FUTURE PROOFING OUR WASTEWATER TREATMENT INFRASTRUCTURE

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ABSTRACT

Fossil fuel and electricity costs could significantly increase in the not too far future. This will affect our industrial sector and waste treatment service providers who are exposed to price changes as they maintain wastewater treatment plants with significant use of electricity. CPG was commissioned in 2007 to estimate the present and future New Zealand biofuel production potential to produce additional biogas fuel via treatment of industrial and primary processing byproducts by anaerobic digestion. The data showed that only about 25 % of the biogas production potential from these materials is currently realized (0.45 PJ biogas /annum). Co-digestion of suitable and available industrial, commercial and institutional sludge materials with the municipal WWTP biosolids in urban environments would produce additionally 0.45 PJ biogas/annum and double the biogas potential to approximately 0.9 PJ biogas/annum. Nationwide systematic capture of wastewater treatment dissolved air floatation (DAF) sludge material from meat processing and dairy factories could quadruple the potential to approximately 1.9 PJ biogas/annum. We compare in this paper the technical and commercial feasibility and advantages/disadvantages of implementing new co-digestion facilities through upgrade of existing municipal digesters or through new construction of dedicated anaerobic digestion facilities next to large industrial energy users.

KEYWORDS

Sludge digesters, trade waste, co-digestion, biofuel, cogeneration, regional digester facility

1 INTRODUCTION

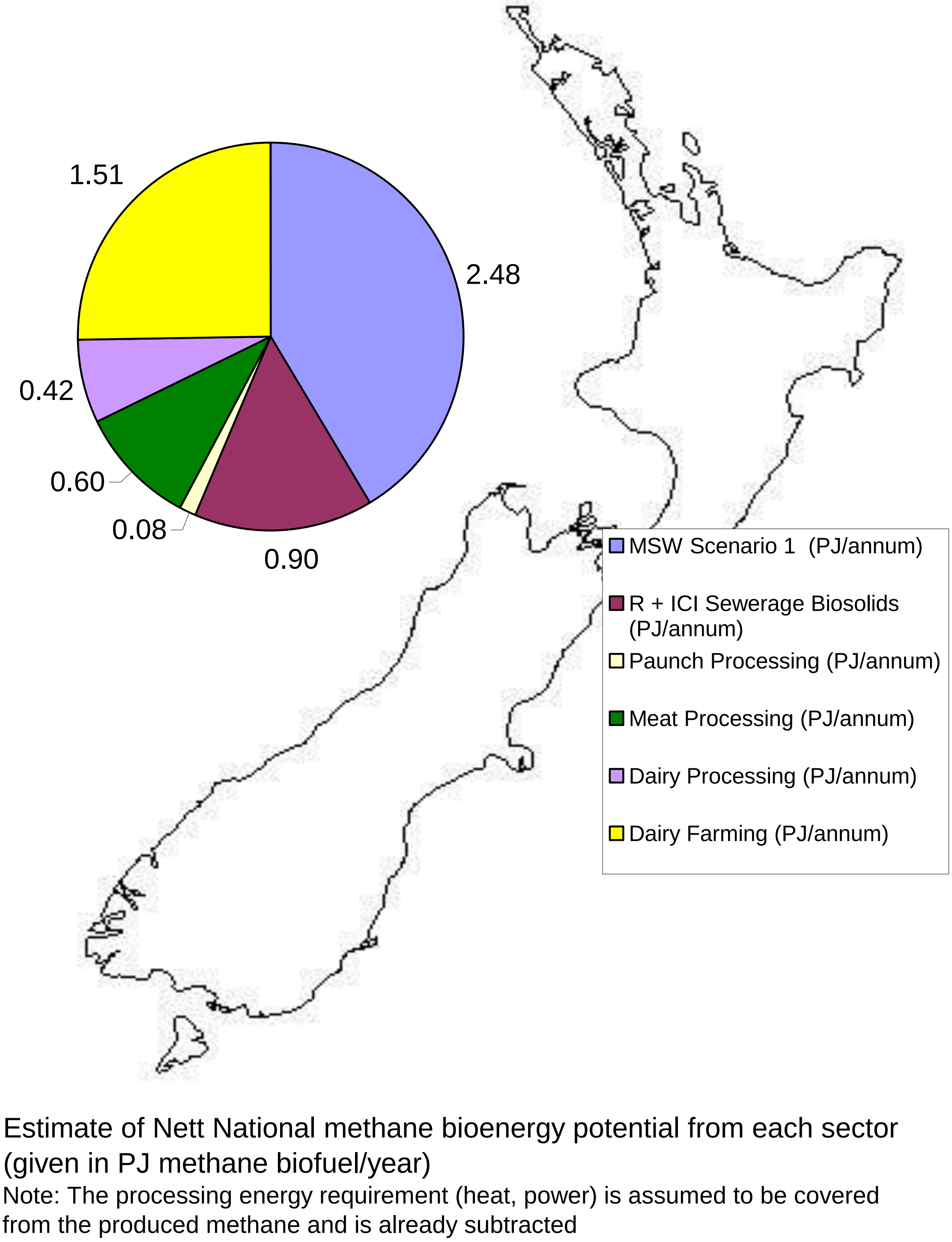
The biofuel recovery through combined digestion (co-digestion) of selected trade waste materials, septage, grease trap waste, animal manures, cheese whey, industrial flotation foams with municipal primary sludge (PS) and waste activated sludge (WAS) or animal manures is a well proven and commercially beneficial method. The Danish government started a respective national initiative in 1988 (Al Seadi, 2000). This leading examples has been widely followed throughout Europe and North America with combined digestion of industrial waste, manure and municipal biosolids in a large number of large regional municipal, agricultural and industrial digester facilities (Al Seadi, 2000).

The biogas from the co-digestion can be used for co-generation of power and heat on site to cover WWTP power requirements (aeration, pumps, blowers, lighting) with the heat mainly used for digester heating and other heat users on the WWTP site. Surplus power can be imported into the electricity grid. Or alternatively, biogas can be used for the digester heating and surplus biogas can be exported to adjacent large commercial energy users as additional fuel for boiler operation.

CPG New Zealand has successfully designed, constructed and commissioned a number of well mixed (10-20 $W/m^3_{digester}$ mixing energy) waste co-digestion facilities with high volatile solids (VS) loading rates (4 - 5 kg VS $m^{-3}_{digester}.day^{-1}$), high biogas productivities (2 - 3 $m^3_{biogas}.\ m^{-3}_{digester}.day^{-1}$) and short hydraulic residence times (10-15 days). These systems use improved gas recirculation mixing, mechanical mixing (EarthPower Digester Facility, Sydney) or hydraulic venturi mixing (Chapel Street Digesters, Tauranga) and have the capability to process approximately 3 times the organic load of comparable municipal sludge digesters. However, the construction of new co-digestion facilities is quite capital intensive and the economic operation relies thus on collection of high gate fees for the waste materials (Thiele, 2000; Hearn and Thiele, 2004).

A previous national survey of the current NZ resource potential for biofuel (biogas) recovery through co-digestion plants identified a total national biogas production potential of approximately 3 PJ biogas from co-digestion of industrial and municipal waste materials (Thiele, 2007). The survey (Figure 1) concluded that the generation of electricity with re-use of generator waste heat to satisfy the digestion process energy requirements was a preferred biogas end use in this case. 3 PJ of biogas used for generation is equivalent to about 7 % of the current national natural gas consumption used for electricity production (Dang et al., 2007).

*Figure 1***:** NZ National usable End Energy Potential and regional biofuel distribution from co-digestion of various industrial, agricultural and municipal waste materials (Thiele, 2007). Values given for each sector are in PJ/annum. 1 PJ = 277.8 GWh. The base year is 2006. The energy required for digester operation is subtracted from the presented values. **R+ICI Sewerage Biosolids:** Residential plus Industrial, Commercial, Institutional wastewater biosolids; **Meat Processing:** Flotation foams from meat processing plant effluent treatment; **Dairy Processing:** Flotation foams from dairy processing plant effluent treatment.



A full digester plant life cycle analysis (including environmental costs & energy usage in construction, operation and energy costs for digester sludge dewatering and transport) demonstrated an energy output /energy input in ratio in the order of 7-8 units bioenergy output/ 1 unit of total energy input (Thiele, 2007).

About 10 large municipal wastewater treatment plants in New Zealand employ anaerobic digestion for the stabilization of wastewater biosolids such as primary sludge (PS) and secondary waste activated sludge (WAS). Often these municipal digesters have floating roofs, limited mixing, mesophilic operation temperatures (35-40^{o}), low organic loading rates (about 1.5 kg VS. $m^{-3}_{digester}$.day^{-1}), long hydraulic residence times (15-20 days) and low biogas productivities (about 0.7 m^{3}_{biogas}. $m^{-3}_{digester}$.day^{-1}). Practical ways to improve the throughput and biogas production from these sludge digesters are thus highly desirable, especially if acceptance of trade waste and industrial byproducts leads to the collection of additional gate fees. Due to lower capital costs for a retrofit versus a new digester plant, this approach could realize lower waste disposal fees for waste producers and thus be more cost effective and appropriate in the New Zealand context and extend the economic life of existing landfills by diverting highly putrescible waste from landfills.

Table 1: Typical electricity consumption/production potential balance for a conventional aerobic wastewater treatment plant (municipal wastewater) with sludge digestion. N/A: not applicable

Parameter	Influent	Primary Sludge (4 % solids)	Waste activated sludge (4 % solids)
Flow (m^{-3} /day).	40,000	260	110
BOD content (kg/day).	13,500	4,650	1,400
Power consumption for treatment (kwh/day).	19,500	1,400	(included in figure for primary sludge)
Power production potential from sludge digestion (kwh/day) and cogeneration from the produced biogas.	N/A	14,000	(included in figure for primary sludge)
Power shortfall (kwh/day).	- 6,900	0	(included in figure for primary sludge)
Power production potential from traditional co-digestion in the sludge digester plant (kwh/day).	N/A	28,000	(included in figure for primary sludge)
Surplus power production for entire WWTP from traditional co-digestion in the sludge digester plant (kwh/day).	7,100	N/A	(included in figure for primary sludge)

Table 1 above gives an example of the typical power use in an activated sludge based WWTP for domestic sewage and the power production from sludge digestion with and without co-digestion of industrial and trade waste materials. It shows that without co-digestion of industrial&trade waste materials there is a power shortfall of about 7000 kwh/day for treatment of a sewage flow of 40,000 m^3/day and with a co-digestion scheme in place, a daily power surplus of 7,100 kwh/day can be achieved

The Palmerston North City Council (PNCC) recently initiated the installation and operation of a 750 KW_{el} generator at its wastewater treatment plant (WWTP). It is planned to operate the generator on a mixture of natural gas, biogas from primary sludge and trade waste digestion at the WWTP and landfill gas recovered at the adjacent landfill to produce power for the WWTP services. The past methane production at the WWTP digesters was about 45 m^3/hour whereas the generator requires a fuel gas flow equivalent to approximately 180 m^3 methane/hour for operation at full capacity. In order to reduce the natural gas consumption costs for the generator operation, PNCC investigated therefore options for increasing methane production from the two anaerobic digesters at the WWTP by implementing a sludge digester upgrade program and commercial and industrial liquid trade waste material co-digestion scheme. CPG suggested that a digester cleanout plus digester mixing efficiency improvement (stage 1) followed by installation of recuperative sludge recycle (booster technology, stage 2) would boost the activity of the methane bacteria and increase the solids residence time in the digesters with the resulting3-4 fold increase of the current digester gas production if digestible trade waste feed stocks would become available on a consistent basis.

This paper presents the design strategy for co-digestion process and digester upgrade design, the costs, the advantages and this with the expected performance of a newly constructed standalone co-digestion facility (Thiele 2010b).

2 RESULTS AND DISCUSSION

2.1 CHARACTERISTICS & DISTRIBUTION OF LIQUID TRADE WASTE

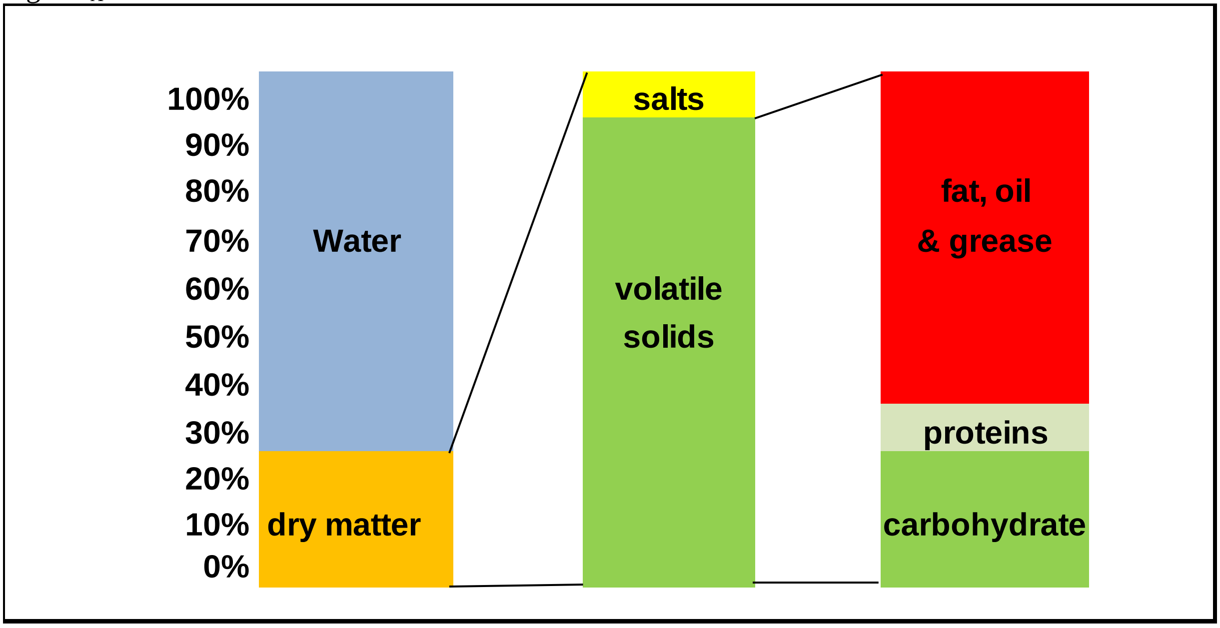
Table 2 gives examples of the typical dry matter content in a range of industrial&trade waste materials that are suitable for co-digestion schemes in municipal sludge digesters. CPG has two decades experience with the successful digestion of industrial waste and wastewater with a high content of fat oil and grease (Broughton et al. 1998; Thiele 2000, Thiele 2011) and materials with a high solids content and medium to high fat content are preferred as they carry a high content of biodegradable COD and thus produce a high methane yield

Table 2: Typical dry matter composition range for co-digestion feed stocks in New Zealand

Feedstock Material	% DS Range
Dissolved Air (DAF) float (dairy factory, meat processing)	10 – 20 % (high fat content)
Cheese whey	5 % (high sugar content)
Grease trap waste (municipal, commercial collection)	5 – 10 % (high fat content)
Municipal biosolids (primary sludge)	3-4 % (medium fat content)

Figure 2 gives an overview of the typical composition for a typical composition of a co-substrate mix designed to maximize the methane production in an anaerobic digester

Figure 2: Typical composition of a co-substrate mix designed to maximize the methane production. Please note that the methane yield (m^3 methane/kg VS degraded) for fat, oil & grease is approximately 1 m^3 methane/kg VS degraded whereas the methane yield (m^3methane/kg VS degraded) for carbohydrate is approximately 0.315 m^3methane/kg VS degraded. Please note that a protein content of 10 % of VS in a waste mixture of 30 % dry matter (TS) with 90 % VS in TS produces a residual ammonia-N concentration in the digestate of about 4,500 mg NH_X-N/L.



2.1.1 REGIONAL DISTRIBUTION OF CO-DIGESTION PLANTS

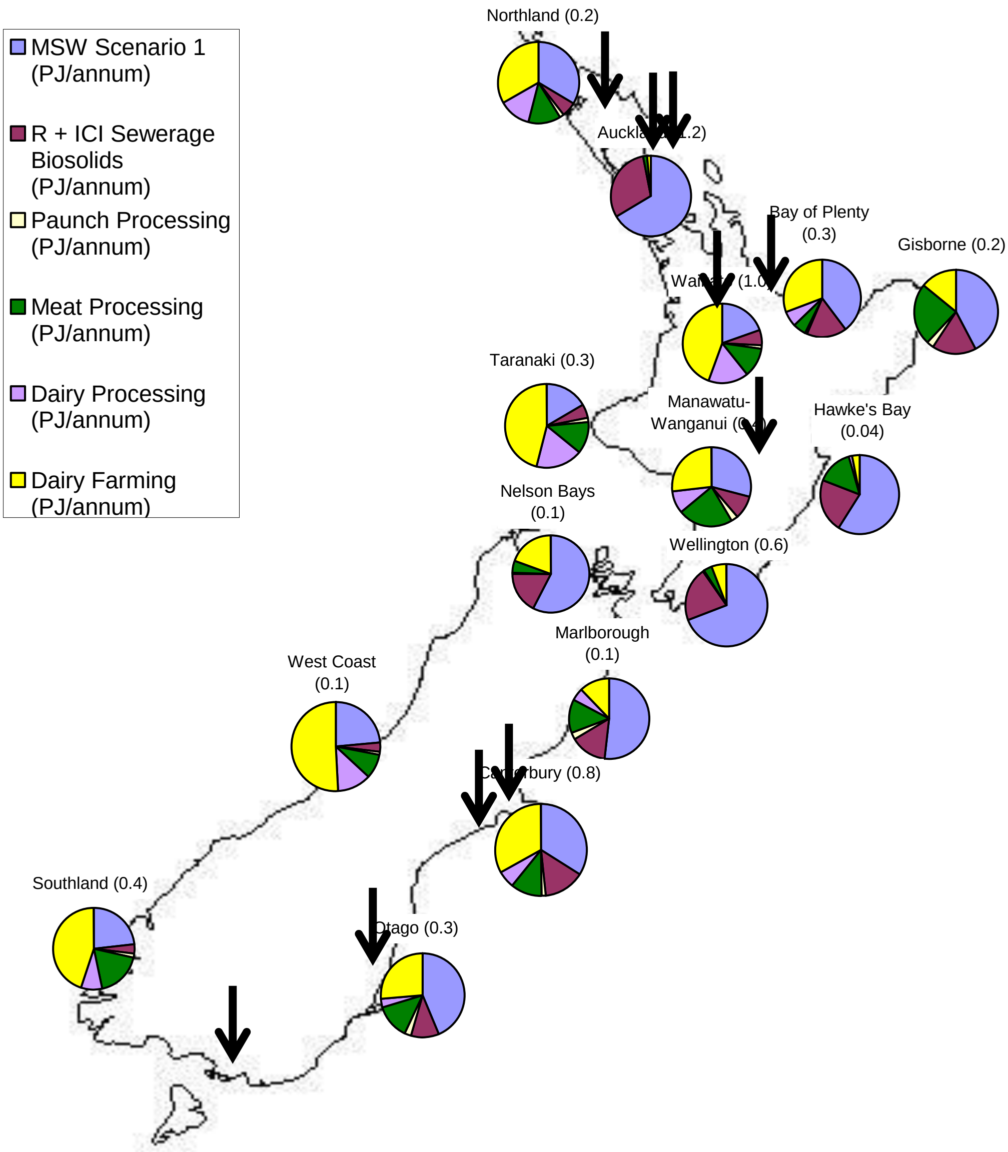
Figure 3 overleaf gives an account of the regional distribution of available industrial & trade waste materials in New Zealand (Thiele 2007). The data present the energy content of the biogas that could be produced from the anaerobic digestion of these materials. The biogas used as process energy in the anaerobic digestion is already subtracted from the values shown.

Three major points are supported by these data

(1) There is already a suitable infrastructure of sludge digester plants in New Zealand that could be used to initiate a nationwide plan to introduce the infrastructure for co-digestion of industrial/trade waste materials to produce the electricity needed for WWTP operation
(2) The ratio of sewage biosolids and industrial waste materials from the dairy an meat processing industries in New Zealand is suitable to at least double the biogas production at each plant by importing industrial/trade waste materials fro co-digestion and power generation
(3) The North Island of New Zealand has the greatest concentrations of digester plants and industrial/trade waste materials that are suitable to sustain such co-digestion schemes

Figure 3: Regional distribution of suitable co-digestion feedstock materials in New Zealand. Values given in () are the PJ/annum of biogas that can be produced from the identified industrial and municipal digestible waste materials (Thiele, 2008). The biogas energy equivalent in the blue coloured sector in each region is from landfilled organic waste(MSW) that is not trade waste and thus unavailable for biogas production via co-digestion

↓ Arrows indicate the availability of major municipal anaerobic sludge digester facilities suitable for traded waste co-digestion in each region. Please note that at the moment about 10 WWTP facilities exist with about 20 % of the facilities using codigestion of industrial & trade waste to boost gas production and power generation



Regional breakdown of current Nett methane biofuel production potential from major wastes in regional areas. The process energy required for methane production (power, heat) is already subtracted.

The estimated total recoverable methane energy value for each region is given in PJ methane/yr in parenthesis

Values were calculated using MSW Scenario 1 and biosolids processing from domestic sewage + ICI sewage.

2.2 UPGRADE OF EXISTING SLUDGE DIGESTER TANKS FOR CO-DIGESTION

2.2.1 TECHNICAL CONSIDERATIONS

The technology development and validation of the PNCC type digester upgrade for co-digestion of industrial&trade waste with municipal biosolids is unusual and innovative and has been described before (Thiele 2009, Thiele 2010a). Details of upgrade implementation and performance validation have been described at previous Water New Zealand Conferences Figures 4 and 5 below therefore only summarize the key elements so advantages and disadvantages of this approach can be understood and better compared with the more traditional co-digestion plant designs (see 2.3) and the reader is referred to the previous Water NZ conference proceedings for details.

Figure 4: Installed hydraulic mixing system and recuperative thickening unit ("digester booster") as part of the upgrade to PNCC digester No 2 (D2) for co-digestion of primary sludge, grease trap waste, whey waste, Dairy DAF sludge and piggery manure.

A: New mixed liquor recirculation ring main with mixed liquor off take (arrow) and re-injection to create a horizontal and vertical rotating digester liquor movement.

B: Details of the mixed liquor recirculation pump system (about 300 m^3/h for each pump)

C: Integration of the containerized recuperative thickener with the digester No 2. The thickener capacity in the containerized facility is fully automated with polymer dosing and for a ixed liquor throughput of 600 m^3/day of digester contents. Thickened sludge is returned at about 8 % DS consistency, polymer consumption is in the order of 4-6 kg polymer/t DS.

It is critical that the implementation of industrial & trade waste co-digestion generates a commercial win:win situation for both, the WWTP operators and the waste management industry. The work described here was thus designed to minimize the technical risk for the WWTP operators and create a commercial win:win situation by selectively specifying only industrial & trade materials that fit the roughly into the general waste mix description given in *Figure 2*.

Critical waste mix characteristics were that the waste material had to be transportable by tanker truck and unloaded by the truck drivers via pumping into the closed, vented tanks of the waste reception area. Further, the waste material must be free of any materials that are inhibitory or toxic to the anaerobic digestion process.. In return, the capital expenditure for the upgrade can be reduced and lower gate fees offered to the contributing industrial&trade waste generators (waste management industry).

Further elements in the process configuration below (*Figure 5*) are the separation of primary sludge treatment (digester 1) from the treatment of waste with a high content of fat, oil and grease (FOG) into different digester tanks. FOG has a very high COD content and thus very methane production potential. It would be preferred but FOG is also known to produce soaps in the process of fat digestion that are inhibitory to methane bacteria. Separating the fat containing waste materials from the primary sludge treatment and only transferring the surplus digester 1 bacterial sludge to the fat waste digester (digester 2, *Figure 5*) is a unique feature of the technology described. All other co-digestion systems described to date combine high fat content and low fat content waste. Digester 1 has then a virtual n+1 redundancy because in case of a toxification by accidental discharge of bacteriotoxic chemicals into the primary sludge stream, diversion of the primary sludge into digester 2 is always an option because the thickener operation allows the digester to be operated at HRT values close to 20 days.

It is unlikely that piggery effluent or cheese whey will have significant bacteriotoxic constituents (except a very rare accidental antibiotic discharge in piggeries from disease treated animal), so combining these two waste material types with the primary sludge treatment is also a reasonable robust process configuration from a microbiological point of view..

Figure 5: Outline of the process steps included in the fully integrated co-digestion plant. At present the recuperative thickening **5** is connected to digester 2 with the option to connect the "booster" facility to digester 1 in the future. Surplus thickened sludge **6** is an optional separate stream, currently the surplus sludge is removed as thickened mixed liquor from digester 2 with the treated effluent stream

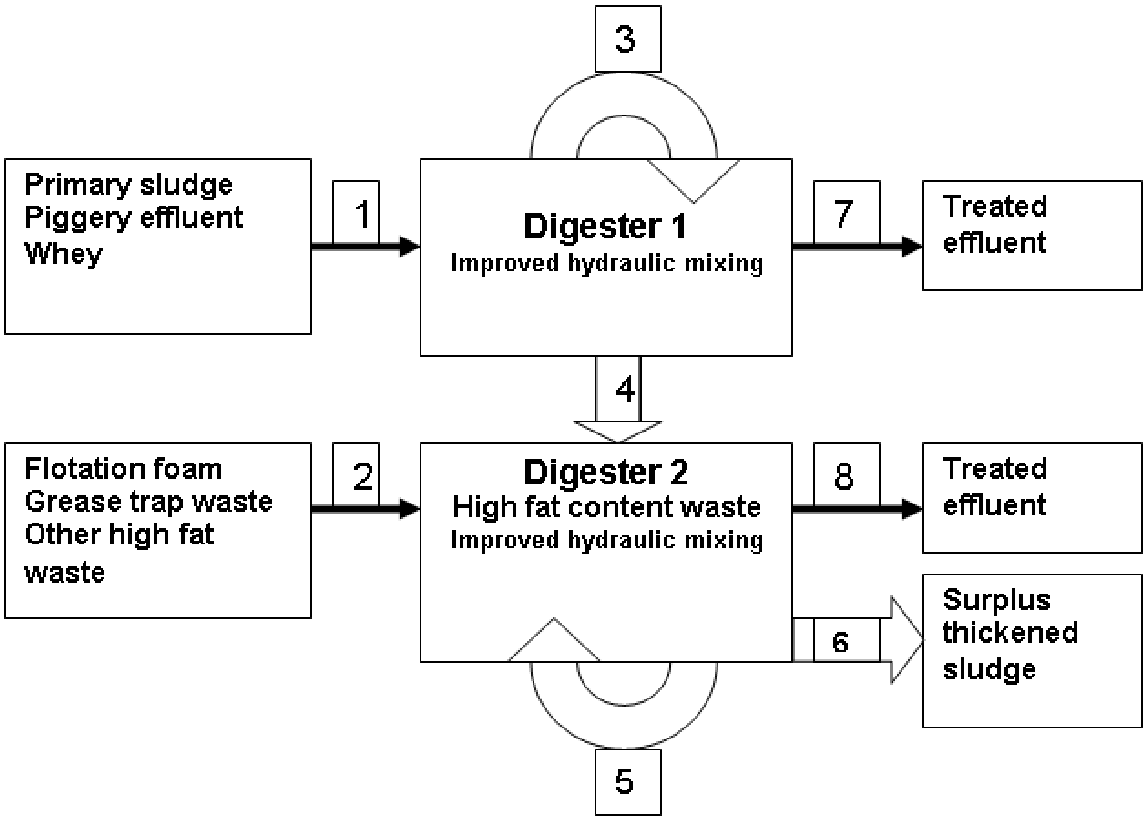


Table 3: Typical anaerobic digester sludge metabolic activity from the PNCC co-digestion facility measured with CPG's anaerobic sludge activity test at 35°C and under obligate anaerobic conditions at the CPG process testing laboratory. The tests are performed with 2,000 mg/L ethanol COD as a standard testing condition.

	2008 prior to the upgrade	**2010 after completion of mixing system upgrade**	**2012 after more than 12 months feeding of dairy factory DAF sludge with high fat content**
Anaerobic sludge activity (kg CH_4-COD.kg $_{VSS}^{-1}$ .day^{-1})	0.07	0.14	0.15

2.2.2 ECONOMIC CONSIDERATIONS

The projected final commercial performance for co-digestion of trade waste with an average biogas yield of 45 - 70 m^3 methane (STP)/t wet trade waste material loaded is shown in *Table 4*. . For comparison, thickened dairy factory DAF sludge with 20 % solids content and 50 % fat, oil & grease in dry solids would have an expected methane yield of 140 m^3 methane (STP)/t wet trade waste material loaded. The value of the additional biogas from the trade waste co-digestion used in the calculations was set at 2.6 c/kwh. Power generation from this biogas with a typical reciprocal engine at a size of 700 kW$_{el}$ would be possible for about 12 c/kwh (including CAPEX, OPEX and biogas purchase).

Table 4: projected final commercial performance for co-digestion of trade waste with an average biogas yield of 45 - 70 m^3 methane (STP)/t wet trade waste material loaded

Upgrade stage	**Digester tank**	**Capital cost estimates (NZ$)**	**Additional Biogas (kwh/day)**	**Additional biogas (NZ$/ annum)**	**Waste processed (t wet /annum)**	**Gate fee income (NZ$/ annum)**	**Polymer costs (NZ$/ annum)**
Stage 1	**Dig 1**	**220,000**	**0**	**0**	**0**	**0**	**0**
	Dig 2 + waste reception	**220,000 +200,000**	**9,000**	**85,000**	**7,300**	**220,000**	**0**
Subtotal Stage 1:		**640,000**	**9,000**	**85,000**	**7,300**	**220,000**	**0**
Stage 2	**Dig 1**	**275,000**	**9,000**	**85,000**	**7,300**	**220,000**	**66,000**
	Dig 2	**275,000**	**21,000**	**200,000**	**11,000**	**330,000**	**99,000**
Total upgrade		**1,190,000**	**30,000**	**285,000**	**18,300**	**550,000**	**(165,000)**

EBITDA: Earnings before Interest, Tax, Depreciation, Amortization

Please note that only the income from sales of the added biogas production from the treated trade waste has been accounted in the calculation in Table 4 , the pre-existing biogas production from primary sludge treatment (about 11,000 kwh/day) was valued as a bonus for the treatment plant operation. This gas can either be used for additional digester heating in the existing biogas boiler or sold for additional power generation by the genset operation @ about 2.6 c/kwh biogas (286 $/day). Operating costs for the genset are covered outside the cogeneration facility.

Table 4 demonstrates that the digester tank upgrade with improved mixing and recuperative thickening for 2 digester tanks in the size range between 1,300 and 2,000 m^3 working volume each is possible within a budget of 600,000 $/tank (1,19 million for 2 tanks). The EBITDA is $ 670,000/annum and the simple payback period for this upgrade is in the order of less than 2 years (excluding interest, tax, depreciation) when average gate fees of 30 $/t wet waste and operating costs for polymer purchase are included.

When the average gate fees are only 20 $/t wet waste, the simple payback period for the digester upgrade increases slightly from less than 2 years to 2.5 years.

2.2.3 ENVIRONMENTAL CONSIDERATIONS

N and P nutrients released during co-digestion into the treated effluent (streams $\boxed{7}$ and $\boxed{8}$ in *Figure 5*) are expected to be around 1500 ppm additional TKN (60-70 %NH_3-N) and less than 100 ppm additional TP above the base levels from primary sludge digestion because the selected trade waste material has typically a high fat content and low protein content.

With a typical treated effluent flow from the co-digestion plant of less than 200 m^3/day in the PNCC example (*Figure 5*) and a dry weather raw sewage flow of 26,000 m^3/day into the inlet works of the wastewater treatment plant , the added N load from co-digestion of industrial & trade waste is in the order or 300 kg N/day and 20 kg TP/day. As the treated effluent from the co-digestion plant will be returned to the WWTP inlet, it is unlikely that this will have a measurable environmental effect in the PNCC application of the technology described in this paper as this added nutrient load is diluted into a very large flow.

It is also well established that N and P in anaerobic digesters can be sequestered as magnesium Ammonium Phosphate (MAP, struvite) which will be captured with the surplus thickened sludge (stream $\boxed{6}$ *Figure 5*).

Therefore we conclude that actual effluent P impact brought in with high P content industrial and trade waste (piggery manure) is largely confined to the thickened surplus sludge stream which is separately caltured (Figure 5) and can be tankered off site and re-used (e.g. fertilizer application in forestry etc.) if it meets the appropriate biosolids guideline criteria.

2.2.4 CHALLENGES FACED/LESSONS LEARNT

Technical challenges: There were only minor technical challenges in this digester upgrade project. The digester upgrade proceeded smoothly without major technical complications. Installation and commissioning of mixing system upgrades was achieved within a 2-3 month period for each digester tank. Operating the WWTP digester on primary sludge with only one digester tank operating for 2-3 months proved to be without technical risk. The operation of the upgraded mixing system was simple with practically no added daily work for the WWTP operators.

The operation of the waste reception facility for liquid waste from commercial and industrial sources was effectively delegated to the liquid waste truck drivers during the unloading from the trucks into the storage tanks. The transfer of the daily delivered liquid waste from the storage tanks into the digesters was through actuating of dedicated pumps without significant time demand on the WWTP operators. Thus operating of a co-digestion digester for liquid trade waste can be easily integrated into the normal WWTP working routines.

A main technical challenge was the rapid onset of the increased biogas production when the trade waste material was delivered in an irregular pattern (Figure 9). This led to the “flaring” of substantial amounts of the produced biogas that otherwise would have been available for genset operation and electricity production. The management of a more regular trade waste supply and adjustment for seasonal effects needs thus to be a focus for the management of a trade waste co-digestion facility in a municipal digester plant.

The recuperative thickener installation and commissioning has only been completed in April 2012. Therefore it is too early to report in detail about this operation. To date there have been no significant problems with this part of the operation and the routine recuperative thickening of anaerobic digester sludge with drum thickeners is practiced elsewhere without technical complications.

Thus, a digester upgrade to co-digestion of liquid trade waste is technically manageable within the capabilities of the normal operation of a municipal sludge digester plant.

Commercial challenges: A major commercial challenge in the start-up of this co-digestion facility was the need to minimize the use of natural gas for genset operation in the start-up period. As natural gas prices are typically increasing over time, the future costs of natural gas use in the 1st year of co-digestion facility operation need to be established/estimated before initiation of the digester plant upgrade project.

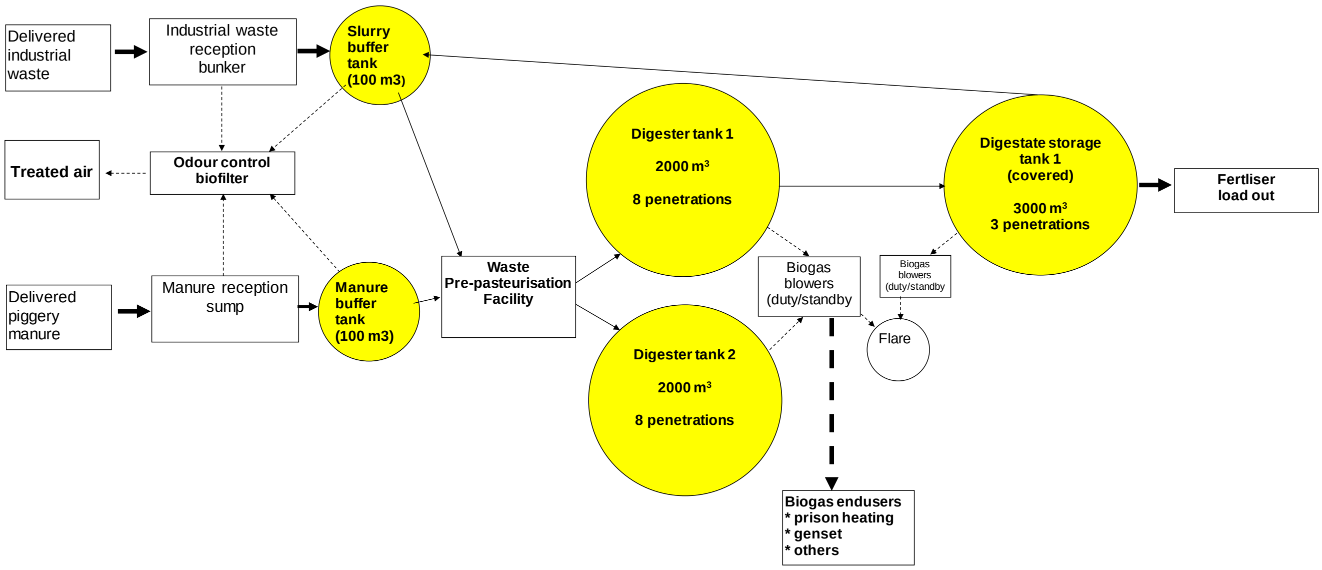
Achievement of a minimum natural gas use depends specifically on the choice of the genset size and the matching establishment of firm longterm contracts for the supply of suitable trade waste materials to match that chosen genset module size.

While the anaerobic digesters with recuperative thickening can receive a wide range of different trade waste materials and in irregular patterns, it is especially important that the daily load of digestible matter (daily load of degradable COD; Figure 9). is balanced within a +/- 20 % bandwidth (trade waste biodegradable COD, kg COD/day) if a +/- 10 % variability of the daily biogas production is the commercial target. It is expected that the variability in volume and consistency of the daily trade waste deliveries will decrease within the 1st year of co-digestion operation as new waste material types and suppliers are coming on stream (law of averages).

2.3 COMPARISION WITH THE CONSTRUCTION OF NEW CO-DIGESTION PLANTS

In order to benchmark the advantages and disadvantages of the WWTP digester upgrade based co-digestion facility design concept shown, cost estimates were prepared for New Zealand conditions for the alternative, a new "greenfields" co-digestion plant for piggery manure and industrial&trade waste materials were prepared (Thiele, 2010b). A concept level site layout diagram is shown in Figure 6.

*Figure 6:*Concept level site layout for the "greenfield" co-digestion facility



The greenfields plant was sized for treatment of a total of 100 t/d of piggery manure and selected industrial waste materials with a high content of fat oil and grease at 35 ^{o}C. The solids residence time was 30 days and practically the same as in the PNCC example with operating recuperative thickener (Thiele 2010a). The volatile solids content of the feed stock mix (piggery manure and industrial&trade waste) was 12 % VS in wet weight and the total solids content of the feed stock approximately 13.5 TS % in wet weight.

The expected methane content in the biogas was 60 % methane and the methane yield from the feedstock mix was approximately 43 m^3 methane/t wet matter and thus at the lower end of the range used form the assessment of the economics for the PNCC digester upgrade case.

2.3.1 ADVANTAGES/DISADVANTAGES OF THE TWO CONCEPTS

The main technical differences between the greenfield new digester facility construction (Thiele 2010b, *Figure 6)* compared to the WWTP digester upgrade based co-digestion plant described in section 2.2 were

(1) The industrial waste materials were slurried up with a chopper pump using digestate as the medium
(2) The industrial waste materials had to be loaded off the truck into a bunker in a closed building
(3) The manure was unloaded from a tanker into a covered manure reception sump
(4) The building and sumps, tanks were vented to an odour control biofilter
(5) The combined mixture of manure and industrial waste slurry was pasteurized prior to digestion to be able to re-use the digestate in the form of a class Aa organic fertilizer
(6) The two parallel mesophilic digester trains were receiving the same feedstock
(7) The biogas was sold as biogas for heating purposes and 20 % of the gross biogas had thus to be used for pasteurization and digester heating (only 80 % of gross biogas could be sold.

Digester tank volume comparison: The total required digester tank working volume (4,000 m^3) required in the traditional co-digestion facility design for an hourly methane production rate of 177 m^3/hour was 1.5 times the working volume of the WWTP plant upgrade based co-digestion facility (section 2.2). This shows the competitive advantage of the process design and technology used for the WWTP digester upgrade based co-digestion facility design approach in the PNCC example where bacterial cells are retained and returned (booster approach) thus reducing the required tank volume for a similar duty.

Capital costs comparison: The capital costs for the traditional co-digestion facility design were estimated between 5-6 million NZ $ excluding the costs of land and excluding the costs for the biogas endues (genset) but allowing for a biogas boiler for digester heating (Thiele, 2010b). Thus the WWTP digester upgrade based approach for high fat content industrial&trade waste is 5 times as capital cost effective from the construction cost approach than a new greenfield based new digester construction approach to create new digester capacity.

Biogas end use comparison: Both, the WWTP digester tank upgrade approach and the greenfield new digester facility approach assume that the biogas can be sold to a third party. However, as the greenfield facility can be constructed close to biogas endusers that offers the highest price for the biogas, the facility in the example here was sited close to an enduser that could replace diesel fuel used for heating with the biogas (Correctional Facility, Christchurch, Thiele 2010b). The flexibility of siting a new facility close to the highest value biogas enduser is a strength of the greenfield new digester facility approach. The value of biogas used (when substituting diesel fuel used for heating) was 15 c/kwh biogas whereas the market value for biogas use as genset fuel is estimated at 2.6 c/kwh biogas. Only 80 % biogas is available for sale in the greenfield new facility approach because 20 % of the gross biogas need to be used on average for digester heating and feedstock heating throughout the year. Pasteurization is not an additional heat load as the waste slurry is concentrated and the latent heat in the pasteurized waste mix is recovered for heating up the fresh feedstock (countercurrent heat exchange).

Operating costs and EBITDA comparison: The operating costs for the greenfield co-digestion facility were estimated as 605,000 $/annum including 275,000 $ for payment to the pig farmers for the nutrient content in the pig slurry (thiele, 2010b). The EBITDA for the greenfield facility is 1,377,407 $/annum compared with EBITDA for the WWTP digester upgrade strategy with an EBITDA of $ 670,000/annum. The initial fertilizer value payments to the pig farmers will then be recovered with a premium of 38 % when the digestate is sold back to other farmers based on the fair nutrient content value.

The payback period for the new greenfields facility in a scenario of current diesel fuel prices is 3.7 years if all biogas can be sold at diesel fuel prices (Table 4). Thisresult needs to be compared with a simple payback period of 2 years for the WWTP digester upgrade facility even when biogas is only sold at 2.6 c/kwh . If all surplus biogas from the greenfields facility is sold at 2.6 c/kwh as fuel for power generation, the payback period increases to 8 years.

Thus the new construction of greenfields codigestion facilities is dependent on the opportunity to site the facility close to biogas endusers that allow to achieve the highest market price for the biogas. Preferential siting dictated by the biogas enduse is also likely to interfere with the logistics to achieve lowest cost waste transport from waste generators to the central co-digestion facility (Thiele, 2010b). Each site selection will thus be an optimization between these two overarching economic constraints that are controlled by geographic constraints.

It is thus expected that the simple and cost effective biogas enduse through on site power generation for the wastewater operation and feeding of surplus power into the electricity grid will dominate the site selection for industrial&trade waste co-digestion plants of piggery manure and trade/industrial waste with an average biogas yield of 43 m^3 methane (STP)/t wet trade waste.

Table 5: Rough order estimate for operating income & expenditure for with an uncertainty of +/- 30 % (Thiele 2010b).

Item	**NZ$/annum**
Operating expenditure	
Labour	
Digester plant operator (1.5 position), incl overheads	90,000
Waste Transport costs	
Piggery manure (piggery 1M, 3R, 4T and 5C; 32,000 t/annum)	108,956
Industrial waste (5060 t/annum)	15,590
Payment to nutrient content of delivered manure (122.2 t N/annum, 1.82 t P/annum, 43 t K/annum)	275,604
Energy	
Electricity use: 500,000 kwh/annum @ 0.11 $/kwh	55,000
Insurance, repair and maintenance	50,000
Digestate carting costs to fertilizer application	By others
Total operating expenditure	**605,150**
Biogas sales as heating fuel (gross production: 19 million kwh/annum) 6 million kwh/annum @ 0.15 $/kwh diesel fuel (current 2012 value)	
Gate fees for industrial waste (average of 80 $/t)	900,000
Fertiliser value of digestate	358,084
Payment received for waste transport services	379,927
Biogas sales to genset operator @ 2.6 c/kwh gas	124,546
	220,000
Total operating income	
	1,982,557
EBITDA	
Simple payback period: 3.7 years	**1,377,407**

EBITDA: Earnings before Interest, Tax, Depreciation, Amortisation

Flexibility to accept waste with higher nutrient content: An important advantage of siting new digester facilities is that they are insensitive to the N,P nutrient burden from the incoming waste materials as no discharge to ri8ver is intended. Thus industrial & trade waste materials that are too N&P rich for treatment in a municipal digester plant should be preferentially treated in standalone co-digestion plants that are separate from municipal WWTP’s.

3 CONCLUSIONS

In conclusion, this paper has demonstrated that the creation of new co-digestion digester capacity for industrial/trade waste through the upgrade of existing municipal sludge digester tanks with improved mixing and sludge thickening is a technically sound, proven and cost effective approach. Under today's economic conditions with a biogas value of 2.6 c/kwh biogas, the digester upgrade approach achieves payback periods of less than 2 years including the costs for a new waste reception facility for the liquid waste. This payback is 4 times faster than the payback period for equivalent biogas production from co-digestion of industrial/trade waste in newly constructed greenfield co-digestion facilities (8 years). Even if newly constructed facilities would be sited next to biogas endusers paying premium prices of 15 c/kwh biogas for diesel fuel substitution with the biogas, co-digestion of industrial/trade waste in newly constructed greenfield co-digestion facilities would have payback periods between 3.7 and 4 years.

Co-digestion of industrial/trade waste in dedicated facilities outside of the WWTP is a clear advantage over co-digestion inside a WWTP infrastructure in cases where the industrial/trade waste feed materials are high in N and P content and where the digestate is taken up by agriculture as fertilizer. The contamination of the fertiliser through sewage derived metals is then avoided, important fertilizer manufacturing energy savings are achieved through the digestate re-use and the additional income from fertilizer sales can compensate for some of the additional capital costs for a new greenfields plant.

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