Potential for Bioenergy Generation and Nutrient Recycling in Horticultural Crop Production Systems in New Zealand

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Abstract

Renewable energy can be produced from a number of sources, including plant biomass. One of the most efficient technologies to generate bioenergy from plant biomass is on-farm anaerobic digestion (AD) producing biogas. Biogas can be used as an equal substitute to natural gas for industrial, commercial and residential use, and/or can be converted to electricity, heat or vehicle fuel using established technologies. Using purified biogas for transport is a highly effective greenhouse gas mitigation strategy. Various organic feed stocks can be converted into biogas: we have identified a large variety of purpose-grown bioenergy crop species (such as Jerusalem artichoke, forage sorghum, whole triticale) under New Zealand conditions, but feedstocks can also include farm and orchard waste streams (reject fruit, clippings, thinning and so on), groundcover biomass and other locally sourced organic municipal and industrial bio-waste as well. A novel biofuel cropping system was developed based on AD technology. It makes full use of the nutrients in the digestate with a unique closed-loop nutrient supply feature that conserves nutrients in the feedstock and recycles them back to the farm and orchard as bio-fertiliser. This eliminates the need for external fertilizer. This paper will explore the considerable potential for bioenergy generation and nutrient recycling in horticultural production systems in New Zealand.

INTRODUCTION

New Zealand's total primary energy supply has a large component of almost 40% of renewable energy due to electricity generation using hydroelectricity, wind and geothermal energy, and is ranked as the 3rd highest using renewables in OECD economies behind Iceland and Norway (MBIE, 2014). However, transport energy in NZ is relying heavily (over 80%) on imported hydrocarbon resources, responsible for generating of over 40% of the energy greenhouse emissions (MfE, 2013). Agriculture is a major player in the NZ trade, while only generating some 6.4% of GDP in 2013; agricultural products comprised over 45% of NZ's total export in the same year (Treasury, 2013). Therefore a focus to reduce the agricultural component of NZ's overall greenhouse gas (GHG) footprint is important (WRI, 2011). The rural sector could utilise some of the NZ land base for purpose-grown bioenergy crops, which will reduce the need for (imported) fossil fuels. There are also opportunities within other primary sectors including horticulture as well. This potential has recently been quantified in a bioenergy industry report (BANZ, 2011). This will also create a more secure rural fuel supply and will diversify land use, which will further reduce the primary industries' environmental footprint (Renquist et al, 2014).

RESULTS AND DISCUSSION

The primary industry sector in New Zealand should prepare for an uncertain global energy future, and should consider renewable energy opportunities such as bioenergy cropping and other processing pathways as smaller scale alternatives like renewable forests plantations, that can provide farmer groups or rural communities with their annual energy requirements of between 1,000 to 100,000 GJ/yr range (equivalent to 28,000 – 2,800,000 l diesel fuel/yr; MED, 2011). Technology schemes that successfully supply this scale of biofuel include biodiesel from oilseed crops and bioethanol from grain fermentation. However, both technologies suffer from low net energy yields per hectare of crop, high energy consumption by the conversion technology itself (i.e. distillation) and very little flexibility regarding soil and climate conditions, since each technology is generally tailored to specific oilseed or sugar/starch crops, often using specific plant parts (e.g. seed).

The most appropriate rural-scale technology alternative for addressing the challenges outlined above is the production of biogas (CH_4) via anaerobic digestion (AD) which is the technology of choice described here. Using AD, the total crop biomass is used and AD can factor in various other feedstock and biological waste streams as well. This process has been widely used in the treatment of wastewater sludge in New Zealand, but notably has not been adopted by agricultural industries, despite a huge uptake and popularity in Europe with over 6500 biogas plants currently operational at farm-scale in the agricultural sector (EBA, 2011). These are often in use and operated by a cluster of farms.

The Biogas Process

Figure 1 present a overview of the biogas system. Biogas production can use various feedstocks; purpose-grown bioenergy crops can be the main source. This does not fundamentally differ from the anaerobic digestion of animal manure and other available agricultural/horticultural wastes or municipal wastewater treatment sludge. These three sources can often be combined. AD is generally conducted in heated and mixed concrete or steel digester tanks, at mesophilic temperatures (35-39°C). The feedstock is often ensiled to ensure year-round supply. The feedstock is introduced into the digester tank with the help of an auger or hydraulic ram. Paddle or pump mixers ensure a good mixing of incoming feedstock with the bacteria-rich liquid slurry inside the digester. Feedstock is added daily, and the feedstock retained inside the digester for 30 to 40 days, during which time anaerobic bacteria degrade most non-woody materials to biogas. Biogas feedstock is often measured in kg volatile solids (VS), calculated as dry matter (DM) minus the mineral ash content, which cannot be degraded by microbes. The VS fraction generally ranges from 88% to 96% of the DM. The AD process does not fundamentally alter the nutrient content (N, P, K and trace elements) of the input material, but converts the nutrients into plant available forms (i.e. organic N into ammonium). The original nutrient content is preserved in the digestate, which is a homogenous slurry that is removed daily from the digester and stored in an adjacent covered pond (for up to 4 months). The digestate is then recycled back as a bio-fertiliser to agricultural/horticultural land where the energy crops (or other crops) are grown. This largely closes the nutrient loop, which is a key feature of the biogas process. The substitution of crop N fertiliser via digestate recycling of nutrients is a significant contribution to reducing GHG (West and Marland, 2012).

Raw biogas produced by the digester is a water-saturated mixture of gases with a CH_4 content of 55-65% and a carbon dioxide (CO_2) content of 35-45%. Raw biogas will also contain varying amounts of corrosive impurities such as hydrogen sulphide (H_2S), ammonia (NH_3) and other volatile organic compounds (VOC's). Without much additional purification, raw biogas can be directly used as a boiler fuel or for electricity generation. However, the highest-value use for biogas is as vehicle fuel, which requires upgrading of the raw biogas to purified and dry bio-methane of > 97% CH_4 purity. For use in vehicles, the purified bio-methane is compressed to 200 bar and stored in standard natural gas pressure cylinders on-board the vehicle. Bio-methane can be used to fuel a range of vehicles such as cars, trucks and tractors since gas conversion options for both spark ignition and diesel engines are available, and are increasingly offered by vehicle manufacturers.

The production of biogas has been evaluated as the most suitable 'rural-scale' energy technology and is the least complicated, most versatile and most economic (Murphy et al., 2009). Merits include the vast range of biological feedstock available, the proven ability to fully recycle plant nutrients within feedstocks into bio-fertiliser and the fact that AD is very scalable and therefore very adaptable to suit rural conditions. Since AD is capable of processing the whole plant, rather than just part of the plant (e.g. seeds or tubers), and because internal energy consumption is only moderate, the AD process can convert the biomass from a hectare of land into at least three times more fuel energy than produced by one hectare of oilseed crop for biodiesel or grain crops for bioethanol (Börjesson et al., 2010; BANZ, 2011).

The potential of dedicated bioenergy crops to supply NZ rural fuel requirements

Determining an accurate cost of production for biogas is rather difficult, as the cost can be case specific. While economies of scale for digestion equipment would favour large digestion facilities, transport costs for digester feedstock and digestate, the limited demand for energy in relatively sparsely populated rural regions and the organisational overhead associated with bigger plants provide justification for the use of more modest-sized biogas schemes under NZ conditions.

Since there are no farm-scale rural biogas plants operating in NZ, the cost structure of the model scenario had to be adapted based on data from the thousands of rural biogas plants working overseas. A summer-sorghum / whole crop winter-wheat or triticale rotation is proposed in a study by Kerckhoffs et al. (2011) as representative of a C_3–C_4 crop rotation in the northern half of the North Island, and perennial lucerne was used as a crop that is representative of a C_3 crop for the summer dry areas in the rest of NZ, on land that is marginal for food crop production and converting the biomass to energy via AD. The net methane yield from 5% (235,000 ha) of the 4.7M ha of marginal summer dry land in NZ would be 580M $m^3 CH_4$ yr^{-1} equal to 548M litres of diesel yr^{-1} equal to 19.7PJ yr^{-1} (Trolove et al., 2014) which is more than twice the diesel fuel requirements of the NZ Agriculture Sector in 2010 (MED, 2011). This finding was very positive, considering how conservatively the bio-methane yield was calculated (Trolove et al., 2014).

The potential to co-digest integrated horticultural waste streams

Horticulture is a relatively small sector in NZ using a land base of 125.000ha, and wine, kiwifruit and pipfruit are the dominant players occupying 36,000, 12,500 and 10,000 ha respectively (Fresh Facts, 2013). Within the horticultural sector there are opportunities to generate renewable energy from several feed stocks and waste streams. However, the lack of long-term feedstock supply contracts and the fact that horticultural residues are limited by the value as a feedstock for other uses are some of the constraints (Cox, 2008).

The kiwifruit industry in NZ has quantified their available waste streams in the kiwifruit industry are made up of pruning waste, fruit waste and kiwifruit hair. Reject kiwifruit at the packhouse varies between 16% and 18%, of which 5% is sold on the domestic market. 95% of the balance is used as stock feed, with a value of $0 - $10 per tonne, and the remaining 5% sent to landfill (Mowat, personal communication). The total kiwfruit waste feedstock available from the packhouses is estimated ca. 60,000 tonnes. Kiwifruit hair is only a small fraction (0.02% of total production).

Loren Poole, BIOFORM Ltd and owner of a kiwifruit orchard (Pahoia, NZ), has performed some detailed analysis into distributed biogas production and nutrient recycling within his kiwifruit production system, which created significant additional value to his fresh export fruit crop. The feedstocks considered for the digester were waste kiwifruit (both from his13-ha own-orchard and 91-ha orchards nearby), on-site grown energy crops, vegetation from kiwifruit blocks, undervine/headlands and locally sourced organic matter. His model achieves full use of the entire fertiliser value from the waste kiwifruit when returned to the orchard. The detailed model study (Poole, personal communication) indicated that the most valuable application of the biogas was to be used as vehicle fuel, compared with other uses (heat, electricity); all the kiwifruit fertiliser requirements were met with the bio-fertiliser from the biogas plant. Additional sensitivity studies showed that if the feedstock price was moved to $30 per tonne the mixed kiwifruit/energy cropping scenario was relatively insulated as it was able to generate its own feedstock with other on-farm sources (Poole, personal communication). In addition, there were significant GHG gains, where his orchard became a net mitigator of CO_2.

Outlook

Table 1 set out the key biogas resources available in NZ with an indication of the outlook of the total potential of these resources to contribute as a major and sustainable alternative source of energy as electricity, heat and transport fuel (BANZ, 2011). The greatest potential for bio-gas production is dedicated energy cropping. Dedicated energy cropping in good farming areas such as the Waikato could yield over 300 GJ ha^{-1} yr^{-1} and only moderately less in some marginal sites with the right cropping rotation and rainfall. This could be a valuable tool to mitigate problems associated with current farming practices and significantly reduce GHG emissions. Agricultural crop wastes are estimated to total over 500,000 tonnes a year of material that can be used to produce biogas (BANZ, 2011).

CONCLUSION

There is a considerable potential for biogas as a promising renewable energy source mainly as transport fuel in NZ with additional benefits regarding recycling of nutrients as bio-fertiliser. There are significant opportunities for the horticultural industry in NZ to add value. Crucial is system integration to co-digest with other on/off farm feedstocks given the seasonal availability of horticultural crop waste streams.

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Table

Table 1. Biogas targets for production and use. Source: BANZ, 2011.

PJ/year	**2010**	**2010 – 2015 Establishment Phase**	**2015 – 2020 Development Phase**	**2020 – 2040 and beyond Expansion Phase**
Landfill	3.5	5	5	7
Water treatment facility	0.7	1	1.5	1.5
Solid waste treatment facility	0	0.2	1.0	1.5
Food processing	<0.1	0.4	1.0	1.5
Rural waste and residues	<0.1	0.5	1.5	3.5
Bioenergy Crops	0	0.4	5	15
Total	4.5	7.5	15	30

Figures

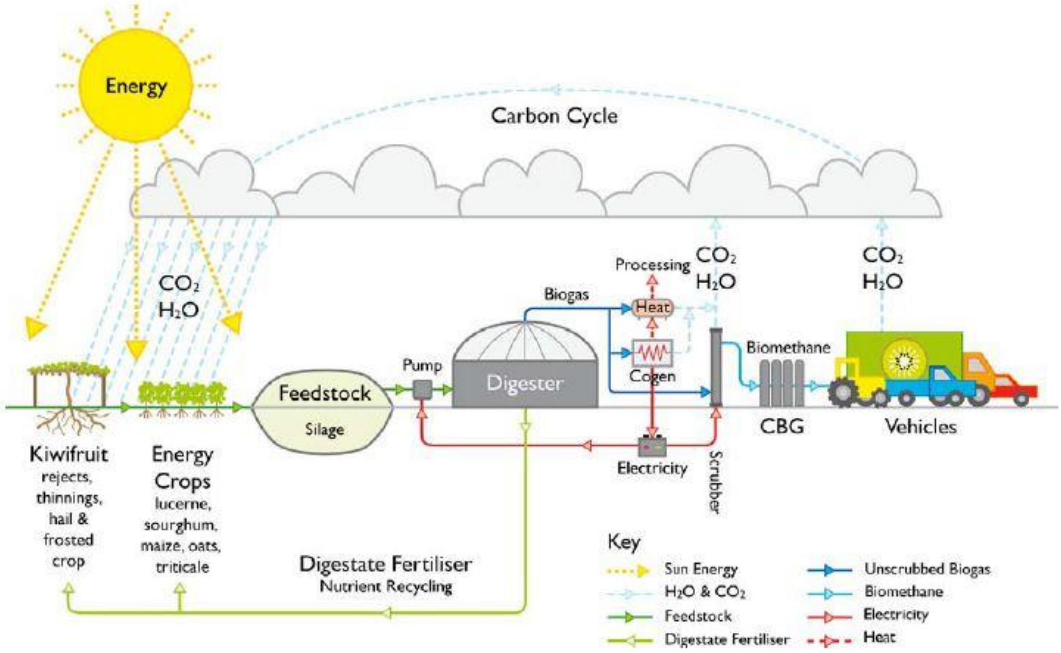

Fig. 1. Integrated biogas system overview. Source: Loren Poole, BIOFORM Ltd.