and other products (VFAs, protein concentrate), 2) the unit prices of the outputs, and 3) the additional energy costs compared to the methane only (AD) option, and 4) the additional capital costs compared to the methane only option. The following prices were used: acetic acid: 400 USD/t, (Bastidas-Oyanedel and Schmidt 2018), butyric acid 2000 USD/t, (Bastidas-Oyanedel and Schmidt 2018) and energy: 0.0285 GBP/kWh (natural gas). For the cost of energy demand of purification of the VFAs, a conservative estimate based on distillation process was used, as suggested by Bonk et al. (2015). This resulted in a value of 0.9 t CO_2e/ t VFA. The capital costs were also based on the estimates provided by Bastidas-Oyanedel and Schmidt (2018). For the protein concentrate, the price was assumed to be equal to soya protein and a value of 300 USD/t soybean meal was used. The running costs of the green biorefinery were based on the energy consumption obtained from Corona et al. (2018).

The grey biorefinery option has much higher running costs (purification) and capital costs compared to the AD option. Despite this, due to the high value of the biorefinery outputs, the profit margin would be much higher (more than £150 per t DM food waste) than in the energy only options (methane and/or hydrogen). In contrast, when considering the running costs only, and assuming the price of the protein concentrate to be of a similar magnitude as soya bean meal, the profit in the green biorefinery would be of the same magnitude both in the AD and protein production options. Assuming similar capital costs as in the grey biorefinery, the protein production in the green biorefinery would not be profitable. It has therefore been suggested that other high value products are needed in green biorefinery, instead of protein only (Corona et al. 2018).

Applicability, current uptake and potential additional maximum uptake

Currently the biorefineries (apart from methane production from anaerobic digestion) are mainly in experimental use only. However, there is a potential for large-scale commercial applications in the future. According the WRAP (2015) report, UK households waste 7.0 million tonnes of food every year (equals to more than 2.1 Mt DM). Most of this food waste is currently collected by local authorities. Some of this will be recycled but most is still going to landfill and thus creates methane. However, although the utilization of food waste can be expected in the future, it is likely that large part of that will be used in AD plants rather than biorefineries, due to the high capital costs of the latter.

For the main products of the food waste biorefinery considered here, the global market for acetic acid is 13,570 kt/yr and for butyric acid only 30 kt/yr, although the latter is expected to increase by 12% per year (Moscoviz et al. 2018). With the yields of acetic acid and butyric acid applied in this study, these markets would be met by annual processing of about 80 Mt and 107 kt DM of food waste in biorefineries, respectively.

The large-scale use of green biorefinery requires that land needed to produce the feedstuff for biorefineries needs to be released from other use. This would mean that if the current demand for ruminant feed will remain unchanged, then an increasing proportion of feed needs to come from other sources replacing the grass used in biorefineries. Further, if there are no changes in the overall demand of feed, the use of grassland as an input for green biorefineries would reduce the total protein supply for livestock when both ruminant and non-ruminant production is taken into account.

Assumptions used in the MACC

1. Emission reductions using grey biorefinery are 1.4 t CO2e/ t DM food waste (mid-range estimate, compared to AD option)
2. Cost-effectiveness: $0/tCO2e (net profit)
3. Emission reductions using green biorefinery for protein extraction are 0.5 t CO2e/ t DM grass
4. Cost-effectiveness of protein extraction in green biorefinery: $200/tCO2e (assuming similar capitals costs as in grey biorefinery)
5. Only grassland without other use can be used for green biorefinery

Ancillary effects

Table 4 Ancillary effects of the operation

Positive effects		**Source**
Off-farm GHG	Reduction of production of various carbon intensive products, e.g. VFAs, fertilisers	
Production		
Adaptation		
Environment	Reduction of non GHG emissions from waste management	
Negative effects		

Off-farm GHG	Emissions associated with constructing of biorefineries	
Production		
Adaptation		
Environment		

Identified implementation challenges and barriers

Table 5 Potential barriers to uptake and key risks/uncertainties

Barrier to uptake	**Source**
New technology that is still under development.	
Economic benefits/risks not very well known	
Other key risks/uncertainties	

References

Atasoya, M., Owusu-Agyemana, I., Plazab, E. and Cetecioglua, Z. 2018. Bio-based volatile fatty acid production and recovery from waste streams: Current status and future challenges. Bioresource Technology 268: 773–786.

Bastidas-Oyanedel, J.-R. and Schmidt, J. E. 2018. Increasing Profits in Food Waste Biorefinery — A Techno-Economic Analysis. Energies 11: 1551; doi:10.3390/en11061551.

Bonk, F., Bastidas-Oyanedel, J.-R. and Schmidt, J. E. 2015. Converting the organic fraction of solid waste from the city of Abu Dhabi to valuable products via dark fermentation – Economic and energy assessment. Waste Management 40: 82–91.

Corona, A., Ambye-Jensen, M., Vega, G.C., Hauschild, M.Z. and Birkved, M. 2018. Techno-environmental assessment of the green biorefinery concept: Combining process simulation and life cycle assessment at an early design stage. Science of the Total Environment 635: 100–111.

de Jong, E. and Jungmeier, G. 2015. Biorefinery concepts in comparison to petrochemical refineries. In: Pandey, A., Höfer, R.,Taherzadeh, M., Nampoothiri, K.M. and Larroche, C. (eds.) Industrial Biorefineries & White Biotechnology. Elsevier, Amsterdam, the Netherlands.

Eory, V., M. Macleod, Philippe Faverdin, D. O'Brien, R. De Oliveira Silva, et al.. Report on developing bottom-up Marginal abatement cost curves (MACCS) for representative farm type. 2015,129 p. <hal-01611406>

MacLeod, M.; Sykes, A.; Leinonen, I.; Eory, V. 2017. Quantifying the Greenhouse Gas Emission Intensity of Scottish Agricultural Commodities: CXC Project; Technical Report; SRUC, Edinburgh, UK

Moscoviz, R., Trably, E., Bernet, N. and Carrère, H. 2018. The environmental biorefinery: state of the art on the production of hydrogen and value-added biomolecules in mixed-culture fermentation. Green Chem. 20: 3159-3179.

Styles, D. Dominguez, E.M. and Chadwick, D. 2016. Environmental balance of the UK biogas sector: An evaluation by consequential life cycle assessment. Science of the Total Environment 560–561: 241–253.

WRAP 2015. Strategies to achieve economic and environmental gains by reducing food waste. Final Report. ISBN: 978-1-84405-473-2.

Prepared by:	Ilkka Leinonen and Michael MacLeod, SRUC
Contact:	Ilkka.Leinonen@sruc.ac.uk Michael.Macleod@sruc.ac.uk