Technical Memo

Date:	Friday, 13 April 2018
To:	Brian Cox
From:	Jurgen H Thiele
SUBJECT:	FINAL REPORT - PROJECT 11 BIOGAS PRODUCTION POTENTIAL FROM MUNICPAL WASTEWATER TREATMENT FACILITIES

EXECUTIVE SUMMARY

This report describes in detail an innovative solution to successfully:

1. Apply sustainable organic waste management practices and derive wastewater treatment cost savings in the process,
2. Produce renewable (non-fossil) fuel (biogas) for heat and power generation,
3. Attract new “zero carbon” manufacturing business activity and new jobs into NZ regions,
4. Assist local businesses to meet their environmental compliance at lowest possible costs,
5. Create new “zero carbon” business (employment) opportunities for new regional economic growth
6. Produce in the process tradeable carbon certificates (greenhouse gas (GHG) emission reduction),
7. Collect new revenue streams for local authorities which partially offset current asset operating costs,
8. Increase waste water treatment plant energy efficiencies (energy cost are a major operating costs)
9. Reduce waste water treatment plant biosolids (sludge) dewatering costs (another major operating cost)
10. Reduce wastewater biosolids (sludge) disposal costs (another major operating cost)
11. Improve the stabilisation grade and value of treatment plant sludge to allow unrestricted beneficial re-use.

Using existing urban and regional wastewater treatment assets for the solution at four fold improved efficiency and without additional major capital spend is a main advantage over more conventional approaches for organic waste treatment by anaerobic digestion.

Calibre completed recently the successful implementation of the suitable solution at two urban wastewater treatment plants in New Zealand (Palmerston North and Hamilton). The brief for the analysis described in this report was therefore to extract the key technical and commercial findings and achieved plant owner benefits from these two successful projects and to apply these across the existing database of operating municipal wastewater treatment plants in New Zealand.

Nationwide application of this concept is expected to be a solid new opportunity for local authorities and central government to reduce their costs and the pressure from their national climate change mitigation and international sustainability obligations.

The Bioenergy Association commissioned therefore Calibre in August 2017 to provide a detailed technical analysis and assess the commercial and technical potential to achieve the 11 objectives above in New Zealand with modern and innovative anaerobic sludge digestion (processing) solutions implemented on all major existing municipal wastewater treatment plants in New Zealand (Figure ES1).

Recommendations

In the context of the key findings and significant GHG emission reductions (650 kt CO2-equiv/annum) detailed further below we recommend to incentivise the implementation of the organic waste co-digestion at major municipal WWTPs in New Zealand.

It is further recommended to investigate and substantiate the expected GHG emission reduction in dedicated anaerobic digestion facilities converting residual landfilled food waste. Very early high-level estimates put the expected GHG emission reduction from food waste digestion in 2050 to GHG abatement contributions in the order of 500 – 600 kt CO2-equiv/annum.

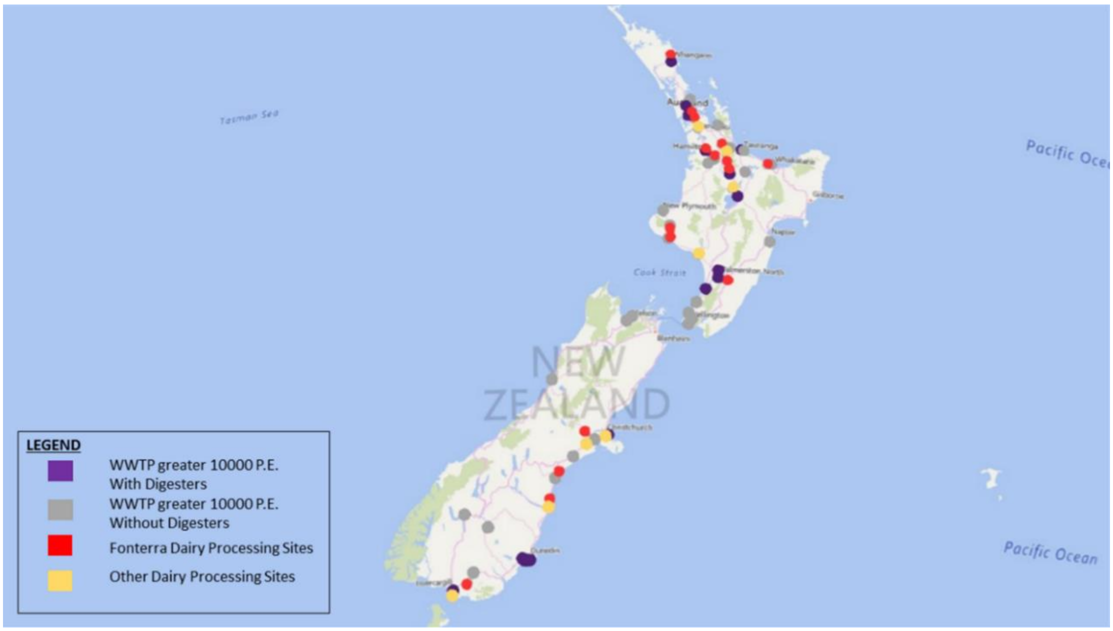

Figure ES1: Geographical alignment (2016 data) of existing WWTPs with existing anaerobic digesters, dairy industry factories (processing sites) with suitable industrial waste feedstock and existing WWTP locations that are potentially suitable for an upgrade to additional on-site biosolids digestion and power generation projects

KEY FINDINGS:

1. Sufficient and suitable high quality organic waste is available in New Zealand to generate in 2050 about 4 PJ of biogas using high rate anaerobic digestion of organic waste at municipal sewage treatment plants. (112 million L diesel equivalent energy/annum - as “zero carbon” renewable methane)
2. Sufficient amounts of suitable waste materials from current municipal sewage treatment operations (municipal biosolids), grease trap waste collections, urban commercial food waste collections, rural commercial food waste collections and dairy processing (DAF sludge) and sheep/beef slaughtering operations (DAF sludge) are available for co-digestion in municipal WWTP. These modern co-digestion solutions allow the achievement of all 11 objectives above when practised at the 25 largest municipal wastewater treatment plants in New Zealand (see Table ES1 below).
3. The total annual GHG emission reduction in 2050 from suitable organic waste achieved by co-digestion in the 25 largest municipal WWTP facilities and at a number of additional industrial digesters is in the order of 650, 000 t CO2-equ. /annum.
4. The total expected biogas methane production in 2030 from co-digestion of suitable organic waste in the 18 largest municipal WWTP facilities and in a number of industrial digesters is about 2.5 PJ/annum (70 million L diesel equivalent energy / annum – as “zero carbon” methane).
5. The total annual GHG emission reduction in 2030 from organic waste co-digestion in the 18 largest municipal WWTP facilities and in a number of industrial digesters is in the order of 450, 000 t CO2-equ. /annum. This amount will be a significant contribution to meet NZ international obligations from the Paris Accord.

6. The total biogas energy production potential from all suitable organic waste in 2050 at municipal wastewater treatment plants and additional, new dedicated industrial and agricultural waste digestion facilities (incl. digestion food waste component in municipal solid waste and digestion of feedlot cattle manure) is about 10 PJ/annum in 2050 (280 million L diesel equivalent energy / annum - as “zero carbon” methane).
7. The total annual GHG emission reduction from anaerobic digestion of all suitable organic waste in 2050 at municipal wastewater treatment plants and in additional, new dedicated industrial and agricultural waste digestion facilities is estimated at around 1,250, 000 t CO2-equ/annum..
8. Organic waste co-digestion to biogas is thus a significant resource to meet NZ international obligations.
9. The total diversion of landfilled organic waste in 2050 with the co-digestion solution at municipal plants is estimated as follows

- Municipal biosolids:	222,000 tonne/annum removed
- Municipal grease trap waste:	330,000 tonne/annum removed
- ICI (institutional, commercial, industrial) food waste:	90,000 tonne/annum removed
Total:	**642,000 tonne/annum removed**

10. The total landfilled organic waste volume reduction with the additional dedicated food waste digestion plants in 2050 is estimated as 225,000 tonne/annum removed.
11. Organic waste co-digestion to biogas is thus a significant opportunity to meet NZ sustainability targets.
12. This report has confirmed the previously estimated renewable energy production potential from municipal and industrial organic waste in New Zealand [17].

Table ES1: Assumed inventory and status of municipal wastewater treatment plants in New Zealand **in 2050 in scenario 1 and 2**. All digester operations shown are assumed to practice anaerobic co-digestion of municipal biosolids with biogas capture, trade waste co-digestion, food waste co-digestion and biogas export into a local biogas grid associated with the wastewater treatment plant operations. The main change to 2030 is that all WWTP with digesters shown adopt trade waste co-digestion with locally available sources (no industrial waste added in scenario 1 but industrial waste sources added in scenario 2). Also, that the benefits of an improved "economy of scale" with added in industrial waste (reduced WWTP size lower limits) and a higher "carbon price" have incentivised seven plants (1/3rd of the remaining 21 plants in 2030) to add anaerobic co-digestion of WWTP biosolids to their treatment process. There are 14 other large WWTP without biosolids digesters, which have not yet been included in this list. The assumptions in the list below are thus conservative (i.e. only proven technologies used and no new council WWTP operations).

Council, Name	Proportion of NZ population (2050)	Wastewater treatment level
Christchurch City Council, Bromley	8.0%	Tertiary
Dunedin City Council, Tahuna (sludge to Green Island)	1.7%	Tertiary
Dunedin City Council, Green Island	0.5%	Tertiary
Dunedin City Council, Mosgiel	0.2%	Tertiary
Hamilton City Council, Pukete WWTP	3.2%	Tertiary
Horowhenua District Council, Levin WWTP	0.4%	Tertiary
Invercargill City Council, Clifton WWTP	1.8%	Tertiary
Palmerston North, Totara Road WWTP	1.8%	Tertiary
South Waikato District Council, Tokoroa WWTP	0.3%	Tertiary
Taupo District Council, Taupo	0.5%	Tertiary
Tauranga City Council, Chapel Street WWTP	1.7%	Tertiary
Watercare, Rosedale WWTP (North Shore)	4.4%	Tertiary
Watercare, Mangere WWTP (Island Road)	26.9%	Tertiary
Whangarei District Council, Whangarei WWTP	1.2%	Tertiary
Manawatu District Council, Fielding WWTP	0.3%	Tertiary
Hutt City Council, Seaview	2.8%	Tertiary
Porirua City Council, Porirua WWTP	1.3%	Tertiary
Wellington City Council, Moa Point	3.6%	Tertiary
Hawkes Bay District Council	2.7%	Tertiary
Nelson City Council, Bells Island	1.1%	Tertiary
Nelson City Council, Nelson North	0.5%	Tertiary
New Plymouth	1.7%	Tertiary
Rotorua District Council	1.2%	Tertiary
Tauranga City Council, Te Maunga	0.7%	Tertiary
Timaru District Council, Industrial + Domestic	1.5%	Tertiary
Total:	70%	

1 INTRODUCTION AND BRIEF

Municipalities and food producers/processors in New Zealand create both solid and liquid organic waste. This waste can be treated in a number of ways to provide a revenue stream, or at least reduce waste treatment plant operating costs.

For example, electricity can be generated from biogas produced by anaerobic digestion of wastewater biosolids at wastewater treatment plants. In addition, the anaerobic digestion treatment of wastewater biosolids to produce biogas for power generation more than halves the dewatering costs and the waste disposal costs for the total wastewater biosolids. Biosolids disposal costs are next to power cost the largest operation cost items for municipal wastewater treatment plants in New Zealand.

Despite the high disposal cost in landfills, a large portion of the total municipal WWTP biosolids production in New Zealand (total about 550,000 tonnes/annum of dewatered wastewater biosolids cake) is disposed in landfills (61 %) where they cause landfill gas (methane + CO_2) emissions.

The current grease trap waste (GTW) inventory from urban commercial and industrial businesses in NZ is not exactly known but international data from OECD countries of similar affluence extrapolated to New Zealand suggest a grease trap waste production in the order of 7 kg GTW fat/person/year [9]. Together with other digestible organic materials in the GTW, an annual dewatered grease trap waste cake volume in the order of 330,000 tonnes is estimated to go to landfill.

It is further estimated that landfill gas from slowly rotting wastewater biosolids cake and grease trap waste is in the order of 625,000 t CO2-equ/annum with about 375,000 kt CO_2-equ/annum captured at the landfill and flared or used for power generation. About 250 kt CO_2-equ/annum escape currently from NZ landfills adding significantly to the landfill operation costs (GHG offset purchase) and the NZ GHG inventory.

A recent “top down” analysis [14] of the food production and consumption system in New Zealand estimated for the year in 2011 a total of 70 kg food waste/capita (commercial/industrial + household food waste in MSW). 28 % of that figure (20 kg/capita/annum) were attributable to total commercial and industrial food waste. Several years of selective industrial, commercial, institutional (ICI) food waste collection in Palmerston North have identified a captured digestible pre-consumer food waste yield in the order of 5 kg/capita/annum with a high quality (no paper, glass, metal, plastic) and suitable for processing in municipal digester plants.

A number of proven and low cost options exist in New Zealand to divert these materials from landfills and increase biogas production and treatment capacity in existing municipal WWTP digesters [17]. These options can be implemented by adding recent technology improvements to existing WWTP digesters without the need for major capital works at the wastewater treatment plants (“low hanging fruits”).

1. Substantially more biogas (about 2-fold increased gas output and thus more electricity) can be generated in municipal WWTP digesters if selected food processing waste, liquid trade waste and pre-consumer food waste residuals (liquid or solid) are combined with the biosolids and then treated together in a process called “trade waste co-digestion”. This process saves food waste treatment costs, generates substantial additional, new revenue for WWTP operators (gate fees for the treated food waste and income from power or gas sales) and in addition generates WWTP operation cost savings. This process is known since decades and is proven in NZ, AU, Asia, North America and Europe. Demonstration projects in New Zealand have shown that upgrade of municipal WWTP to co-digest larger volumes of industrial biosolids and other suitable biomass is one of the most energy-efficient and cost effective biosolids treatment options and typically, renders municipal WWTP energy self-sufficient.

2. In addition, recent developments in New Zealand (Palmerston North and Hamilton City Council digesters) have demonstrated that addition of a specific new anaerobic digestion treatment plant efficiency upgrade technology, “recuperative thickening”, is able to further double the treatment capacity of municipal digesters that benefit already from trade waste/food waste co-digestion. This new method has been introduced in 2008 and is now proven in nearly 10 operating municipal anaerobic digestion plants in New Zealand and Australia [17, 19]. The commercial potential of this innovation is significant for New Zealand because it could quadruple the daily biogas production in small municipal WWTP. This new method would enable commercially viable trade waste co-digestion in those regional WWTP sites that were previously considered too small (i.e., below the viable minimum digester plant scale and size threshold for commercial viability of municipal sludge digestion).

3. New commercially attractive municipal biosolids digester plant projects could then be established in selected smaller rural towns. These new regional digester plants would be designed for processing wastewater biosolids collected from a number of regional WWTP’s (“feeder plants”) and trade waste from industrial sites and selected urban trade waste collections. The “economy of scale” lower limit for municipal sludge digestion has then been shifted by recuperative thickening from about 100,000 EP to about 30,000 EP if trade waste co-digestion and process improvements are utilised in combination with recuperative thickening.

4. In addition, new proven digester systems and biosolids pre-treatment solutions exist (Temperature phased anaerobic digestion, TPAD; Thermal hydrolysis plant). These allow about doubled solids degradation efficiencies for municipal biosolids and doubled solids loading rates to the biosolids digesters [17, 19]. The solutions are typically cost effective at larger scale plants (> 200,000 EP) but in certain circumstances can also be used at smaller scale in conjunction with trade waste co-digestion for cost effective biogas production from municipal biosolids and selected trade waste.
5. In 2016, 84.8 % of the total electricity generation New Zealand came from renewable resources. The renewable energy content of electricity in New Zealand is expected to increase further in the next decade(s) due to the expected large scale implementation of solar and wind based generation systems. Municipal trade waste/biosolids co-digestion plants for renewable electricity production (in CHP co-generation configuration) and electricity export to grid in New Zealand would thus typically displace electricity with a high renewable energy content. That would significantly lessen the greenhouse gas (GHG) emission abatement and climate change benefit from projects realising the options I – IV listed above.
6. Therefore, in the work described here, the end use of the biogas from future municipal biosolids and trade waste/food waste co-digestion plants was split into two portions. A 20 % onsite portion (WWTP digester heating, lowest CAPEX option) and an 80 % off site portion for industrial heat production to be used in co-sited commercial/industrial parks adjacent to the WWTP digester premises. This arrangement generates the opportunity to sell (lower cost) partially refined biogas (H_2S, moisture and siloxane removal) at a higher price with a "high renewable carbon content" as boiler fuel – for example for industrial/commercial heat replacing mainly natural gas and LPG (where appropriate). Also the opportunity to use the biogas as a "zero carbon" genset fuel for industrial on-site co-generation with maximum beneficial re-use of the co-generation heat (where appropriate). If the genset was sited on the WWTP premises the heat would be largely "wasted".
7. The sale of partially purified biogas to co-sited commercial and industrial businesses is thus a combined climate stabilisation and employment generation initiative for new carbon neutral industries in rural and urban New Zealand

In summary, the brief given to Calibre for this project was thus an initial assessment (and at high level with large inherent uncertainties) of the technical potential to realise the options I – VII above and to estimate the approximate level of combined energy and GHG abatement benefits from such developments. At the outset, the brief was specifically limited to the biogas production options at municipal WWTP premises in New Zealand utilising municipal biosolids and good quality municipal trade waste (= municipal organic waste). And where possible, the addition of selected suitable industrial waste to the digester feedstock mix that is specifically used for co-digestion with other municipal organic waste.

The results of the analysis of the biogas production potential and opportunities from wastewater biosolids, grease trap waste, industrial waste and ICI food waste in municipal digester plants in New Zealand are presented in the next section of this report.

The detailed methodology used for our analysis of the biogas generation from wastewater biosolids, grease trap waste, industrial waste and ICI food waste in municipal digester plants in New Zealand is given in section 4 further below.

The respective analysis methodology and results of the biogas generation from industrial waste (excluding biogas from the industrial waste used for co-digestion at municipal plants) is presented elsewhere [1].

2 RESULTS AND DISCUSSION

2.1 Current "state of play"

While the current boom in population growth is good news for the New Zealand economy, it puts pressure on the management of the infrastructure in major cities and urban centres. Finding smarter ways to deal with larger quantities of sewage, sewage biosolids, food waste and industrial wastewater is one critical area for adaptation to the "pressures of growth".

Interesting areas are around energy capture at sewage treatment plants – especially using the methane produced as a by-product of municipal WWTP biosolids (sludge) digestion to heat boilers, for power production or to put back into the gas grid [15].

A survey of the New Zealand WWTP database (source Water NZ, 2016 status) gave the following indicative results as a snapshot (Table 1). About 50 % of the municipal wastewater treatment biosolids in New Zealand are currently already captured by sludge digestion on municipal WWTP premises with biogas capture and efficient dewatering of stabilised biosolids. Still, a significant proportion of the total biosolids from municipal wastewater treatment is not pre-treated by anaerobic digestion and disposed in partially dewatered form to be either composted and re-used (or landfilled) and/or used for other permitted purposes such as incineration, drying or application for land rehabilitation purposes.

Table 1: Current inventory and status of municipal wastewater treatment plants in New Zealand practicing anaerobic digestion of municipal biosolids with biogas capture.

Council, Name	Proportion of NZ population (2017)	Wastewater treatment level	2016 Wastewater Volume (kL/annum)
Christchurch City Council, Bromley	8.0%	Tertiary	60908280
Dunedin City Council, Tahuna (sludge to Green Island)	1.7%	Tertiary	11251548
Dunedin City Council, Green Island	0.5%	Tertiary	4150092
Dunedin City Council, Mosgiel	0.2%	Tertiary	1444401
Hamilton City Council, Pukete WWTP	3.2%	Tertiary	16395046
Horowhenua District Council, Levin WWTP	0.4%	Secondary	2563643
Invercargill City Council, Clifton WWTP	1.8%	Tertiary	13824850
Palmerston North, Totara Road WWTP	1.8%	Tertiary	11145052
South Waikato District Council, Tokoroa WWTP	0.3%	Tertiary	841061
Taupo District Council, Taupo	0.5%	Secondary	2266439
Tauranga City Council, Chapel Street WWTP	1.7%	Tertiary	6822573
Watercare, Rosedale WWTP (North Shore)	4.4%	Tertiary	19013353
Watercare, Mangere WWTP (Island Road)	26.9%	Tertiary	115220386
Whangarei District Council, Whangarei WWTP	1.2%	Tertiary	5628498
Manawatu District Council, Fielding WWTP	0.3%	Secondary, Tertiary	262800
Total:	53 %		**2.72×10^8**

A consensus is now developing in New Zealand and Australia that an efficient use of anaerobic sludge digestion with power generation from the biogas can render municipal WWTP energy self-sufficient with potential to export surplus power to the grid. However, current low feed-in tariffs in New Zealand and an expected future electricity price competition with low cost solar and wind based generation limits the business case for on-site WWTP power generation for export of surplus power to the electricity grid.

2.2 Current economic drivers increase the attraction of municipal biosolids digestion

Currently, the benefits of anaerobic sludge digestion for municipal sludge digestion in most treatment plants in table 1 are as follows:

1. Reduced sludge solids amounts due to digestion to biogas (20-60% cost reduction, case by case).
2. Further reduced dewatered sludge cake amounts going to disposal (due to improved dewatering after digestion).
3. On site power production to offset power purchase for WWTP operation (100% power self-sufficiency possible).
4. Reduced odour in the digested biosolids (less objectionable odour).
5. Good stabilisation grade reduced vector attraction and thus improved biosolids quality for potential beneficial re-use.

Despite these benefits, not all municipal WWTPs in New Zealand practice biosolids sludge digestion. A number of different locally justified reasons exist for this situation such as (a) capital costs, (b) operational complexity, (c) technical preferences and (d) small scale. The "rule of thumb" lower economic size limit for establishment of new municipal sludge digester operations in existing wastewater treatment plants is typically believed to be about 50,000 – 75,000 population equivalent (EP) per site. Thus, a large number of the operating sewage treatment plants (STP) in New Zealand (mainly the smaller plants) appear currently excluded from the benefits above. There are of course some exceptions (see Table 1). Smaller operating plants in Table 1 with operating sludge digesters at sites with 20,000 – 50,000 population equivalents are often justified by higher local industrial contributions increasing the sewage BOD load, higher local landfilling or transport costs for undigested biosolids and often preferences by local engineers, operators who see the five benefits above as relevant for their local requirements.

Since 2008, two additional drivers for commercially viable biosolids digestion on comparatively small municipal WWTP have been established [16]. This was demonstrated with convincing technical and commercial success in the case of the capacity upgrade of the Palmerston North (Totara Road WWTP, 2012; 17) and the successor project in Hamilton (Pukete WWTP, 2014; 19). The implementation of high rate co-digestion of municipal biosolids and selected industrial trade waste in the existing Totara Road sludge digesters was initiated in 2010 and completed in 2012. Only minor modifications were required at less than1/3rd of the capital costs for equivalent digester capacity upgrades with new additional digester plant for biosolids digestion. The upgrade tripled the treatment capacity of the plant [16, 17].

In essence, the efficiency upgrade of the existing municipal digesters at the PNCC municipal WWTP introduced an innovative new scale for the "dual purpose use" of municipal sludge digesters. The use of the improved digesters with co-digestion enables now cost effective power generation at sufficient economy of scale (720 KWel genset) and offers at the same time a community supported, local, cost effective waste management service designed to service local industries (dairy factory, restaurants, supermarkets).

Currently, PNCC is in the process to further expand the range of benefits by actively diverting ICI (**I**ndustrial, **C**ommercial, **I**nstitutional) food waste from landfill disposal and enabling the processing of the diverted food waste to power and organic fertiliser.

Going forward, the benefits of co-digestion of selected organic trade waste at municipal WWTP are therefore:

1. Reduced sludge solids amounts due to digestion to biogas (20-60 % cost reduction, case by case)
2. Further reduced dewatered sludge cake amounts going to disposal (due to improved dewatering after digestion)
3. On site power production to offset power purchase for WWTP operation (100 % power self-sufficiency possible)
4. Additional power production for electricity export to grid (tripled gas output from efficient waste co-digestion)
5. Additional revenue from power sales to grid, sales of genset generation capacity ("ripple control, frequency control") and gate fees for processed industrial trade waste. Gate fees typically exceed power production related revenue.
6. Additional revenue for council from diversion of selected food waste from landfill disposal, reducing landfill gas emissions and support for local businesses by avoiding landfill tipping fees for food waste
7. Production of organic fertiliser from the food waste/industrial waste train for re-sale/re-use into landscaping, horticulture, agricultural businesses
8. Reduced odour in the digested biosolids (less objectionable odour)
9. Good fertiliser stabilisation grade, reduced vector attraction and thus improved quality for potential beneficial re-use

The four additional benefits (4 - 7 above) and associated added revenue streams for the standard municipal digester operation have in essence initiated a paradigm shift for municipal sludge digestion. Our preliminary estimate is that this paradigm shift has lowered the present minimum economic size for municipal sludge digesters from 50,000 – 75,000 population equivalent per site to 20,000 – 50,000 population equivalent- virtually doubling the number of potential trade waste co-digestion sites in New Zealand.

2.3 New technologies for improved resource recovery during municipal biosolids digestion

In addition to the conventional engineering solutions applied in the digester efficiency upgrades and the attainable benefits described in section 2.2, there is a family of new biosolids hydrolysis technologies arriving in the Australasian market [15]. These technologies have the potential to improve the overall destruction efficiency of the biosolids, the power yield from biosolids and to reduce the disposal cost for the digested biosolids when used in conjunction with the technology options described in section 2.2. These “add-on” biosolids hydrolysis options are capital intensive, initially designed for the European and North American market and thus likely to be gradually adopted (and only if proven to be commercially advantageous under NZ conditions). Due to their emerging commercial benefits, these new technologies have not yet been included in the work described in this report and can be added-on at a later time if and once proven advantageous to council digester operations.

2.4 Sustainability drivers to stimulate future municipal biosolids digestion projects in NZ

High capital costs for new greenfield biosolids digester plants in New Zealand are likely to be a barrier and to be prohibitive for an expansion of the number of NZ WWTP with practiced on-site biosolids digestion. New Zealand councils and water companies are typically risk averse (technical and commercial) and must follow stringent asset management guidelines.

Tables 2 and 3 further below account for the number and examples of existing municipal wastewater treatment plants in New Zealand that can be upgraded to efficient trade waste co-digestion over the next 30 years. An important stimulus will be carbon trading with carbon prices expected to increase from $NZ 20/ tonne CO_2equ. (today, Figure 1) to $NZ 30/ tonne CO_2equ. (2030) and to levels in excess of $NZ 100/ tonne CO_2equ. in 2050. Figure 2 states the regional distribution of these plants. Figures 3 and 4 further below present the expected annual GHG emission reductions and renewable fuel production.

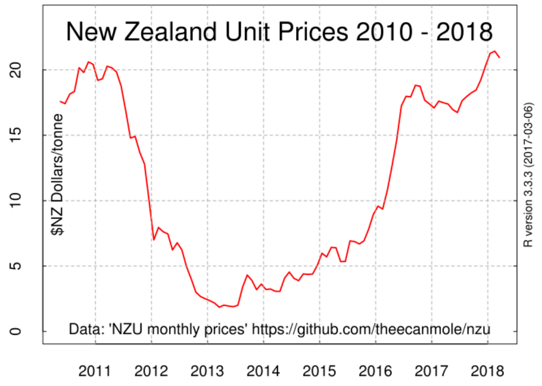

Figure 1: Recent NZ Carbon Emission Unit prices ($NZ/tonne CO_2equ., Wikipedia)

Table 2: Assumed inventory and status of municipal wastewater treatment plants in New Zealand in **2030 in scenario 1 and 2**. All digester operations shown are assumed to practice anaerobic co-digestion of municipal biosolids with biogas capture, trade waste co-digestion, food waste co-digestion and biogas export into a local biogas grid associated with the wastewater treatment plant operations. The main change to 2017 is that all WWTP with digesters shown adopt trade waste co-digestion with locally available sources (no industrial waste added in scenario 1 but industrial waste sources added in scenario 2). Also assumed is that all three municipal WWTP operations in the Greater Wellington area follow Rosedale, Hamilton, Tauranga, Christchurch and Dunedin examples (all at comparable scale) and have amended their WWTP infrastructure with biosolids digesters (currently no anaerobic digestion of biosolids practiced in the Greater Wellington area). Please note that there are 21 other WWTP without biosolids digesters in NZ, which have not yet been included in this list. The assumptions in the list below are thus highly conservative (i.e. only proven technologies and no new council WWTP operations).

Council, Name	Proportion of NZ population (2030)	Wastewater treatment level
Christchurch City Council, Bromley	8.0%	Tertiary
Dunedin City Council, Tahuna (sludge to Green Island)	1.7%	Tertiary
Dunedin City Council, Green Island	0.5%	Tertiary
Dunedin City Council, Mosgiel	0.2%	Tertiary
Hamilton City Council, Pukete WWTP	3.2%	Tertiary
Horowhenua District Council, Levin WWTP	0.4%	Tertiary
Invercargill City Council, Clifton WWTP	1.8%	Tertiary
Palmerston North, Totara Road WWTP	1.8%	Tertiary
South Waikato District Council, Tokoroa WWTP	0.3%	Tertiary
Taupo District Council, Taupo	0.5%	Tertiary
Tauranga City Council, Chapel Street WWTP	1.7%	Tertiary
Watercare, Rosedale WWTP (North Shore)	4.4%	Tertiary
Watercare, Mangere WWTP (Island Road)	26.9%	Tertiary
Whangarei District Council, Whangarei WWTP	1.2%	Tertiary
Manawatu District Council, Fielding WWTP	0.3%	Tertiary
Hutt City Council, Seaview	2.8%	Tertiary
Porirua City Council, Porirua WWTP	1.3%	Tertiary
Wellington City Council, Moa Point	3.6%	Tertiary
Total:	61%	

As Figure 1 above shows, the recent history in the NZ carbon market in the past 6 years has actively discouraged such investment. The technical expertise for realisation of the Regional Biosolids Processing Centre technology is available in New Zealand. Viable long term and stable investment strategies will be critical for private sector participation – private bank funded or crowd funded. The proposed pathway for a conservative and gradual implementation path of biosolids co-digestion in NZ driven by market demand is thus detailed in Tables 2 and 3.

The concept of greenfield constructed dedicated regional biosolids processing centres has emerged in recent years in Australia and is very well suited to the more decentralised regional, rural and suburban infrastructure.

As soon as a vibrant carbon market with a GHG emission abatement cost correlated carbon price has been established in New Zealand, we expect movement in this sector. With fair New Zealand Unit prices– priced to the market value of the additional GHG abatement benefits generated by implementation of defined projects - private sector banks specialising in sustainability infrastructure projects could be interested to fund new Biosolids Processing Centres designed to co-digest trade waste and biosolids from a number of smaller regional WWTP. Calibre has recently been involved in a case study about the commercial merits of the realisation of the biogas production options I – VII (see introduction section) in biosolids processing centres.

Using the GHG emission abatement estimates calculated for scenario 2 in Figure 3 below, the estimated additional annual GHG emission reduction in 2030 is about 250,000 t CO_2-equ/annum and in 2050, about 450,000 t CO_2-equ/annum. Even with a low but stable carbon price of $NZ 30/ t CO_2-equ. (pegged by international prices), we estimate that on a national level an additional revenue stream above $NZ 7.5 million/annum in 2030 and above $NZ 13.5

million/annum in 2050 is likely to be available - in addition to the revenue earned with the 9 benefits listed in section 2.2. These are good drivers to fund at least one new biosolids processing centre project/annum using domestic climate change compliance cost savings, resource recovery revenue, power production and gate fee revenue and directly related avoided carbon emission abatement costs at landfills and for domestic industrial biogas users in the heat or heat & power market.

The good geographic and regional synergy between potential municipal biosolids processing sites, cities and industrial sources of suitable dairy industry waste sources (no contamination with paper, plastic, glass, metals) is shown in Figure 2.

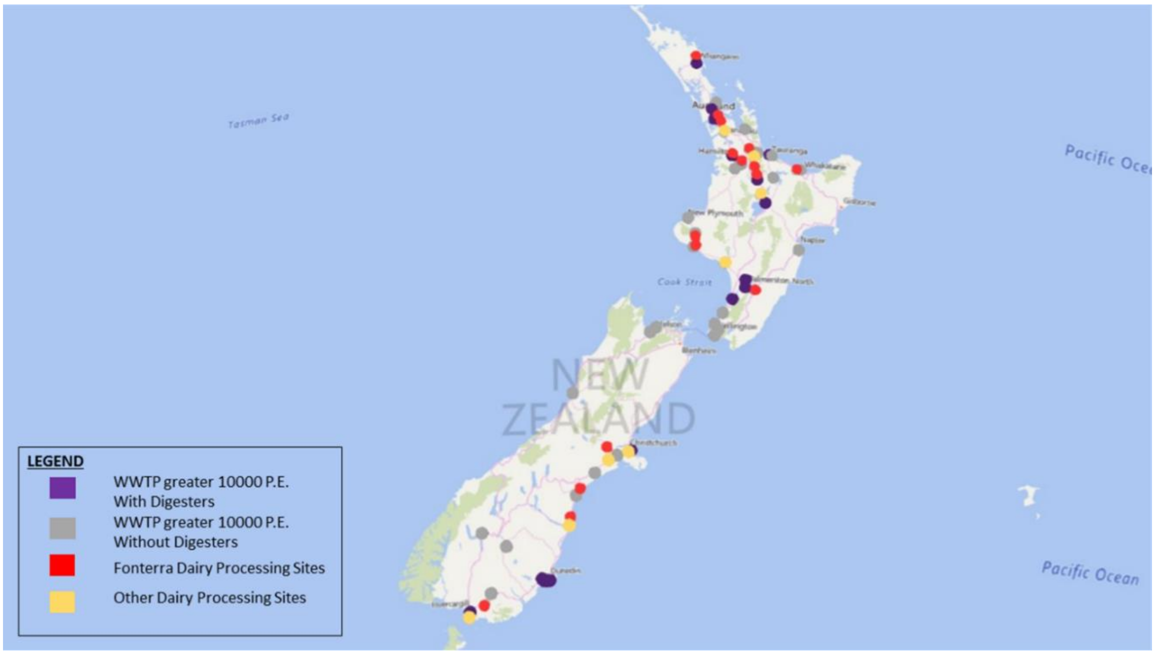

Figure 2: Geographical alignment (2016 data) of existing WWTPs with existing anaerobic digesters, dairy industry factories (processing sites) with suitable industrial waste feedstock and existing WWTP locations that are potentially suitable for an upgrade to additional on-site biosolids digestion and power generation projects.

Figure 2 indicates regions in New Zealand where dairy industry waste availability is likely to limit the technical opportunity to maximise the co-digestion biogas output. However, these are regions with tourism, viticulture, aquaculture, fisheries, horticulture, sheep, and beef meat processing sites that produce in combination significant amounts of highly digestible organic waste residues. Thus, most certainly, there will be a need for an optimisation step and “mixing and matching” on the pathway to implementation. An optimisation was beyond the brief of this high-level report here. The large number of “grey” dots in Figure 2 provides confidence that a nationwide coverage of existing WWTP’s with modern biosolids processing operations including anaerobic digestion is plausible and supported by tested engineering solutions.

Table 3: Assumed inventory and status of municipal wastewater treatment plants in New Zealand **in 2050 in scenario 1 and 2**. All digester operations shown are assumed to practice anaerobic co-digestion of municipal biosolids with biogas capture, trade waste co-digestion, food waste co-digestion and biogas export into a local biogas grid associated with the wastewater treatment plant operations. The main change to 2030 is that all WWTP with digesters shown adopt trade waste co-digestion with locally available sources (no industrial waste added in scenario 1 but industrial waste sources added in scenario 2). Also, that the benefits of improved "economy of scale" with added in industrial waste (reduced WWTP size lower limits) and a higher "carbon price" have incentivised seven plants (1/3rd of the remaining 21 plants in 2030) to add anaerobic co-digestion of WWTP biosolids to their treatment process. There are 14 other WWTP (not shown) of sufficient scale and without biosolids digesters in NZ, which have not yet been included in this list. The assumptions in the list below are thus conservative (i.e. only proven technologies and no new council WWTP operations).

Council, Name	Proportion of NZ population (2050)	Wastewater treatment level
Christchurch City Council, Bromley	8.0%	Tertiary
Dunedin City Council, Tahuna (sludge to Green Island)	1.7%	Tertiary
Dunedin City Council, Green Island	0.5%	Tertiary
Dunedin City Council, Mosgiel	0.2%	Tertiary
Hamilton City Council, Pukete WWTP	3.2%	Tertiary
Horowhenua District Council, Levin WWTP	0.4%	Tertiary
Invercargill City Council, Clifton WWTP	1.8%	Tertiary
Palmerston North, Totara Road WWTP	1.8%	Tertiary
South Waikato District Council, Tokoroa WWTP	0.3%	Tertiary
Taupo District Council, Taupo	0.5%	Tertiary
Tauranga City Council, Chapel Street WWTP	1.7%	Tertiary
Watercare, Rosedale WWTP (North Shore)	4.4%	Tertiary
Watercare, Mangere WWTP (Island Road)	26.9%	Tertiary
Whangarei District Council, Whangarei WWTP	1.2%	Tertiary
Manawatu District Council, Fielding WWTP	0.3%	Tertiary
Hutt City Council, Seaview	2.8%	Tertiary
Porirua City Council, Porirua WWTP	1.3%	Tertiary
Wellington City Council, Moa Point	3.6%	Tertiary
Hawkes Bay District Council	2.7%	Tertiary
Nelson City Council, Bells Island	1.1%	Tertiary
Nelson City Council, Nelson North	0.5%	Tertiary
New Plymouth	1.7%	Tertiary
Rotorua District Council	1.2%	Tertiary
Tauranga City Council, Te Maunga	0.7%	Tertiary
Timaru District Council, Industrial + Domestic	1.5%	Tertiary
Total:	70%	

Table 3 shows that the municipal biogas production scenarios in this report are based on capture of up to 70 % of the existing biosolids potential of existing sewage treatment plants and are at appropriate scale (> 30,000 EP/site in 2050).

The number of identified WWTP sites with potential for biosolids digestion in 2050 is for more of 80 % of the total NZ population. A 68 % capture of the produced biosolids in 2050 is thus a conservative assumption. Also, the available actual waste resource of grease trap waste, high quality food waste from pre-consumer sources (no contamination with paper, plastic, glass, metal, electronics, other foreign objects) in New Zealand is larger than the amounts assumed to be utilised in the scenario calculations presented here (**68 %** see section 4).

Critical factors that control the trade waste co-digestion implementation rate are the rewards for private sector initiatives and the robustness of the macro-economic investment stimuli for a low carbon economy as well as regional factors. All of them depend more or less on the effective carbon price, the landfilling costs for putrescible waste, the availability of landfilling options (or lack of, see German example) and of course the price of fossil fuel energy (petroleum, petrol, diesel, LPG and natural gas).

The achieved total diversion of landfilled organic waste expected to be achieved in 2050 with the organic waste co-digestion at municipal plants is estimated as follows

- Municipal biosolids:	222,000 tonne/annum removed from landfill
- Municipal grease trap waste:	330,000 tonne/annum removed from landfill
- ICI (institutional, commercial, industrial) food waste:	90,000 tonne/annum removed from landfill
Total:	**642,000 tonne/annum removed from landfill**

The total landfilled organic waste volume reduction expected to be achieved with the planned additional dedicated food waste digestion plants in 2050 is estimated as 225,000 tonne food waste/annum removed.

Organic waste co-digestion to biogas at existing municipal plants and new dedicated food waste digestion facilities is thus a significant contribution to NZ sustainability targets.

2.5 Expected Greenhouse Gas (GHG) Emissions Offsets from Municipal Biogas Production

Our estimate of the GHG emission abatement benefits from municipal WWTP based biogas production was based on the comparison of three different detailed municipal wastewater treatment sector specific industry operation scenarios for the period 2017 – 2050 (Figure 3, below, scenario details in section 4). The underlying detailed quantitative assumptions for the scenarios are also detailed in section 4.

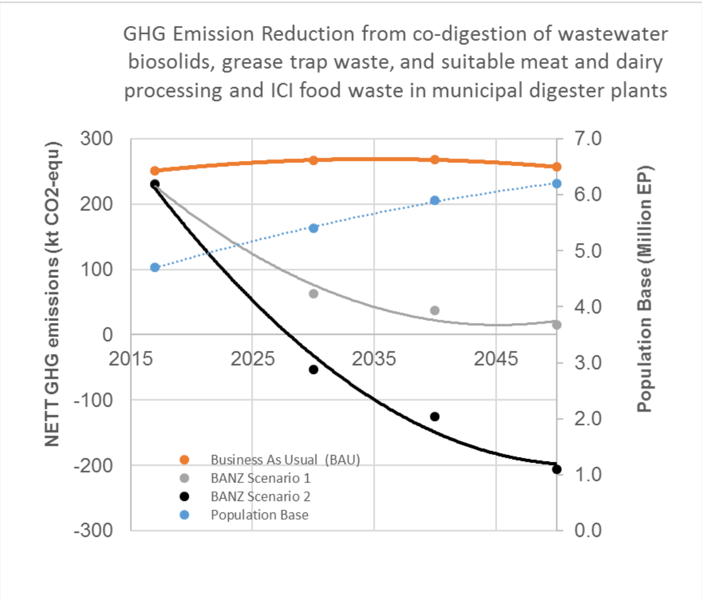

Figure 3: Comparison of the projected annual GHG emission reduction in the BAU scenario, scenario1 and scenario 2. Please note that scenario 1 with a simple digester efficiency upgrade (recuperative thickening) treating ICI quality pre-consumer food waste and grease trap waste by co-digestion and without use of additional industrial waste is already able to “nearly fully” offset the current and future GHG emissions from biosolids and GTW management in the BAU scenario. Please note that co-digestion of 70 % of suitable meat and dairy processing industry waste material in scenario 2 is expected to generate an additional GHG offset of about – 200 kt CO_2-equ/annum.

The reference scenario BAU (Business as usual) projects and continues the 2017 industry behaviour, processes and sustainability ambitions (until 2050). It is the scenario representing an approach of using a limited set of actions to reduce the GHG output of municipal wastewater treatment (electricity conservation measures) and to reduce landfill treatment emissions for municipal wastewater treatment biosolids. 53 % of the population are assumed to be served in municipal WWTP with anaerobic digesters using the biogas for onsite generation of heat and power where already currently practiced. While the total population size would increase between 2017 and 2050 by 36 %, the proportion New Zealanders connected to municipal sewage treatment with biosolids digesters would remain constant. 61 % of the annual biosolids from municipal WWTP would go to landfill. Landfill space availability is assumed to be non-limiting. Due to public pressure (councils, central government, international peer pressure and tourism), NZ landfills continuously improve the average landfill gas capture efficiency where commercially possible and construct new landfills with state-of the art landfill gas capture installations. The scenario assumes that this will gradually increase the average landfill gas capture efficiency from 60 % (2017) to 69 % (2050). The result is a more or less constant annual landfill gas emission of about 250 kt CO2-equ methane from landfilled biosolids and grease trap waste. For simplicity reasons, municipal WWTP biosolids specific GHG emission from other uses (horticulture and forestry fertiliser, composting, land reclamation, agriculture) were assumed to remain the same every year and thus are negligible for determination of the GHG emission differences between the three scenarios.

In Scenario 1, it is assumed that local government, central government and the waste management industry establish close cooperation links aimed at maximising the initiation of projects for reasonable GHG gas emission reductions. The scenario is based on implementation of municipal digester efficiency upgrades (mixing and recuperative thickening upgrades or equivalent solutions, see PNCC as example) to all 15 NZ WWTP that have currently anaerobic sludge digestion (Table 1). In addition, additionally, install by 2030 anaerobic digestion of WWTP biosolids at three WWTP in the Greater Wellington region. 20 % of the produced biogas would be used for on site for digester heating. Co-digestion of biosolids with grease trap waste which is collected from urban, regional businesses and ICI (industrial, commercial, institutional) food waste occurs in these plants. By 2030, these measures in combination would more than “triple” the total biogas production from municipal WWTP in New Zealand (to 1.5 PJ biogas/annum). Co-digestion plant revenues are driven by avoided biosolids disposal costs, collected gate fees for received trade waste and food waste and biogas sales into the local industrial heat market. In comparison to the BAU scenario, the per capita total biogas production in New Zealand would increase about 3-fold to about 1.9 PJ/annum by 2050 (Figure 4). Please note that this is based on the addition of biosolids digesters to seven further WWTP (total of 70 % capture of WWTP biosolids by anaerobic digestion, see Table 3).

The major GHG abatement benefit from this scenario is diversion of sufficient amounts of biosolids, grease trap waste and ICI food waste from landfills (to beneficial re-use and production of industrial boiler fuel) to practically offset all residual GHG emissions from the municipal WWTP biosolids that would be landfilled in the BAU scenario (Figure 3). This makes the biogas a virtually “nett zero carbon renewable fuel”.

It is assumed that low cost renewable electricity is available from combined centralised and new distributed grid generation using hydro, solar, wind, biomass and some natural gas. It is further assumed that the current electricity purchase costs for commercial users (about 12 c/kwh$_{el}$ as variable costs) would be about the same or even lower than the pro rata apportioned CAPEX + OPEX for combined genset power generation cost from biogas (about 11-13 c/kwhel from biogas, no ACOT payments). This assumption includes all costs for biogas clean-up, genset purchase, genset installation and tie-in, genset operation and maintenance + biogas clean-up operating cost (filter materials) providing the raw municipal biogas at “zero cost”.

Aiming at minimising the national GHG emission footprint from the WWTP operations, 80 % of the produced biogas at the WWTP is proposed to be sold as boiler fuel to co-sited industrial gas users which use the biogas to replace natural gas (assumed discounted fuel value: $NZ 10/GJ biogas). The GHG emission abatement credit income to WWTP operators (at low value of $NZ 30/t CO2-equ in 2030) would be additional and substantial. We estimate $NZ 1.6 /GJ biogas or $NZ 0.037/m^3 biogas @ 65 % methane. This biogas marketing strategy would be an even better strategy for marketing biogas in 2030 than on-site power generation. In addition, a much better biogas marketing strategy in 2050 when the price of carbon is estimated to be in excess of $NZ 100/t CO2-equ [18].

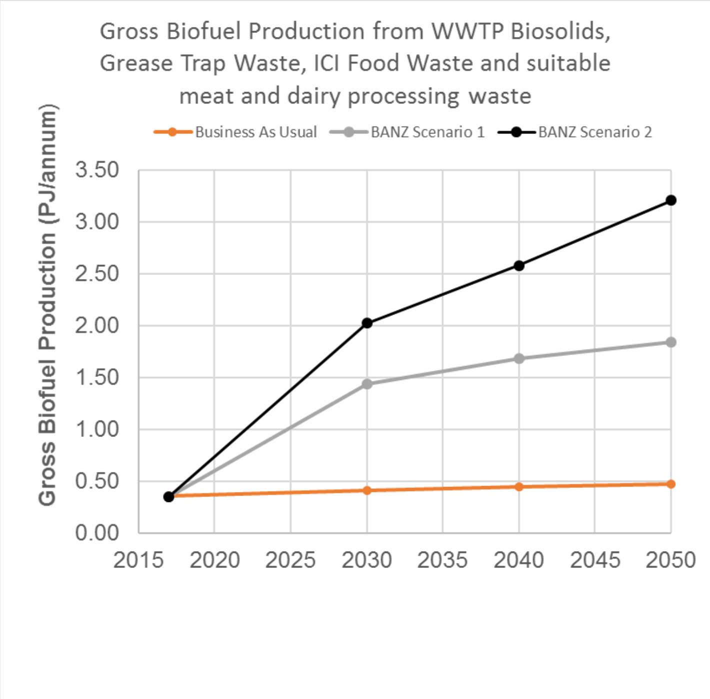

Figure 4: Projected annual biogas production in the BAU scenario, scenario1 and scenario 2. Please note that scenario 1 with a simple digester efficiency upgrade (recuperative thickening) without use of additional industrial waste is already able to more than triple the biogas output from current municipal treatment plants. The majority of this additional biogas is available for use as biofuel for industrial/commercial heat production in proposed regional industrial parks. These industrial parks are close to the existing urban and new regional co-digestion sites. About 1.5 PJ/annum of biogas from co-digestion of industrial waste is expected to be produced in 2050 (difference between scenario 2 and scenario 1).

In Scenario 2 it is assumed that the initiatives represented in scenario 1 are optimised by maximising the gas production efficiency and biogas productivity in all WWTP with sludge digesters and without compromising the normal biosolids treatment efficiency and GHG abatement efficiency of the WWTP operations. Additional biogas production is achieved by import of selected additional industrial waste from dairy and meat processing factories. By 2050, the biogas output from modern WWTP with sludge digesters serving 68 % of the NZ population is expected to be about 4 PJ of biogas (gross) with 20 % used on site for digester heating etc. Nett biogas is thus about 3.2 PJ/annum (Figure 4). Revenues from all nine-digester process benefits (see section 2.2) and additional carbon credits will drive a vibrant resource recovery business at the WWTP premises. The additional gate fee revenue from the processing of food waste and industrial waste and substantially increased carbon credit revenues are used to finance predominantly advanced biosolids digester systems on the larger WWTP plants (2 x Auckland, 3 x Wellington, Christchurch, and 4 others). Examples are mesophilic digester with recuperative thickening (PNCC 2012), temperature phased anaerobic digesters (TPAD, ChCh 2010) and thermal hydrolysis process based municipal digesters (THP digester, AKL 2025). These advanced systems increase the biogas yield from the biosolids (1.3 fold improved yield and solids destruction) and double the biogas productivity of existing and new digester systems. The total gross average biogas output in 2050in New Zealand based on the achieved biogas production results (4160 Nm^3 methane projected /84,000 EP based digester plant at PNCC in 2017) represents about 50 PNCC WWTP size plant equivalents.

The major GHG abatement benefits from this scenario by 2050 are the diversion of sufficient amounts of biosolids, grease trap waste and ICI food waste from landfills to practically offset all residual GHG emissions from the municipal WWTP biosolids that are landfilled in the BAU scenario (Figure 3) plus generation of additional GHG offsets of about 200 t CO2-equ/annum. This makes the biogas a “negative carbon renewable fuel”.

The additional carbon emission reductions can be used to offset carbon emissions in the participating industrial sector. In addition to the low gate fee, these offsets could become a key attraction for primary processing industries to “hedge their carbon costs” and potentially participate in a large number of shared co-digestion joint venture waste management businesses at municipal WWTP premises.

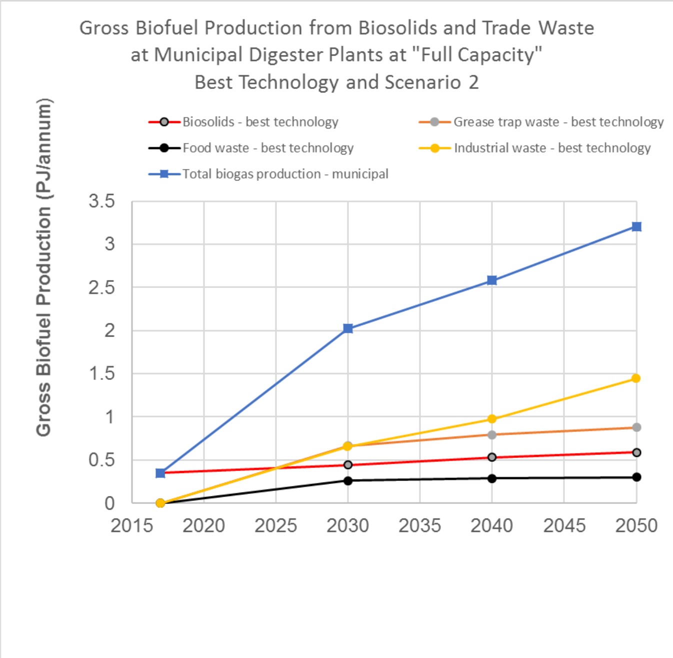

Figure 5: Projected annual biogas production from trade waste co-digestion in existing and new municipal sludge digesters in scenario 2. Please note the importance of the gas production from the added industrial co-digestion feedstock material in the overall picture in scenario 2.

Figure 5 summarises the breakdown of the contributions of the various documented and available municipal waste resources in New Zealand than can be utilised for GHG emission abatement through targeted waste co-digestion systems on existing municipal WWTP. The advantage of the strategy explored in this report is that

1. The often high capital costs for dedicated organic waste digestion systems (Earthpower Food Waste digester, NSW; Yarra Valley Water Food Waste digester, VIC as examples) are substantially reduced by re-using existing digester facilities and adding new revenue streams without substantial added investment costs
2. The anaerobic co-digestion services are possible at a smaller WWTP scale with logistics benefits from reduced waste transport and procurement chain costs and improved logistics for marketing of the digestion residues
3. The attraction for biogas use in the industrial heat market has been substantially increased
4. The contribution of biogas from municipal operations as “negative carbon fuel in New Zealand” is now significant
5. Biogas has become a well-established and flexible biofuel and all proposed co-digestion investment options represent “low hanging fruits” with fast payback and low commercial risk. A number of parallel biogas energy end use options exist (heat, cooling, heat& power, power only, bio-methane transport, EV transport) which can be “mixed and matched” to site specific, customer specific and/or specific seasonal requirements.

The biogas production potential from other organic waste in NZ (source segregated post-consumer food waste, agricultural residues, manure) not shown in Figure 5 was outside the scope for this report. This additional potential is estimated to be in the order of 6 PJ biogas/annum in 2050.

Adding up all options for biogas generation from organic waste in New Zealand gives an expected total renewable energy pool in the form of usable biogas from digestible organic waste in New Zealand of around 7.4 PJ/annum in 2017 and about 10 PJ/annum in 2050.

A breakdown for 2050 would look as follows:

- Up to 3.2 PJ of biogas in 2050 from municipal WWTP based co-digestion systems combining selected municipal organic waste, dairy processing waste and meat processing waste (this report)
- About 1 PJ of biogas in 2050 from dedicated new industrial WWTP using engineered on site digestion systems servicing the residual portion of dairy, red meat, poultry, viticulture and pulp & paper processing waste from factories not connected to co-digestion systems

- about 4 PJ of biogas from dedicated new greenfield digester plants targeting the biogas production from mixed post-consumer food waste (contaminated with foreign objects) such as source segregated kitchen waste and other mixed food waste from food premises
- About 1.5 PJ of potential biogas from potential future dairy and feedlot farm digesters in New Zealand (same as 2006)

If one scales the results from the previous anaerobic digestion technical biogas potential estimate [17; 2006 data; EnergyScape project] from the 2006 population to 6.4 million people (2050 expected) the following very similar picture emerges:

- Up to 2.9 PJ of biogas in 2050 from municipal WWTP based co-digestion systems combining selected municipal organic waste, dairy processing waste and meat processing waste (this report)
- About 1 PJ of biogas in 2050 from dedicated new industrial WWTP using engineered on site digestion systems servicing the residual portion of poultry, viticulture and pulp and paper processing waste from factories not connected to co-digestion systems
- About 3.8 PJ of biogas from dedicated new greenfield digester plants targeting the biogas production from mixed post-consumer food waste (contaminated with foreign objects) such as source segregated kitchen waste and other mixed food waste from food premises
- About 1.5 PJ of potential biogas from potential future dairy and feedlot farm digesters in New Zealand (same as 2006)

3 SUMMARY AND CONCLUSIONS

The total biogas energy potential in New Zealand from digestible organic waste is estimated to be about 10 PJ/annum in 2050 and is thus significant. This report on the biofuel production and GHG abatement potential in New Zealand is based on modern, high rate biosolids digestion solutions implemented at existing municipal WWTPs and has confirmed the previously estimated renewable energy production potential from municipal and industrial organic waste in New Zealand [17].

The engineering pathway used to harness this potential is based on proven technology (operating demonstration plants). Potential owners of future co-digestion plants can already get first hand operators experience (realistic New Zealand operating conditions) to build investor confidence. The required infrastructure (reticulated wastewater treatment infrastructure) is already fully constructed and remaining additional efficiency upgrade investments are expected to be “minor works” providing a rapid investment payback [17].

The scenario calculations presented in this report were based on “up to date” official data from Statistics NZ, Water NZ, Australian Water Association (AWA). Based on a number of conservative and robust assumptions (see section 4 below), the calculations demonstrated an annual nett biogas production potential in operating municipal wastewater plant co-digestion systems in NZ of about 3.2 PJ biogas/annum. The resulting GHG emission reduction potential from municipal WWTP co-digestion combined with dedicated industrial waste digester systems in New Zealand gives a combined potential (municipal + industrial) in the order of 650 kt CO2-equiv/annum in 2050. That is a significant contribution to meet NZ international obligations.

The gross biogas energy production potential in 2050 is in the order of 4 PJ biogas/annum. The gross biogas production potential from other organic waste in NZ (post-consumer food waste, agricultural) in 2050 is in the order of 6 PJ biogas/annum:

In this context, it would thus be important to further detail the expected GHG emission reduction from residual landfilled food waste when diverted to dedicated anaerobic digestion facilities. Very early high-level estimates put the expected GHG emission reduction in 2050 in the order of 500 – 600 kt CO2-equiv/annum in 2050 – thus a very similar additional GHJG emission reduction opportunity to the estimates derived here.

4 APPENDIX: TECHNICAL BACKGROUND INFORMATION FOR THIS REPORT

4.1 Brief description of the three scenarios used in the biogas potential analysis

(1) Business as usual (BAU)

Municipal digester/landfill operations:
No particular efforts from WWTP owners to maximise the biogas production in municipal wastewater treatment. Existing plants with digesters (15) will adjust their digester capacity to population growth. Population growth as per Stats NZ projections (2016 – 2068). Landfill owners are enticed to gradually improve the average landfill gas capture efficiency from 60 % (today) to 69 % (2050). Carbon price and power price are low and thus not an incentive for change. Total municipal biogas production 2050: **0.47 PJ.** The nett GHG emission from this operation is practically 250 kt CO2-equ/ annum (“Zero carbon increase goal for councils”).

(2) BANZ Scenario 1

Municipal digester/landfill operations:
Changes in carbon price, industrial heat prices (natural gas), landfill costs for trade waste disposal and public pressure incentivise councils and water corporations (over 30 years) to upgrade large existing WWTP (14 currently w/o anaerobic digesters) to new “WWTP with local trade waste/food waste co-digestion” and to upgrade the digester capacities of the existing 15 municipal digesters to also accept locally produced commercial trade waste/food waste and grease trap waste. That would be in total 29 municipal WWTP with trade waste co-digestion. All trade waste BOD to be converted to biogas and suitable trade waste nutrients (N, P, S) to digestate fertiliser. Overall population grows as per Stats NZ projections. The nett effect of these changes is that the percentage age of NZ population with municipal WWTP anaerobic sludge digestion increases from 53 % (today) to 68 % (2050). Landfill owners are enticed to gradually improve the average landfill gas capture efficiency from 60 % (today) to 69 % (2050). Power price is low and thus not an incentive to generate power from biogas. Significant more biogas is produced than in BAU and all gas is used for industrial heat in co-located commercial and industrial businesses and local biomethane or biogas networks. Total biogas production capacity from municipal operations in 2050 is: **1.47 PJ.** The nett GHG emission from this operation is practically close to Zero (Zero carbon emission goal for councils).

(3) BANZ Scenario 2

Municipal digester/landfill operations:
Significant changes in carbon price, industrial heat prices (natural gas), landfill costs for trade waste disposal and public pressure incentivise councils and water corporations (over 30 years) to upgrade large existing WWTP (14 currently w/o anaerobic digesters) to new “WWTP with local trade waste/ICI food waste/suitable industrial waste co-digestion” and to upgrade the digester capacities of the existing 15 municipal digesters to also accept locally produced commercial trade waste/ICI food waste, suitable industrial waste and grease trap waste. That would be in total 29 municipal WWTP with extended co-digestion operations. Locally produced grease trap waste and other industrial feed stocks (dairy, meat processing) are converted to biogas (significant digester technology upgrades needed, recuperative thickening, thermal hydrolysis plant (Watercare), other measures). Overall population grows as per Stats NZ projections. All trade waste BOD to be converted to biogas and suitable trade waste nutrients (N, P, S) to digestate fertiliser. The nett effect of these changes is that the percentage age of NZ population serviced with WWTP with anaerobic digestion increase from 53 % (today) to 68 % (2050). Landfill owners are enticed to gradually improve the average landfill gas capture efficiency from 60 % (today) to 69 % (2050). Power price is low and thus not an incentive to change. Significant more biogas is produced that is used for industrial heat in co-located commercial and industrial businesses and local gas networks. Total biogas production capacity from municipal operations in 2050 is **2.95 PJ.** The nett GHG emission from this operation is ZERO in 2030 and negative in 2050 and helps to offset GHG emissions from other sectors (Zero carbon emission goal for councils).

4.2 List of parameters and assumptions used in the analysis

(1) Business as usual (BAU)

Table 4-1: Values used for the Business As Usual (BAU) Scenario.

Parameter	Parameter name	Units of measure	Value 2017	Value 2030	Value 2040	Value 2050	Source
A	Total EP in NZ	million EP	4.7	5.4	5.9	6.2	[2]
B	% of EP with WWTP with AD	%	53	53	53	53	[3]
C	% of EP in WWTP without AD	%	47	47	47	47	[3]
D	Total amount of WWTP biosolids	Dry tonnes /annum (t TS/annum)	88000	101200	110468	116085	[4]
E	% of biosolids landfilled	%	61	61	61	61	[5]
F	Average landfill gas capture efficiency in NZ	%	60	63	66	69	[6]
G	VS content of landfilled municipal biosolids (% of TS)	%	65	65	65	65	[7]
H	VS degradation efficiency of landfilled municipal biosolids	%	40	40	40	40	[7]

(2) BANZ Scenario 1

Table 4-2: Values used for Scenario 1.

Parameter	Parameter name	Units of measure	Value 2017	Value 2030	Value 2040	Value 2050	Source
A	Total EP in NZ	million EP	4.7	5.4	5.9	6.2	[2]
B	% of EP with WWTP with AD	%	53	59	64	68	[3]
C	% of EP in WWTP without AD	%	47	41	36	32	[3]
D	Total amount of WWTP biosolids	Dry tonnes /annum (t TS/annum)	88000	101200	110468	116085	[4]
E	% of biosolids landfilled	%	61	61	61	61	[5]
F	Average landfill gas capture efficiency in NZ	%	60	63	66	69	[6]
G	VS content of landfilled municipal biosolids (% of TS)	%	65	65	65	65	[7]
H	VS degradation efficiency of landfilled municipal biosolids	%	40	40	40	40	[7]
I	Total grease trap waste capture by co-digestion in WWTP	% of total production	0	59	64	68	[8]
J	Annual grease trap waste production value	kg FOG/EP	7	7	7	7	[9]
K	GHG emission factor for methane gas	t CO2-equ/ t methane	25	25	25	25	[10]
L	GHG emission factor for industrial use of biogas	kg CO2-equ/ GJ natural gas	-53.3	-53.3	-53.3	-53.3	[11]
M	Suitable industrial waste used in WWTP co-digestion	PJ methane/ annum	0.08	0.25	0.36	0.51	[1]
N	COD content of FOG in grease trap waste	Kg COD/kg FOG	3	3	3	3	[7]

(3) BANZ Scenario 2

Table 4-3: Values used for Scenario 2.

Parameter	Parameter name	Units of measure	Value 2017	Value 2030	Value 2040	Value 2050	Source
A	Total EP in NZ	million EP	4.7	5.4	5.9	6.2	[2]
B	% of EP with WWTP with AD	%	53	59	64	68	[3]
C	% of EP in WWTP without AD	%	47	41	36	32	[3]
D	Total amount of WWTP biosolids	Dry tonnes /annum (t TS/annum)	88000	101200	110468	116085	[4]
E	% of biosolids landfilled	%	61	61	61	61	[5]
F	Average landfill gas capture efficiency in NZ	%	60	63	66	69	[6]
G	VS content of landfilled municipal biosolids (% of TS)	%	65	65	65	65	[7]
H	VS degradation of landfilled municipal biosolids	%	40	40	40	40	[7]
I	Total grease trap waste capture by co-digestion in WWTP	% of total production	0	59	64	68	[8]
J	Annual grease trap waste production value	kg FOG/EP	7	7	7	7	[9]
K	GHG emission factor for methane gas	t CO2-equ/ t methane	25	25	25	25	[10]
L	GHG emission factor for industrial use of biogas	kg CO2-equ/ GJ natural gas	-53.3	-53.3	-53.3	-53.3	[11]
M	Suitable industrial waste used in WWTP co-digestion	PJ methane/ annum	0.08	0.25	0.36	0.51	[1]
N	COD content of FOG in grease trap waste	Kg COD/kg FOG	3	3	3	3	[7]
O	Effective capture of suitable ICI food residuals (natl. average)	t wet matter/ 100,000 EP	0	2000	2000	2000	[12]
P	Average biogas methane yield from ICI food waste	Nm^3methane/t wet matter	68	68	68	68	[13]

5 LIST OF INFORMATION SOURCES USED FOR THE ANALYSIS

[1] BPO report, Alzbeta Bouskova 2018

[2] Statistics NZ: National Population Projections: 2016(base)–2068

[3] Detailed analysis of Water NZ WWTP database 2016 and own investigations

[4] Based on data from [2] and [3]

[5] ANZPB commissioned 2015 biosolids survey. Australian Water Association, AWA 2015

[6] LFG recovery efficiency: 42–90%; Site specific; SKM, 2009 (NZ GHG Inventory, 2015)

[7] Industry experience, Calibre, conservative value used to obtain conservative value for derived emissions

[8] Assumption in analogy to assumed progress in WWTP upgrades

[9] Process Safety and Environmental Protection 90, (2012): 231–245

[10] NZ GHG inventory and industry data

[11] Voluntary GHG reporting summary tables: emission factors 2015, NZ Ministry for the Environment, INFO 734

[12] Industry experience from ICI food waste co-digestion system design for Palmerston North

[13] average of industry experience, this is an assumed value based on the experience gained in [12]

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