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Forest Research Institute (SCION)

Bioenergy Options Project
PROJ-12011-ORI-FRIO

Bioenergy Resource Assessment
Municipal Biosolids and Effluent
and
Dairy Factory, Meat Processing
and Wool Processing Waste

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ABBREVIATIONS:

BOD	Biochemical Oxygen Demand
CAFO	Centralised Animal Feeding Operation
CHP	Combined Heat and Power
COD	Chemical Oxygen Demand
R + ICI	Residential + Institutional, commercial, industrial
TK	Total Potassium
R&D	Research and Development
RD&D	Research, Development & Demonstration
TKN	Total Kjeldahl N
TN	Total Nitrogen
TP	Total Phosphorus
TS	Total solids
TSS	Total suspended solids
VS	Volatile solids
VSS	Volatile suspended solids

1.0 BACKGROUND AND BRIEF

Anaerobic digestion (AD) is a mature technology with a wide range of different applications, system designs, reactor technologies and biofuel end use options which are practiced globally since many years, especially in Europe, Asia and The Americas. The International Energy Agency (IEA) has recognised the importance of this technology for the supply of biofuel for production of power and transport fuel and has produced excellent general information material about the technology characteristics and its applications (25). Research and development over the past 30 years have produced substantial progress in the understanding of the technology on the engineering, biotechnological and now even the molecular level. The International Water Association (IWA) holds regular global conference events on these technology topics. The reader is referred to the proceedings of recent conferences for an update on the latest developments in this technology (26, 27, 31).

Waste Solutions Ltd (WSL) was previously engaged by the Energy Efficiency and Conservation Authority (EECA) to conduct a nationwide study on the technical potential, technology pathways and expected range of production costs to produce transport fuel grade ethanol from urban putrescible waste, agricultural residues and agro-industrial processing waste in New Zealand (22). As part of the initial screening of the municipal and industrial waste resource in NZ, the study identified manure from livestock operations, sewage biosolids and effluent/flotation foams from NZ meat works as resources for which bioethanol production technology does not exist due to fundamental scientific and technological reasons (22). However, the study pointed out that technology for production of biogas from waste by anaerobic digestion, subsequent syngas production from biogas and syngas conversion to biomethanol does exist that could be potentially valuable for NZ to complement the bioethanol biofuel production with other alcohol fuels (28, 29,30). Syngas from biogas could also be used as supplement for production of Fischer Tropsch synthesis based other biofuels such as biomass to liquid (BTL) biodiesel.

In particular, the previous study (22) concluded:” Significant additional opportunities exist to produce bioalcohol from all those putrescible waste resources that appear unsuitable for ethanol fermentation with current technology (low carbohydrate, high protein, high lipid, high water content; effluent treatment flotation foams, paunch and feedlot manure) or are too contaminated with plastic, glass and metal (urban food residuals). Proven technologies exist to convert those materials to biogas and then to biomethanol. Biomethanol is useful in the manufacture of biodiesel transport fuel from waste fat and tallow. Methanol costs in New Zealand have recently increased due to the gradual depletion of our low cost natural gas resources. We estimate that another putrescible waste feedstock pool suitable for production of 1.5 - 2.5 PJ of renewable transport fuel is currently not utilised.”

It is thus a major objective of this report to start the process to follow the previous research and to demonstrate the resource potential, its distribution, potential constraints and technology pathways for this additional putrescible waste to produce biofuel for future transport and energy production options in New Zealand.

Waste Solutions Ltd is active in specialist advice, research & development, design, project management and project commissioning for anaerobic digester facilities in Australasia for over 30 years. In the last seven years, more than 17 large anaerobic digester (AD) facility design projects have been successfully completed by WSL for agro-industrial corporate clients, animal feedlots and local authorities with a realised overall renewable energy production of more than 4.2 GWh/day of biogas production capacity. In addition, WSL has post-construction operational experience with most of these plants. This places WSL in a unique position as the most experienced company in New Zealand in AD design, construction and operation.

Most anaerobic digester facilities use the biogas for heat and power production. Biogas purification to genset quality standard for heat and power is implemented where necessary. Typically very little biogas is actually flared and biogas use as a boiler fuel is a proven alternative to genset use of biogas. Some recent projects are given as examples in appendix 1 to this report.

In the course of designing a large number of successful digester facility projects, WSL has gained invaluable experience that enables the company to produce cost effective tailor made site specific digestion facility design that maximises environmental and commercial performance. This invaluable experience is commercially sensitive, is a trade secret and is incorporated as inbuilt bioprocess intelligence in WSL digester facility detailed design works. Digester facility operation and design experience is not covered in this report.

The EnergyScape Project is a collaborative research project between CRL Energy, IRL, Scion, GNS, NIWA and associates about the indigenous energy options for New Zealand and to identify priority energy research areas that allow the realisation of some or all of these options. The work on Bioenergy Options within the EnergyScape Project is led by NZ Forest Research Institute (SCION)

WSL was subcontracted by SCION to contribute to the situation analysis phase for the EnergyScape Project with a factual summary of the resource volume, location, and distribution of municipal solid waste, municipal biosolids & effluent, and dairy factory, meat processing & wool processing waste in the context of using these residues for the production of biogas through anaerobic digestion. This factual summary is provided in sections 2,3 and 4 of this report.

In the course of the work for this report it was consistently found that processing industries in NZ consider their site specific information about volume and composition and strength of effluent and solid waste as commercially sensitive and thus are normally not prepared to release that information. Therefore the research team had to adopt for this study a “top down” approach using publically available information about the regional distribution for processing capacities for specific industries (obtained from industry bodies and Statistics NZ). General industry experience about waste material volume and composition and the typical specific waste production ratios (unit waste / unit processed) from the technical literature and case studies were used to estimate the total resource volume, composition, bioenergy value and regional distribution. The yield of usable enduser bioenergy was then determined based on relevant and applicable industry experience from past realised anaerobic digester facility projects and case studies after subtracting the “parasitic” energy use (heat, power) from the produced biofuel potential. Therefore the work determined the GROSS bioenergy potential as well as the NETT bioenergy potential for each industry sector and region studied.

Based on the extensive experience overseas with the anaerobic digestion (AD) of processing waste on full scale (25, 31) it has been found that co-digestion of processing waste (sludge, slurries) with animal manure (cattle, pigs) as co-substrate is advantageous and generates significant synergy. To provide the basis for the adoption of an anaerobic digestion component in the future NZ indigenous energy pathway, the research team thus added to the study brief an assessment of the regional distribution, volume and bioenergy production from animal manure (cattle, pigs) to provide a suitable technology context. Only manure sources from dairy sheds and piggeries with flush system were considered as they provide an easily recoverable co-substrate.

The anaerobic digestion technology brings with it some unique attributes such as targeted greenhouse gas (GHG, CH_4, N_2O) emission abatement opportunities that generate tradable carbon emission reduction (CER) certificates, improved management of primary production related water pollution, improved farming ”run-off management (“dirty dairying” discussion), rural employment opportunities. Drivers for the technology are thus not only energy policy but also environmental and market differentiation opportunities for our exports (clean and green). All these carry significant environmental, social and economic values that would justify a more detailed discussion than the specific brief for this energy production focussed “technical summary report” can provide.

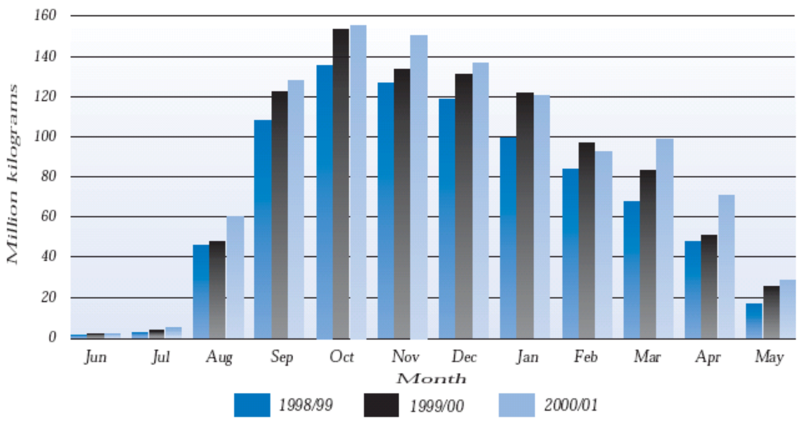
2.0 RESULTS AND FINDINGS

2.1 Dairy Farming Waste Resource

Dairy farming waste biofuel resource calculation basis (2006)

- The total annual number of dairy cattle is the annual average of the total dairy cattle census number in the time window 2004 to 2006 (14).
- "Herds >400 hd" are defined as the number of cattle on a farm with a herd size greater than 400 cattle. It is assumed that the fraction of total NZ cattle with herd sizes greater than 400 is the same as in 2002 (based of MAF 2002 Dairy Cattle by Herd Size Groups and Region (15)). This is a conservative assumption because the relative proportion of large dairy farms is likely to increase in future.
- Based on results from current farm scale anaerobic digestion trials by WSL in Canterbury, it is assumed that dairy farms with less than 400 hd would produce insufficient daily manure to utilise current commercial digester technology (> 50 m^3 tank digester, > 5 KWel genset).
- It is assumed that the relative seasonal trend in milk solids production (graph 2.1 below) remains typical for NZ conditions. It is assumed that the cows are milked 30 days per month between September and March and 15 days per month in August, April and March (based on the graph 2.1 below)

Graph 2.1 **Seasonal trend in total milksolids processed**



- The usable amount of manure volatile solids (VS) captured in the yard waste of a milking shed is fixed as 0.25 kg-VS per head of cattle per day milked (this capture was actually measured by WSL for a large rotary milking shed; for comparison see data in table 1 obtained from Dr Rupert Craggs, NIWA with an average of 0.4 kg-VS per head of cattle per day milked with a high of 0.5 and a low of 0.2. The 0.25 kg-VS per head of cattle per day milked value for the realistic manure VS capture used here is thus conservative.
- It was assumed that 45% of the VS in the dairy shed effluent is degraded to biogas in a heated, mixed digester with appropriate hydraulic residence times and that 1.05 m^3 biogas is produced for every kg of VS degraded. A value of 22 MJ/m^3 biogas was used as lower heating value of the captured dairy farm manure biogas.
- It was assumed that 90 % of the gross biogas is available as biofuel (PJ) because all the digester process heat requirements are satisfied by generator waste heat. "Parasitic" manure digester mixing pump electricity requirements are assumed as 10 % of the generated power. In an operating WSL designed dairy farm effluent digester the digester mixing pump electricity requirements are less than 10 %.

- For the achieved net biofuel energy value (PJ) it is assumed that the manure biogas substitutes diesel fuel or natural gas used elsewhere in NZ for transport or for stationary power generation without heat capture (no CHP).
- For the projected biofuel production in 2020 it was assumed that the dairy cattle population will grow on average by 2 % p.a.

Dairy Shed Effluent Composition						
Parameter	**Unit**	**Low**	**High**	**Typical**	**Typical Concentration**	
Volume	L/cow/d	30	70	50		
Total Solids	kg/cow/d	0.3	0.6	0.55	11000	mg/L
Volatile Solids	kg/cow/d	0.2	0.5	0.4	8000	mg/L
BOD5	kg/cow/d	0.04	0.13	0.12	2400	mg/L
TKN	g/cow/d	7	30	22	440	mg/L
TP	g/cow/d	0.5	4.5	2.5	50	mg/L
TK	g/cow/d	5.5	26	20	400	mg/L
T Sulphur	g/cow/d	1	4	3	60	mg/L

Data courtesy of Dr Rupert Craggs, NIWA

Dairy Farming Waste Biofuel Resource Assessment (2006)

Regional Council	Total Dairy Cattle	Herds > 400 hd		Total VS (tonne/yr)	Total VS destroyed (tonne/yr)	Total Biogas Production (m3/yr)	Gross Biogas Production (GJ/yr)	Net Biogas Production (PJ/yr)
		Fraction of Cattle	Number of Cattle					
North Island								
Northland Region	373,470	0.35	131,809	8,403	3,781	3,970,334	87,347	0.08
Auckland Region	128,622	0.23	29,800	1,900	855	897,632	19,748	0.02
Waikato Region	1,715,779	0.43	730,668	46,580	20,961	22,009,090	484,200	0.44
Bay of Plenty Region	317,069	0.51	161,282	10,282	4,627	4,858,116	106,879	0.10
Gisborne Region	6,561	0.34	2,225	142	64	67,021	1,474	0.00
Hawke's Bay Region	84,659	0.56	47,665	3,039	1,367	1,435,759	31,587	0.03
Taranaki Region	626,394	0.34	212,811	13,567	6,105	6,410,266	141,026	0.13
Manawatu-Wanganui Reg	394,118	0.49	192,297	12,259	5,517	5,792,346	127,432	0.11
Wellington Region	97,862	0.57	55,805	3,558	1,601	1,680,951	36,981	0.03
Total North Island	3,744,534	0.42	1,568,040	99,963	44,983	47,232,305	1,039,111	0.94
South Island								
Nelson Bays Region	68,126	0.47	32,164	2,050	923	968,840	21,314	0.02
Marlborough Region	27,739	0.41	11,321	722	325	341,010	7,502	0.01
West Coast Region	144,167	0.49	70,808	4,514	2,031	2,132,870	46,923	0.04
Canterbury Region	620,025	0.74	457,871	29,189	13,135	13,791,933	303,423	0.27
Otago Region	172,201	0.77	133,144	8,488	3,820	4,010,547	88,232	0.08
Southland Region	357,669	0.75	268,378	17,109	7,699	8,084,049	177,849	0.16
Total South Island	1,391,875	0.70	978,693	62,392	28,076	29,480,068	648,562	0.58
Total New Zealand	**5,136,408**	**0.49**	**2,527,308**	**161,116**	**72,502**	**76,127,256**	**1,674,800**	**1.5**

Dairy Farming Waste Biofuel Resource Assessment (2020)

The same general calculation basis as above was used. A national herd growth rate of 2 %/year between 2006 and 2020 was assumed.

			Herds > 400 hd						
Regional Council	**Total Dairy Cattle 2006**	**Total Dairy Cattle 2020**	**Fraction of Cattle**	**Number of Cattle**	**Total VS (tonne/ yr)**	**Total VS destroyed (tonne/yr)**	**Total Biogas Production (m3/yr)**	**Gross Biogas Production (GJ/yr)**	**Net Biogas Production (PJ/yr)**
North Island									
Northland Region	373,470	492,786	0.35	173,919	11,087	4,989	5,238,766	115,253	0.10
Auckland Region	128,622	169,714	0.23	39,321	2,507	1,128	1,184,422	26,057	0.02
Waikato Region	1,715,779	2,263,934	0.43	964,101	61,461	27,658	29,040,530	638,892	0.58
Bay of Plenty Region	317,069	418,366	0.51	212,809	13,567	6,105	6,410,206	141,025	0.13
Gisborne Region	6,561	8,657	0.34	2,936	187	84	88,438	1,946	0.00
Hawke's Bay Region	84,659	111,706	0.56	62,893	4,009	1,804	1,894,455	41,678	0.04
Taranaki Region	626,394	826,514	0.34	280,799	17,901	8,055	8,458,192	186,080	0.17
Manawatu-Wanganui Reg	394,118	520,030	0.49	253,732	16,175	7,279	7,642,884	168,143	0.15
Wellington Region	97,862	129,127	0.57	73,634	4,694	2,112	2,217,994	48,796	0.04
Total North Island	3,744,534	4,940,834	0.42	2,064,144	131,589	59,215	62,175,888	1,367,870	1.23
South Island									
Nelson Bays Region	68,126	89,891	0.47	42,440	2,706	1,217	1,278,372	28,124	0.03
Marlborough Region	27,739	36,601	0.41	14,938	952	429	449,961	9,899	0.01
West Coast Region	144,167	190,225	0.49	93,429	5,956	2,680	2,814,257	61,914	0.06
Canterbury Region	620,025	818,110	0.74	604,151	38,515	17,332	18,198,161	400,360	0.36
Otago Region	172,201	227,216	0.77	175,681	11,200	5,040	5,291,841	116,421	0.10
Southland Region	357,669	471,937	0.75	354,120	22,575	10,159	10,666,758	234,669	0.21
Total South Island	1,391,875	1,833,980	0.70	1,284,759	81,903	36,857	38,699,350	851,386	0.77
Total New Zealand	5,136,408	6,774,814	0.49	3,348,903	213,493	96,072	100,875,238	2,219,255	- 2.00

2.2 Pig Farming Waste Resource

Pig Farming Waste Biofuel Resource Assessment (2006)

Regional Council	Total Pigs	Waste water (m3/day)	Wastewater Composition					Biogas (m3/day)	Biogas (m3/yr)	Gross Biofuel Energy (GJ/yr)	Net Energy (PJ/yr)
			TS (kg/day)	VS (kg/day)	TN (kg/day)	TP (kg/day)	TK (kg/day)				
North Island											
Northland	5,574	56	1,068	881	92	30	23	416.4	151,982	3,344	0.00
Auckland	11,094	111	2,126	1,754	183	60	47	828.7	302,493	6,655	0.01
Waikato	54,830	548	10,505	8,669	905	296	230	4,095.9	1,495,012	32,890	0.03
Bay of Plenty	7,541	75	1,445	1,192	124	41	32	563.3	205,615	4,524	0.00
Gisborne	1,104	11	212	175	18	6	5	82.5	30,102	662	0.00
Hawke's Bay	6,273	63	1,202	992	104	34	26	468.6	171,042	3,763	0.00
Taranaki	17,190	172	3,294	2,718	284	93	72	1,284.1	468,708	10,312	0.01
M-watu- W-ganui	27,164	272	5,205	4,295	448	147	114	2,029.2	740,662	16,295	0.01
Wellington	15,954	160	3,057	2,522	263	86	67	1,191.8	435,007	9,570	0.01
Total North Island	146,724	1,467	28,112	23,197	2,421	792	616	10,960.6	4,000,624	88,014	0.08
South Island											
Nelson Bays	490	5	94	77	8	3	2	36.6	13,360	294	0.00
Marlborough	6,487	65	1,243	1,026	107	35	27	484.6	176,877	3,891	0.00
West Coast	304	3	58	48	5	2	1	22.7	8,289	182	0.00
Canterbury	189,179	1,892	36,247	29,909	3,121	1,022	795	14,132.1	5,158,215	113,481	0.05
Otago	15,657	157	3,000	2,475	258	85	66	1,169.6	426,909	9,392	0.00
Southland	3,028	30	580	479	50	16	13	226.2	82,562	1,816	0.00
Total South Island	215,145	2,151	41,222	34,014	3,550	1,162	904	16,071.8	5,866,213	129,057	0.06
Total New Zealand	361,869	3,619	69,334	57,211	5,971	1,954	1,520	27,032.4	9,866,836	217,070	0.14

Pig farming waste biofuel resource calculation basis (2006)

- It is assumed that the NZ North Island (NI) piggeries are organised as centralised animal feeding operations (CAFO's) using milk wash water, whey and meal as feed with animal manure recovery with flush systems (365 days/annum).
- It is assumed that biogas production is economic at any scale of pig farm CAFO mainly for reasons of odour control and odour destruction.
- It is assumed that only 50 % of the NZ South Island (SI) piggeries are organised as centralised animal feeding operations (CAFO's) using milk wash water, whey and meal as feed with animal manure recovery with flush systems (365 days/annum). Any bias in this assumption is virtually insignificant because of the small size of the bioenergy resource potential from pig farming waste.
- Only pig manure from flush operations is counted for the biofuel potential.
- It was assumed that 45 % of the VS in the flushed CAFO piggery shed effluent is degraded to biogas in a heated, mixed digester with appropriate hydraulic residence times and that 1.05 m^3 biogas is produced for every kg of VS degraded. A value of 22 MJ/m^3 biogas was used as the lower heating value of captured pig farm manure biogas.
- It was assumed that 90 % of the gross biogas is available as biofuel (PJ) because all the digester process heat requirements are satisfied by generator waste heat. Parasitic manure digester mixing pump electricity requirements are assumed as 10 % of the generated power.
- For the achieved nett biofuel energy value (PJ) it is assumed that the manure biogas substitutes diesel fuel or natural gas used elsewhere in transport or stationary power generation without heat capture (no CHP).

2.3 Dairy Factory Effluent Waste Resource

Dairy Processing wastewater biofuel resource calculation basis

- The accurate regional number of milked dairy cattle is obtained from Statistics NZ (13,14).
- The regionally processed milk is essentially the same as predicted from the proportion of regionally milked dairy cattle in the national cattle census and the total annual national milk production.
- Transport of milk from one region to milk processing plants in adjacent regions (processing capacity equalisation) cancels out on a national level. Any potential effects on the regional bioenergy potential from dairy processing wastewater are ignored for the intended "broad brush, order of magnitude" bioenergy potential assessment in this report.
- The total amount of milk processed by Fonterra plants represents approx. 95% of the total milk produced in NZ (19).
- The base amount of milk processed by Fonterra is 14,340 ML/yr (based on the Fonterra annual report 2006 (18)).
- Normally, dairy factory wastewater in NZ has COD contents in the order of 2000 – 3000 mg/L and a specific wastewater production in the range of approximately 1 - 2 L wastewater/L milk processed (20,21). In the absence of site specific wastewater composition information, estimated average values of 2500 mg COD/L and 2 L wastewater/L milk processed were used for the calculations in this report.

- The COD content (mg/L) in dairy factory wastewater is highly site and production specific (milk powder, cheese, yoghurt, lactose, casein etc.). The specific COD load (kg COD in wastewater/L milk processed) is relatively constant in the order of about 5 g effluent COD /L milk processed for dairy processing plants in NZ (20, 21). The uncertainty on the COD load value used is approximately +/-20 %.
- Aerobic treatment of dairy processing wastewater with land application or discharge of treated effluent is currently the industry norm.
- Acid cracking, Dissolved Air Floatation (DAF) prior to aerobic DAF underflow "polishing" is suitable to remove a substantial portion of the high protein, high lipid COD content in untreated dairy processing effluent in the form of DAF floatation foams (DAF sludge). That reduces aerobic treatment costs and captures high COD content DAF sludge. An overall COD capture by acid cracking/DAF treatment equivalent to 70 % of untreated dairy processing effluent COD content was assumed to be normally achieved.
- DAF sludge recovered from treatment of dairy processing wastewater is suitable as feedstock for anaerobic sludge digestion (ASD).
- 90% COD destruction efficiency is achieved with dairy processing DAF sludge in dedicated fat digestion ASD technology. The methane yield typically achieved is 0.23 kg methane/kg COD destroyed (for high lipid waste).
- "Digester parasitic energy usage" for the dairy effluent DAF sludge digester operation equates to a maximum of 25 % of the produced methane bioenergy and is used for added pumping, mixing and digester heating requirements. Surplus biogas use as boiler fuel in the dairy factory will be the primary biogas use substituting coal and natural gas. Energy credits for avoided power use through reduced aerobic effluent treatment aeration are not included in this report for reasons of simplicity and conservativeness of the bioenergy potential assessment. These aeration energy (power) credits will be site specific and can be significant.
- The residue from DAF treatment of dairy processing wastewater (DAF underflow) will be aerobically/anaerobically treated without methane capture and in the same way as the raw dairy processing effluent (i.e. nutrient removal, 20) or will applied to land. It is assumed that the ASD of DAF sludge has not removed significant amounts of N and P. It is further assumed that 30 % of raw dairy processing effluent COD left in the DAF underflow is adequate to supply adequate RBCOD (readily biodegradable COD) for biological nutrient removal (if required).
- The biosolids residue (anaerobic sludge) from ASD of DAF sludge will be used via the same route as the aerobic waste activated sludge (WAS) biosolids that otherwise would be have been generated without use of DAF and ASD treatment. The total volume of digested DAF sludge + residual aerobic WAS from the aerobic treatment of the DAF underflow is less than the equivalent sludge volume from aerobic treatment of dairy processing wastewater. There are thus added energy savings in DAF biosolids digestion which were not included here.
- The cartage of dairy DAF sludge off site and use as stock (piggeries) feed supplement is considered to be less attractive than implementation of ASD facilities on site and biogas use as boiler fuel for the following reasons: (i) The dairy DAF sludge transport costs ($ and energy) can be significant if DAF sludge dewatering is highly variable or inefficient (average TS < 25 %). This constraint does not apply to the on site ASD option. (ii) The dairy DAF sludge is usually tainted with process chemicals (acid, polyelectrolytes) that may interfere with pig health (H_2S).(iii) CAFO piggeries may have to undergo a future market repositioning due to consumer preference of "natural pork". That would cause an added uncertainty and operational risk for the dairy factory forcing the construction of "onsite" ASD facilities at this time

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Dairy Processing Waste Biofuel Resource Assessment (2006)

Regional Council	Dairy Processing Companies	Total Milked Dairy Cattle 2006	Fraction of Total Cattle	Milk Processed 2006 (ML/yr)	Waste water Produced (m3/yr)	COD produced (tonne/yr)	COD removed (tonne/yr)	Methane produced (tonne/yr)	Gross Energy Production (PJ/yr)	Nett Energy Production (PJ/yr)
North Island										
Northland Region	Maungaturoto - Fonterra	303,297	0.07	1,107	3,320,536	5,645	3,556	818	0.04	0.03
Auckland Region		95,818	0.02							
Waikato Region [a]	Hautapu - Fonterra, Lichfield - Fonterra, Morrinsville - Fonterra, Reporoa - Fonterra, Te Awamutu - Fonterra, Tirau - Fonterra, Waitoa - Fonterra, Tatua Dairy Co-operative	1,438,047	0.35	5,823	17,468,734	29,697	18,709	4,303	0.22	0.16
Bay of Plenty Region	Edgecumbe - Fonterra	235,889	0.06	861	2,582,545	4,390	2,766	636	0.03	0.02
Gisborne Region	Gisborne Milk	4,063	0.00	15	44,482	76	48	11	0.00	0.00
Hawke's Bay Region		61,725	0.01							
Taranaki Region	Eltham - Fonterra, Kapuni - Fonterra, Whareroa - Fonterra, Taranaki Milk	488,246	0.12	1,782	5,345,383	9,087	5,725	1,317	0.07	0.05
Manawatu-Wanganui	Longburn - Fonterra, Pahiatua - Fonterra,	293,896	0.07	1,376	4,128,257	7,018	4,421	1,017	0.05	0.04
Wellington Region [b]		83,178	0.02			-	-	-	-	
Total North Island		3,004,159	0.73	10,963	32,889,937	55,913	35,225	8,102	0.41	0.30
South Island										
Nelson Bays Region	Takaka - Fonterra	49,174	0.01	179	538,364	915	577	133	0.01	0.00
Marlborough Region	Tuamarina - Fonterra	19,264	0.00	70	210,905	359	226	52	0.00	0.00
West Coast Region	Westland Dairy Co-op	119,219	0.03	435	1,305,226	2,219	1,398	322	0.02	0.01
Canterbury Region	Clandeboye - Fonterra, Kaikoura - Fonterra, Plains - Fonterra	505,446	0.12	1,845	5,533,691	9,407	5,927	1,363	0.07	0.05
Otago Region	Stirling - Fonterra	144,828	0.04	529	1,585,596	2,696	1,698	391	0.02	0.01
Southland Region	Edendale - Fonterra	294,159	0.07	1,073	3,220,492	5,475	3,449	793	0.04	0.03
Total South Island		1,132,090	0.27	4,131	12,394,274	21,070	13,274	3,053	0.15	0.11
Total New Zealand		4,136,249	1.00	15,095	45,284,211	76,983	48,499	11,155	0.56	0.42

[a] includes Auckland and Hawke's Bay

[b] includes Wellington

Dairy Processing Waste Biofuel Resource Assessment (2020)

Dairy Processing Wastewater Biofuel Resource Calculation Basis

- For the projected biofuel production in 2020 it was assumed that the dairy cattle population will grow on average by 2 % p.a.

Regional Council	Total Milked Dairy Cattle 2006	Fraction of Total Cattle	Milk Processed 2006 (ML/yr)	Total Milked Dairy Cattle 2020	Milk Processed 2020 (ML/yr)	Wastewater Produced (m3/yr)	COD produced (tonne/yr)	COD destroyed (tonne/yr)	Methane produced (tonne/yr)	Gross Energy Production (PJ/yr)	Nett Energy Production (PJ/yr)
North Island											
Northland Region	303,297	0.07	1,107	400,194	1,460	4,381,377	7,448	6,704	1,542	0.08	0.06
Auckland Region	95,818	0.02		126,430			-	-	-	-	
Waikato Region [a]	1,438,047	0.35	5,823	1,897,472	7,683	23,049,625	39,184	35,266	8,111	0.41	0.30
Bay of Plenty Region	235,889	0.06	861	311,251	1,136	3,407,613	5,793	5,214	1,199	0.06	0.04
Gisborne Region	4,063	0.00	15	5,361	20	58,693	100	90	21	0.00	0.00
Hawke's Bay Region	61,725	0.01		81,445			-	-	-	-	
Taranaki Region	488,246	0.12	1,782	644,230	2,351	7,053,120	11,990	10,791	2,482	0.12	0.09
Manawatu-Wanganui	293,896	0.07	1,376	387,790	1,816	5,447,148	9,260	8,334	1,917	0.10	0.07
Wellington Region [b]	83,178	0.02		109,752			-	-	-	-	
Total North Island	3,004,159	0.73	10,963	3,963,925	14,466	43,397,576	73,776	66,398	15,272	0.76	0.57
South Island											
Nelson Bays Region	49,174	0.01	179	64,884	237	710,359	1,208	1,087	250	0.01	0.01
Marlborough Region	19,264	0.00	70	25,418	93	278,285	473	426	98	0.00	0.00
West Coast Region	119,219	0.03	435	157,307	574	1,722,218	2,928	2,635	606	0.03	0.02
Canterbury Region	505,446	0.12	1,845	666,925	2,434	7,301,588	12,413	11,171	2,569	0.13	0.10
Otago Region	144,828	0.04	529	191,097	697	2,092,161	3,557	3,201	736	0.04	0.03
Southland Region	294,159	0.07	1,073	388,137	1,416	4,249,371	7,224	6,502	1,495	0.07	0.06
Total South Island	1,132,090	0.27	4,131	1,493,768	5,451	16,353,982	27,802	25,022	5,755	0.29	0.22
Total New Zealand	4,136,249	1.00	15,095	5,457,693	19,917	59,751,557	101,578	91,420	21,027	1.05	0.79

2.4 Dairy Factory Whey Resource

The biofuel production potential from whey and whey like residues of milk processing (cheese whey, casein whey, acid whey, whey permeate (UF), other forms of whey) has been assessed before (22). Whey like residues are typically used in NZ to produce either lactose and/or alcohol (bioethanol). The wastewater from bioethanol production is treated by anaerobic digestion and the biogas us used as process energy in the alcohol production. The residue from lactose production is used as stock food supplement.

Three Fonterra plants (Anchor Ethanol) produce currently ethanol from whey. Most is used as industrial alcohol or food grade ethanol for food and drinks. A recent industry estimate suggested that about up to 1/3rd of this current whey derived ethanol volume could be utilised as biofuel in NZ. Bioethanol use as biofuel (E100) or fuel additive (E10) would need to be dehydrated with added costs and economies of scale constraints (22). The total current ethanol production is estimated as 15-17 million L ethanol/annum equating to about 0.35 PJ biofuel.

Industry expert estimates in 2005 (22-25) suggested a maximum whey ethanol biofuel potential in NZ of up to 0.7 PJ. This estimate is not longer supported by Fonterra experts in 2007. With the current and medium term international dairy food market price development expectation and assumption of continuing high global dairy product prices as underlying background the lactose recovery from whey and whey like residues from milk processing is considered to be substantially more profitable than bioethanol or biogas production from cheese whey and whey like residues.

Fonterra controls more than 95 % of the milk processing in NZ and WSL was informed for this report that the cooperative has decided to optimise its return on the available whey resource in the food market and outside the biofuel space. Any increase in milk production by the cooperative is currently also considered as highly unlikely to be used for production of biofuel from whey. This view point may change with the advent of a global transport fuel crisis or biofuel subsidies but at the moment food production takes precedence over biofuel production. Recovered lactose from whey will be mainly marketed with dry milk powder as food. The resulting whey processing residue (mother liquor, about 30 % of the whey lactose) is intended to be used as stock food.

In addition to Fonterra, various smaller cheese processing companies (5-8 companies) produce smaller amounts of whey. Their whey production is very seasonal and as such constitutes a more complex situation for anaerobic digester process design and operation. One of the largest non- Fonterra whey producer with an annual whey production of about 14,000 t per annum would create the opportunity to generate in the order of 0.01 PJ of biofuel which is less than 0.5 % of the industrial wastewater based biofuel production potential in New Zealand.

2.5 Slaughterhouse Effluent Waste Resource

Meat Processing Biofuel Resource Calculation Basis

- All slaughterhouse waste composition data were taken from van Oostrom 2001, Waste Management (11)
- The head slaughtered (cattle and sheep) specified for “super regions” Northland, Auckland, Bay of Plenty; Hawke’s Bay, Gisborne; Taranaki, Manawatu-Wanganui, Wellington; Marlborough, West Coast, Nelson Bays; Canterbury; and Otago, Southland were obtained from correspondence with Statistics NZ (13)
- The average number of head processed per slaughter facility in “super regions” were determined by dividing the total annual slaughter (cattle and sheep separated) by the number of slaughter facilities in each “super region” obtained from MeatNZ directory of meat facilities (17). Any potential bias through slight capacity differences between individual meat works in each super region was ignored and were deemed immaterial for the intended “broad brush, order of magnitude” bioenergy potential assessment in this report.
- The head processed (cattle and sheep) in a region were determined as being proportional to the number of slaughter facilities (beef, lamb and mutton). The average number processed per slaughtering facility in each region was obtained from MeatNZ directory of meat facilities (17).
- Wastewater volumes produced per processed animal were assumed as per van Oostrom 2001 (11), Waste Management (Table 1, page 636)

- cattle	1350	L/animal
- sheep and lamb	500	L/animal

- Dressed carcass weights for each type of animal used (personal communication, Albert van Oostrom (12))

- cattle	250	kg/carcass
- sheep and lamb	18	kg/carcass

- Typical pollutant loadings in the total screened or settled wastewater from slaughterhouses with minimal by-products processing done on site (kg/tonne dressed carcass) as per van Oostrom 2001 (11), Waste Management (Table 6, page 639)

	Cattle	Sheep/Lambs
- COD	27	33
- Soluble COD	16	21
- BOD$_5$	13	16
- TKN	1.8	2.2
- TP	0.18	0.19

- Consistent with experience by practitioners in the field it was assumed that the total slaughterhouse wastewater pollutant loadings produced was twice that for total screened or settled wastewater listed in Table 6 (from personal correspondence with Albert van Oostrom (12))
- Total suspended solids is estimated as 1100g/m^3 which is the mean for typical concentration ranges for pollutants in the combined screened or settled wastewater from slaughterhouses as per van Oostrom 2001 (11), Waste Management (Table 2, page 637).
- Combined screened or settled wastewater from slaughterhouses is currently typically treated in a series of anaerobic, facultative and aerobic ponds. Covering anaerobic ponds with synthetic liners for biogas capture + additional custom designed low cost, mixed in ground anaerobic digester technology (where appropriate) can achieve significant COD conversion to methane.

- It was assumed that the methane yield from anaerobic digestion with optimised systems is 0.23 kg methane per kg of COD removed (as per van Oostrom 2001 (11), Waste Management), with an 80% wastewater COD removal efficiency and a calorific value of 50 MJ per kg of methane recovered.
- “Digester parasitic energy usage” for the meat processing effluent digester operation equates to a maximum of 25 % of the produced methane bioenergy and is used for added pumping, mixing and digester heating requirements. Surplus biogas use as boiler fuel in the slaughter facility will be the primary biogas use substituting coal and natural gas. Energy credits for avoided power use through reduced aerobic effluent treatment aeration are not included in this report for reasons of simplicity and conservativeness of the bioenergy potential assessment. These aeration energy (power) credits will be site specific and can be significant.
- For the projected slaughterhouse wastewater biofuel production in 2020 it was assumed that the slaughtered (dairy + beef) cattle numbers will fall by 1.5 % p.a., slaughtered sheep numbers fall by 1% p.a. and slaughter lamb numbers fall by 0.5 % p.a. of 2006 stock numbers.

Slaughterhouse Waste Water Biofuel Resource Assessment (2006)

	Super-Regional Livestock Slaughtered 2006 (000 Head/yr)			Number of Slaughtering facilities			Regional Livestock Slaughtered 2006 (000 Head/yr)			Wastewater produced (m3/yr)				Wastewater Composition								
Region	Beef	Sheep	Lamb	Beef	Sheep	Lamb	Beef	Sheep	Lamb	Beef	Sheep	Lamb	Total	BOD (tonne/yr)	COD (tonne/yr)	TSS (tonne/yr)	TKN (tonne/yr)	TP (tonne/yr)	Methane Production (tonne/yr)	Gross Energy (GJ/yr)	Gross Energy (PJ/yr)	Nett Energy (PJ/yr)
Northland	1,686	533	2,482	2	1	1	281	89	414	379,357	44,392	206,811	630,559	2,116	4,390	694	293	29	808	40,392	0.04	0.03
Auckland				1	1	1	141	89	414	189,678	44,392	206,811	440,880	1,203	2,494	485	166	16	459	22,941	0.02	0.02
Waikato				8	3	3	1,124	266	1,241	1,517,426	133,174	620,432	2,271,031	8,174	16,965	2,498	1,131	111	3,122	156,076	0.16	0.12
Bay of Plenty				1	1	1	141	89	414	189,678	44,392	206,811	440,880	1,203	2,494	485	166	16	459	22,941	0.02	0.02
Gisborne	183	524	4,009		1	1	-	87	668	-	43,666	334,053	292,000	435	897	321	60	5	165	8,257	0.01	0.01
Hawke's Bay				2	5	5	183	437	3,341	247,504	218,329	1,670,262	2,136,094	3,367	6,962	2,350	464	42	1,281	64,053	0.06	0.05
Taranaki	1,002	974	6,001	2	1	1	286	122	750	386,562	60,874	375,078	822,514	2,363	4,901	905	327	32	902	45,093	0.05	0.03
Manawatu-Wanganui				4	6	6	573	730	4,501	773,125	365,244	2,250,469	3,388,837	6,736	13,946	3,728	930	87	2,566	128,305	0.13	0.10
Wellington				1	1	1	143	122	750	193,281	60,874	375,078	629,233	1,433	2,969	692	198	19	546	27,311	0.03	0.02
Total North Island	2,872	2,031	12,492	21	20	20	2,872	2,031	12,492	3,876,609	1,015,336	6,245,802	11,137,746	27,030	56,019	12,252	3,735	358	10,307	515,371	0.52	0.39
Nelson Bays	159	91	545		1	1	-	91	545	-	45,465	272,398	317,863	366	755	350	50	4	139	6,948	0.01	0.01
Marlborough				1			80	-	-	107,449	-	-	107,449	517	1,074	118	72	7	198	9,885	0.01	0.01
West Coast				1			80	-	-	107,449	-	-	107,449	517	1,074	118	72	7	198	9,885	0.01	0.01
Canterbury	392	759	6,040	4	5	5	392	759	6,040	529,802	379,610	3,020,081	3,929,493	6,467	13,376	4,322	892	82	2,461	123,056	0.12	0.09
Otago	326	1,393	7,653	2	3	3	130	522	2,870	176,045	261,191	1,434,972	1,872,208	2,802	5,791	2,059	386	35	1,065	53,273	0.05	0.04
Southland				3	5	5	196	871	4,783	264,068	435,319	2,391,619	3,091,006	4,528	9,357	3,400	624	56	1,722	86,089	0.09	0.06
Total South Island	878	2,243	14,238	11	13	13	878	2,243	14,238	1,184,814	1,121,584	7,119,069	9,425,467	15,198	31,428	10,368	2,095	192	5,783	289,137	0.29	0.22
Total New Zealand	3,749	4,274	26,730	32	33	33	3,749	4,274	26,730	5,061,423	2,136,920	13,364,871	20,563,213	42,228	87,446	22,620	5,830	549	16,090	804,508	0.80	0.60

Slaughterhouse Waste Water Biofuel Resource Assessment (2020)

	Super-Regional Livestock Slaughtered 2006 (000 Head/yr)			Super-Regional Livestock Slaughtered 2020 (000 Head/yr)			Number of Slaughtering facilities			Regional Livestock Slaughtered 2020 (000 Head/yr)			Wastewater produced (m3/yr)				Wastewater Composition								
Region	**Beef**	**Sheep**	**Lamb**	**Beef**	**Sheep**	**Lamb**	**Beef**	**Sheep**	**Lamb**	**Beef**	**Sheep**	**Lamb**	**Beef**	**Sheep**	**Lamb**	**Total**	**BOD (tonne/yr)**	**COD (tonne/yr)**	**TSS (tonne/yr)**	**TKN (tonne/yr)**	**TP (tonne/yr)**	**Methane Production (tonne/yr)**	**Gross Energy (GJ/yr)**	**Gross Energy (PJ/yr)**	**Nett Energy (PJ/yr)**
Northland	1,686	533	2,482	1,364	463	2,314	2	1	1	227	77	386	307,012	38,565	192,795	538,372	1,745	3,620	592	241	24	666	33,302	0.03	0.02
Auckland							1	1	1	114	77	386	153,506	38,565	192,795	384,866	1,006	2,085	423	139	13	384	19,180	0.02	0.01
Waikato							8	3	3	910	231	1,157	1,228,045	115,695	578,385	1,922,125	6,712	13,930	2,114	929	91	2,563	128,152	0.13	0.10
Bay of Plenty							1	1	1	114	77	386	153,506	38,565	192,795	384,866	1,006	2,085	423	139	13	384	19,180	0.02	0.01
Gisborne	183	524	4,009	148	455	3,737		1	1	-	76	623	-	37,935	311,414	292,000	402	830	321	55	5	153	7,636	0.01	0.01
Hawke's Bay							2	5	5	148	379	3,114	200,304	189,673	1,557,069	1,947,045	2,977	6,153	2,142	410	37	1,132	56,610	0.06	0.04
Taranaki	1,002	974	6,001	811	846	5,595	2	1	1	232	106	699	312,844	52,884	349,659	715,387	1,970	4,085	787	272	26	752	37,581	0.04	0.03
Manawatu-Wanganui							4	6	6	463	635	4,196	625,686	317,305	2,097,955	3,040,945	5,795	11,996	3,345	800	75	2,207	110,359	0.11	0.08
Wellington							1	1	1	116	106	699	156,422	52,884	349,659	558,965	1,217	2,521	615	168	16	464	23,190	0.02	0.02
Total North Island	2,872	2,031	12,492	2,324	1,764	11,645	21	20	20	2,324	1,764	11,645	3,137,323	882,069	5,822,525	9,841,917	22,829	47,303	10,826	3,154	301	8,704	435,191	0.44	0.33
Nelson Bays	159	91	545	129	79	508		1	1	-	79	508	-	39,497	253,938	293,435	338	697	323	46	4	128	6,414	0.01	0.00
Marlborough							1			64	-	-	86,959	-	-	86,959	419	870	96	58	6	160	8,000	0.01	0.01
West Coast							1			64	-	-	86,959	-	-	86,959	419	870	96	58	6	160	8,000	0.01	0.01
Canterbury	392	759	6,040	318	660	5,631	4	5	5	318	660	5,631	428,767	329,785	2,815,410	3,573,961	5,688	11,761	3,931	784	72	2,164	108,198	0.11	0.08
Otago	326	1,393	7,653	264	1,210	7,135	2	3	3	106	454	2,675	142,472	226,909	1,337,724	1,707,104	2,488	5,142	1,878	343	31	946	47,309	0.05	0.04
Southland							3	5	5	158	756	4,459	213,709	378,181	2,229,540	2,821,430	4,033	8,333	3,104	556	50	1,533	76,664	0.08	0.06
Total South Island	878	2,243	14,238	710	1,949	13,273	11	13	13	710	1,949	13,273	958,866	974,371	6,636,611	8,569,847	13,385	27,672	9,427	1,845	168	5,092	254,586	0.25	0.19
Total New Zealand	3,749	4,274	26,730	3,034	3,713	24,918	32	33	33	3,034	3,713	24,918	4,096,189	1,856,440	12,459,135	18,411,764	36,214	74,976	20,253	4,998	469	13,796	689,776	0.69	0.52

2.6 Slaughterhouse Paunch Content Waste Resource

Paunch content biofuel resource calculation basis

- Paunch content from beef and sheep is the residual grass material that has not been defecated into the slaughtering facility wastewater prior to slaughter and is released during slaughter (11).
- The paunch content amount is 40 kg wet weight/head for beef cattle of 250 kg carcass weight (16 % of wet carcass weight) and was assumed to factor in the same proportion for sheep and lamb carcasses. Any difference in paunch content %-age of wet carcass weight between beef and sheep/lambs was ignored and deemed immaterial for the intended “broad brush, order of magnitude” bioenergy potential assessment in this report.
- The digestibility of paunch content (% COD destruction efficiency) is substantially lower than for meat processing wastewater organics. Thus paunch needs to be treated separately in the assessment of the specific biofuel resource calculation but is subsequently conveniently combined with the biofuel yield from AD of slaughterhouse wastewater in each region.
- In conjunction with a lower energy yield in AD, paunch content digestion could contribute 10-20 % of the total biofuel production from slaughtering waste treatment (excluding offal and rendering operations).
- The digester technology for AD of paunch content is different from the AD technology for slaughterhouse wastewater and requires therefore separate dedicated bioreactor modules.
- Currently, paunch content is predominantly treated by composting and/or land disposal. Paunch treated first with AD will allow additional energy recovery, shortens subsequent composting times of anaerobically stabilised paunch contents and reduces composting costs. It will also reduce land disposal costs for any residues.
- The same assumptions about regional distribution of slaughter activities and changes to 2020 used for the slaughterhouse wastewater biofuel potential were applied to the biofuel potential from paunch content anaerobic digestion.
- The effect of changes in slaughter numbers between 2006 and 2020 (see above) on the biofuel potential from paunch content conversion were considered insignificant.

Paunch Content Biofuel Resource Assessment (2006)

Region	Beef Cattle Slaughtered (000 Head/yr)	Beef Paunch Wet Weight (tonne/yr)	TS (tonne/yr)	COD (tonne/yr)	TN (tonne/yr)	TP (tonne/yr)	Na (tonne/yr)	Methane Production (m^{3}/yr) [a]	Gross Energy (GJ/yr)	Gross Energy (PJ/yr)	Nett Energy (PJ/yr)
Northland	281	11,240	1,124.0	927.3	14.1	4.918	28	131,447.1	4,705.8	0.00	0.00
Auckland	141	5,620	562.0	463.7	7.0	2.459	14	65,723.3	2,352.9	0.00	0.00
Waikato	1,124	44,961	4,496.1	3,709.3	56.2	19.670	112	525,788.0	18,823.2	0.02	0.01
Bay of Plenty	141	5,620	562.0	463.7	7.0	2.459	14	65,723.3	2,352.9	0.00	0.00
Gisborne	-	-	-	-	-	-	-				
Hawke's Bay	183	7,333	733.3	605.0	9.2	3.208	18	85,760.0	3,070.2	0.00	0.00
Taranaki	286	11,454	1,145.4	944.9	14.3	5.011	29	133,943.6	4,795.2	0.00	0.00
Manawatu-Wanganui	573	22,907	2,290.7	1,889.9	28.6	10.022	57	267,887.7	9,590.4	0.01	0.01
Wellington	143	5,727	572.7	472.5	7.2	2.505	14	66,971.8	2,397.6	0.00	0.00
Total North Island	2,872	114,862	11,486.2	9,476.2	143.6	50.252	287	1,343,244.9	48,088.2	0.05	0.04
					-						
					-						
Nelson Bays	-	-	-	-	-	-	-				
Marlborough	80	3,184	318.4	262.7	4.0	1.393	8	37,231.1	1,332.9	0.00	0.00
West Coast	80	3,184	318.4	262.7	4.0	1.393	8	37,231.1	1,332.9	0.00	0.00
Canterbury	392	15,698	1,569.8	1,295.1	19.6	6.868	39	183,576.4	6,572.0	0.01	0.00
Otago	130	5,216	521.6	430.3	6.5	2.282	13	60,999.7	2,183.8	0.00	0.00
Southland	196	7,824	782.4	645.5	9.8	3.423	20	91,499.6	3,275.7	0.00	0.00
Total South Island	878	35,106	3,510.6	2,896.2	43.9	15.359	88	410,538.1	14,697.3	0.01	0.01
					-						-
Total New Zealand	3,749	149,968	14,996.8	12,372.4	187.5	65.611	375	1,753,783.0	62,785.4	0.06	0.05

Region	Sheep + Lamb Slaughtered (000 Head/yr)	Sheep + Lamb Paunch Wet Weight (tonne/yr)	TS (tonne/yr)	COD (tonne/yr)	TN (tonne/yr)	TP (kg/yr)	Na (kg/yr)	Methane Production (m^3/yr) [a]	Gross Energy (GJ/yr)	Gross Energy (PJ/yr)	Nett Energy (PJ/yr)
Northland	502	1,447	144.7	119.4	25.1	8.792	50	16,920.9	605.8	0.00	0.00
Auckland	502	1,447	144.7	119.4	25.1	8.792	50	16,920.9	605.8	0.00	0.00
Waikato	1,507	4,341	434.1	358.1	75.4	26.376	151	50,762.6	1,817.3	0.00	0.00
Bay of Plenty	502	1,447	144.7	119.4	25.1	8.792	50	16,920.9	605.8	0.00	0.00
Gisborne	755	2,176	217.6	179.5	37.8	13.220	76	25,443.0	910.9	0.00	0.00
Hawke's Bay	3,777	10,878	1,087.8	897.5	188.9	66.101	378	127,214.7	4,554.3	0.00	0.00
Taranaki	872	2,511	251.1	207.2	43.6	15.258	87	29,365.6	1,051.3	0.00	0.00
Manawatu-Wanganui	5,231	15,067	1,506.7	1,243.0	261.6	91.550	523	176,193.3	6,307.7	0.01	0.00
Wellington	872	2,511	251.1	207.2	43.6	15.258	87	29,365.6	1,051.3	0.00	0.00
Total North Island	14,522	41,824	4,182.4	3,450.5	726.1	254.140	1,452	489,107.3	17,510.0	0.02	0.01
					-						
					-						
Nelson Bays	636	1,831	183.1	151.0	31.8	11.125	64	21,411.1	766.5	0.00	0.00
Marlborough	-	-	-	-	-	-	-				
West Coast	-	-	-	-	-	-	-				
Canterbury	6,799	19,582	1,958.2	1,615.5	340.0	118.989	680	229,001.8	8,198.3	0.01	0.01
Otago	3,392	9,770	977.0	806.0	169.6	59.366	339	114,252.8	4,090.3	0.00	0.00
Southland	5,654	16,283	1,628.3	1,343.4	282.7	98.943	565	190,421.4	6,817.1	0.01	0.01
Total South Island	16,481	47,466	4,746.6	3,916.0	824.1	288.423	1,648	555,087.1	19,872.1	0.02	0.01
					-						-
Total New Zealand	31,004	89,290	8,929.0	7,366.5	1,550.2	542.563	3,100	1,044,194.4	37,382.2	0.04	0.03

2.7 Sewage Treatment Biosolids Waste Resource

Sewerage Biosolids biofuel resource calculation basis

- Many reticulated sewage treatment plants (STP) in New Zealand generate sewage biosolids (60 % primary sludge, 40 % secondary sludge) that could be used to generate biogas at various scales of operation. The appropriate technology for cost effective sludge digestion on small scale (50-500 m^3 digester tank) is comparable to the sludge digestion technology recently demonstrated by WSL on a large Canterbury dairy farm. On larger scale STP conventional sewage sludge digestion technology is suitable..
- The sewage biosolids digestion is a de facto industry standard in Europe and many other parts of the world but has not yet been widely implemented in New Zealand. NZ Cities like Manukau, Christchurch, Hamilton and others have sewage biosolds digesters with biogas conversion to electricity.
- The main purpose of AD of sewage sludge is the biosolids destruction to save on sludge disposal costs and improve sludge dewatering. The biogas energy can be used for electricity generation and the electricity contributes significantly to the sewage treatment plant operation. The biogas derived electricity is produced in distributed generation and substitutes grid power that is currently taken from the grit for the WWTP operation.
- It was thus assumed that the full biogas primary energy is available as generator biofuel to primarily substitute electricity from coal and natural gas based power generation without CHP. It was further assumed that the generator waste heat on the WWTP does not have any other use and can fully contribute all heating energy for digester operation. The gross biofuel energy thus equals the nett biofuel energy in this case as power fro dugster operation is tyoucally less than the power that would have been expended for alternative sewage sludge disposal.
- The population information used is based on the urban population base connected to a reticulated sewage collection system and does not include industrial waste from primary processing industries (see above).
- The population estimate for the urban centres and the secondary urban centres is based on the 2001 Census (4).
- In cases where actual sewage production data were not available approximately 200L/person/day of domestic wastewater production was used (based on AS/NZS1547 standard (9)).
- In cases where actual sewage production data were not available, 70g-BOD/person/day is produced (based on National Inventory Report (6))
- In cases where actual sewage production data were not available the production of COD**:**BOD**:**TSS**:**VSS ratios was assumed to be 2.3**:**1**:**1**:**0.75 (based on Metcalfe and Eddy (10)).
- 90% capture of Influent Suspended Solids was assumed for primary sludge production; there is approximately 65%VS in the biosolids dry matter; that 50% of the sewage biosolids VS is converted to biogas; that for every kg of VS converted 1m^3 of biogas is produced (based on Metcalfe and Eddy Wastewater Engineering third edition (10)).
- A lower heating value of 19 MJ/m^3 (conservative estimate) was used for the produced biogas.
- Additional ICI (institutional, commercial, industrial) sewage discharge into reticulated sewage collection was assumed to be regulated by strict bylaws and to be nationwide approx. in the same proportion to domestic (residential = R) sewage discharge as currently for the capture area of the ChCh WWTP. That means that ICI discharge into the sewage system will approx double biogas energy yield that is calculated from anaerobic digestion of domestic sewage biosolids alone.

Sewage Biosolids Biofuel Resource Assessment (2006)

Regional Council	Reticulated Population	Total Domestic Wastewater Produced (m3/day)	BOD (tonne/ day)	COD (tonne/ day)	TSS (tonne/ day)	VSS (tonne/ day)	TN (tonne/ day)	Biosolids (tonne/ day)	VS converted to Biogas (tonne/ day)	Biogas Production (m3/day)	Biogas Production (m3/yr)	Domestic Wastewater Gross Energy Production (GJ/yr)	Domestic Wastewater Gross Energy Production (PJ/yr)	R + ICI Wastewater Gross Energy Production (GJ/yr)	R + ICI Wastewater Gross Energy Production (PJ/yr)
North Island															
Northland Region	48,700	9,740	3.4	7.7	3.4	2.6	0.6	3	1.0	997	363,953	6,915	0.01	13,830	0.01
Auckland Region	1,282,900	256,580	89.8	204.1	89.8	67.4	16.3	81	26.3	26,267	9,587,593	182,164	0.18	364,329	0.36
Waikato Region	210,350	42,070	14.7	33.5	14.7	11.0	2.7	13	4.3	4,307	1,572,024	29,868	0.03	59,737	0.06
Bay of Plenty Region	185,150	37,030	13.0	29.5	13.0	9.7	2.4	12	3.8	3,791	1,383,695	26,290	0.03	52,580	0.05
Gisborne Region	32,700	6,540	2.3	5.2	2.3	1.7	0.4	2	0.7	670	244,379	4,643	0.00	9,286	0.01
Hawke's Bay Region	120,100	24,020	8.4	19.1	8.4	6.3	1.5	8	2.5	2,459	897,552	17,053	0.02	34,107	0.03
Taranaki Region	49,800	9,960	3.5	7.9	3.5	2.6	0.6	3	1.0	1,020	372,174	7,071	0.01	14,143	0.01
Manawatu-Wanganui R	138,000	27,600	9.7	22.0	9.7	7.2	1.8	9	2.8	2,826	1,031,326	19,595	0.02	39,190	0.04
Wellington Region	431,350	86,270	30.2	68.6	30.2	22.6	5.5	27	8.8	8,832	3,223,640	61,249	0.06	122,498	0.12
Total North Island	2,499,050	499,810	174.9	397.6	174.9	131.2	31.8	157	51.2	51,168	18,676,338	354,850	0.35	709,701	0.71
South Island															
Nelson Bays Region	60,500	12,100	4.2	9.6	4.2	3.2	0.8	4	1.2	1,239	452,139	8,591	0.01	17,181	0.02
Marlborough Region	28,700	5,740	2.0	4.6	2.0	1.5	0.4	2	0.6	588	214,486	4,075	0.00	8,150	0.01
West Coast Region	9,560	1,912	0.7	1.5	0.7	0.5	0.1	1	0.2	196	71,445	1,357	0.00	2,715	0.00
Canterbury Region	416,300	83,260	29.1	66.2	29.1	21.9	5.3	26	8.5	8,524	3,111,166	59,112	0.06	118,224	0.12
Otago Region	115,200	23,040	8.1	18.3	8.1	6.0	1.5	7	2.4	2,359	860,933	16,358	0.02	32,715	0.03
Southland Region	47,300	9,460	3.3	7.5	3.3	2.5	0.6	3	1.0	968	353,491	6,716	0.01	13,433	0.01
Total South Island	677,560	135,512	47.4	107.8	47.4	35.6	8.6	43	13.9	13,873	5,063,660	96,210	0.10	192,419	0.19
Total New Zealand	3,176,610	635,322	222.4	505.4	222.4	166.8	40.4	200	65.0	65,041	23,739,998	451,060	0.45	902,120	0.90

Sewage Biosolids Biofuel Resource Assessment (2020)

Regional Council	Reticulated Population 2006	Predicted Population Change (%)	Reticulated Population 2021	Total Domestic Wastewater Produced (m3/day)	BOD (tonne/day)	COD (tonne/ day)	TSS (tonne/ day)	VSS (tonne/ day)	TN (tonne/ day)	Biosolids (tonne/ day)	VS converted to Biogas (tonne/ day)	Biogas Production (m3/day)	Biogas Production (m3/yr)	Domestic Wastewater Gross Energy Production (GJ/yr)	Domestic Wastewater Gross Energy Production (PJ/yr)	R + ICI Wastewater Gross Energy Production (GJ/yr)	R + ICI Wastewater Gross Energy Production (PJ/yr)
North Island																	
Northland Region	48,700	7%	52,351	10,470	3.7	8.3	3.7	2.7	0.7	3.3	1.1	1,071.9	391,239	7,434	0.01	14,867	0.01
Auckland Region	1,282,900	36%	1,745,952	349,190	122.2	277.8	122.2	91.7	22.2	110.0	35.7	35,748.4	13,048,154	247,915	0.25	495,830	0.50
Waikato Region	210,350	12%	234,582	46,916	16.4	37.3	16.4	12.3	3.0	14.8	4.8	4,803.1	1,753,119	33,309	0.03	66,619	0.07
Bay of Plenty Region	185,150	23%	226,816	45,363	15.9	36.1	15.9	11.9	2.9	14.3	4.6	4,644.1	1,695,081	32,207	0.03	64,413	0.06
Gisborne Region	32,700	-4%	31,305	6,261	2.2	5.0	2.2	1.6	0.4	2.0	0.6	641.0	233,954	4,445	0.00	8,890	0.01
Hawke's Bay Region	120,100	1%	120,764	24,153	8.5	19.2	8.5	6.3	1.5	7.6	2.5	2,472.6	902,515	17,148	0.02	34,296	0.03
Taranaki Region	49,800	-7%	46,106	9,221	3.2	7.3	3.2	2.4	0.6	2.9	0.9	944.0	344,567	6,547	0.01	13,094	0.01
Manawatu-Wanganui R	138,000	2%	140,096	28,019	9.8	22.3	9.8	7.4	1.8	8.8	2.9	2,868.5	1,046,990	19,893	0.02	39,786	0.04
Wellington Region	431,350	9%	469,148	93,830	32.8	74.6	32.8	24.6	6.0	29.6	9.6	9,605.8	3,506,119	66,616	0.07	133,233	0.13
Total North Island	2,499,050		3,067,120	613,424	214.7	488.0	214.7	161.0	39.0	193.2	62.8	62,799.3	22,921,738	435,513	0.44	871,026	0.87
South Island																	
Nelson Bays Region	60,500	23%	74,315	14,863	5.2	11.8	5.2	3.9	0.9	4.7	1.5	1,521.6	555,384	10,552	0.01	21,105	0.02
Marlborough Region	28,700	9%	31,156	6,231	2.2	5.0	2.2	1.6	0.4	2.0	0.6	637.9	232,840	4,424	0.00	8,848	0.01
West Coast Region	9,560	-12%	8,453	1,691	0.6	1.3	0.6	0.4	0.1	0.5	0.2	173.1	63,172	1,200	0.00	2,401	0.00
Canterbury Region	416,300	12%	466,214	93,243	32.6	74.2	32.6	24.5	5.9	29.4	9.5	9,545.7	3,484,192	66,200	0.07	132,399	0.13
Otago Region	115,200	5%	120,907	24,181	8.5	19.2	8.5	6.3	1.5	7.6	2.5	2,475.6	903,583	17,168	0.02	34,336	0.03
Southland Region	47,300	-8%	43,305	8,661	3.0	6.9	3.0	2.3	0.6	2.7	0.9	886.7	323,635	6,149	0.01	12,298	0.01
Total South Island	677,560		744,350	148,870	52.1	118.4	52.1	39.1	9.5	46.9	15.2	15,240.6	5,562,807	105,693	0.11	211,387	0.21
Total New Zealand	3,176,610		3,811,470	762,294	266.8	606.4	266.8	200.1	48.5	240.1	78.0	78,039.8	28,484,545	541,206	0.54	1,082,413	1.08

2.8 Municipal Solid Waste Resource (Scenario 1 and 2)

MSW biofuel resource calculation basis

Scenario 1:

- the regional production of MSW is the same as the 2002 landfill census (1).
- where the regions have been aggregated (eg Nelson Bays and Marlborough) the MSW production for each region is proportional to the relative populations from the 2006 census (2).
- the composition of landfill waste has not greatly changed since the 2006 Waste Composition and Construction Data Report (4).
- It is assumed that the gross yield of landfill gas is 80 m^3 biogas for every tonne of waste sent to landfill.
- It is assumed that 50 % of the landfill gas is recovered (based on NZ NIR 2006 calculated methane recovered 46Gg compared with calculated methane produced 125.8Gg (6))
- It is assumed that the landfill gas has a heat value of 19MJ/m^3 (from EECA Renewable Energy Industry Status Report, 2006 (5))

Scenario 2:
In addition to the assumptions for Scenario 1

- 61% of the total landfilled organics are estimated as putrescible (based on the MfE 2006 Review of Progress (4) and assuming that the green waste fraction of the total organics is not suitable to economically produce biogas outside of a landfill).
- Approximately 85% of the organic and paper waste to landfill can be diverted for energy recovery (from CCC 2006 Towards Zero Waste (7) with current greenwaste to landfill of 200kg/peron/day and is working towards 30kg/person/day, a 85% reduction !!)
- nett biogas production (after process heat) of high quality source segregated putrescibles waste in a dedicated anaerobic digester facility is 125m^3 biogas/tonne of biowaste with a heating value of 22MJ/m^3 (based on information from WSL 2000 Expression of Interest for an Organics Processing Plant (8)).

MSW Biofuel Resource Assessment (2006, Scenario 1 and 2)

					Scenario 1: All MSW to landfill				Scenario 2: degradeable waste seperated							
Regional Council	**2006 Census Usually Resident Population Count**	**2001 Census Usually Resident Population Count**	**Total Landfilled 2002 MSW (000 tonnes/ annum; wet)**	**Estimated Landfilled 2006 MSW (000 tonnes/annum; wet)**	**Gross Landfill Gas Production (m^3/yr) [a]**	**Economically Recovered Landfill Gas (m^3/yr)**	**Energy From Landfill Gas (GJ/yr)**	**Energy From Landfill Gas (PJ/yr)**	**Digestible material to landfill (000 tonnes/ annum; wet)**	**Divertable digestible material (000 tonnes/ annum; wet)**	**Nett Biogas Production from digestible material (m^3/yr)**	**Residual material to landfill (000 tonnes/annum; wet)**	**Gross Biogas Production from residual material (m^3/yr) [a]**	**Recovered Biogas Production (m^3/yr)**	**Biofuel Energy From MSW (GJ/yr)**	**Biofuel Energy From MSW (PJ/yr)**
North Island																
Northland Region	148,470	140,133	98	104	8,306,429	4,153,214	78,911	0.08	14.6	13.1	1,174,715	91	7,257,576	4,803,503	91,267	0.09
Auckland Region	1,303,068	1,158,891	930	1,046	83,656,064	41,828,032	794,733	0.79	146.7	132.0	11,830,841	914	73,092,812	48,377,248	919,168	0.92
Waikato Region	382,713	357,726	237	254	20,284,347	10,142,174	192,701	0.19	35.6	32.0	2,868,661	222	17,723,043	11,730,183	222,873	0.22
Bay of Plenty Region	257,379	239,412	151	162	12,986,560	6,493,280	123,372	0.12	22.8	20.5	1,836,590	142	11,346,747	7,509,964	142,689	0.14
Gisborne Region	44,499	43,974	32	33	2,622,913	1,311,457	24,918	0.02	4.6	4.1	370,939	29	2,291,718	1,516,798	28,819	0.03
Hawke's Bay Region	147,783	142,947	108	111	8,899,248	4,449,624	84,543	0.08	15.6	14.0	1,258,553	97	7,775,540	5,146,323	97,780	0.10
Taranaki Region	104,124	102,858	60	61	4,859,080	2,429,540	46,161	0.05	8.5	7.7	687,183	53	4,245,524	2,809,944	53,389	0.05
Manawatu-Wanganui R	222,423	220,089	163	165	13,178,287	6,589,143	125,194	0.13	23.1	20.8	1,863,705	144	11,514,264	7,620,837	144,796	0.14
Wellington Region	448,959	423,768	501	531	42,462,566	21,231,283	403,394	0.40	74.5	67.0	6,005,158	464	37,100,818	24,555,567	466,556	0.47
Total North Island	3,059,418	2,829,798	2,280	2,465	197,200,593	98,600,296	1,873,406	1.87	345.8	311.3	27,888,581	2,154	172,300,074	114,038,618	2,166,734	2.17
South Island																
Nelson Bays Region	87,516	82,917	71	75	6,021,944	3,010,972	57,208	0.06	10.6	9.5	851,638	66	5,261,553	3,482,414	66,166	0.07
Marlborough Region	42,558	39,558	35	37	2,984,925	1,492,463	28,357	0.03	5.2	4.7	422,135	33	2,608,019	1,726,145	32,797	0.03
West Coast Region	31,326	30,300	25	26	2,067,723	1,033,861	19,643	0.02	3.6	3.3	292,422	23	1,806,631	1,195,738	22,719	0.02
Canterbury Region	521,832	481,431	340	369	29,482,585	14,741,293	280,085	0.28	51.7	46.5	4,169,498	322	25,759,819	17,049,407	323,939	0.32
Otago Region	193,800	181,539	162	173	13,835,308	6,917,654	131,435	0.13	24.3	21.8	1,956,622	151	12,088,324	8,000,784	152,015	0.15
Southland Region	90,876	91,005	109	109	8,707,639	4,353,820	82,723	0.08	15.3	13.7	1,231,455	95	7,608,126	5,035,518	95,675	0.10
Total South Island	967,908	906,756	742	792	63,363,263	31,681,631	601,951	0.60	111.1	100.0	8,960,985	692	55,362,384	36,642,177	696,201	0.70
Total New Zealand	4,027,947	3,737,277	3,022	3,257	260,563,096.3	130,281,548	2,475,349	2.48	457.0	411.3	36,849,458	2,846	227,661,794.1	150,680,355	2,862,927	2.86

MSW Biofuel Resource Assessment (2020, Scenario 1 and 2)

					Scenario 1: All MSW to landfill				Scenario 2: degradeable waste seperated								
Regional Council	**2021 Census Usually Resident Population Count**	**2001 Census Usually Resident Population Count**	**Total Landfilled 2002 MSW (000 tonnes/ annum; wet)**	**Estimated Landfilled 2021 MSW (000 tonnes/ annum; wet)**	**Gross Landfill Gas Production (m^3/yr) [a]**	**Recovered Landfill Gas (m^3/yr)**	**Energy From Landfill Gas (GJ/yr)**	**Energy From Landfill Gas (PJ/yr)**	**Digestible material to landfill (000 tonnes/ annum; wet)**	**Divertable digestible material (000 tonnes/ annum; wet)**	**Nett Biogas Production from digestible material (m^3/yr)**	**Residual material to landfill (000 tonnes/ annum; wet)**	**Gross Biogas Production from residual material (m^3/yr) [a]**	**Recovered Biogas Production (m^3/yr)**	**Biofuel Energy From MSW (GJ/yr)**	**Biofuel Energy From MSW (PJ/yr)**	
North Island																	
Northland Region	158,100	140,133	98	111	8,845,197	4,422,599	84,029	0.08	15.5	14.0	1,250,909	97	7,728,314	5,115,066	97,186	0.10	
Auckland Region	1,668,700	1,158,891	930	1,339	107,129,385	53,564,692	1,017,729	1.02	187.9	169.1	15,150,495	1,170	93,602,157	61,951,573	1,177,080	1.18	
Waikato Region	418,100	357,726	237	277	22,159,910	11,079,955	210,519	0.21	38.9	35.0	3,133,908	242	19,361,778	12,814,797	243,481	0.24	
Bay of Plenty Region	303,500	239,412	151	191	15,313,685	7,656,843	145,480	0.15	26.9	24.2	2,165,698	167	13,380,026	8,855,711	168,259	0.17	
Gisborne Region	43,300	43,974	33	32	2,594,465	1,297,233	24,647	0.02	4.6	4.1	366,915	28	2,266,862	1,500,346	28,507	0.03	
Hawke's Bay Region	149,800	142,947	107	112	8,975,771	4,487,885	85,270	0.09	15.7	14.2	1,269,375	98	7,842,400	5,190,575	98,621	0.10	
Taranaki Region	99,100	102,858	60	58	4,624,628	2,312,314	43,934	0.04	8.1	7.3	654,026	51	4,040,676	2,674,364	50,813	0.05	
Manawatu-Wanganui R	226,600	220,089	163	168	13,425,769	6,712,884	127,545	0.13	23.5	21.2	1,898,704	147	11,730,497	7,763,953	147,515	0.15	
Wellington Region	485,100	423,768	501	574	45,880,784	22,940,392	435,867	0.44	80.5	72.4	6,488,571	501	40,087,417	26,532,279	504,113	0.50	
Total North Island	3,552,400	2,829,798	2,280	2,862	228,976,683	114,488,342	2,175,278	2.18	401.6	361.4	32,382,432	2,501	200,063,797	132,414,331	2,515,872	2.52	
South Island																	
Nelson Bays Region	105,000	82,917	72	91	7,270,055	3,635,028	69,066	0.07	12.7	11.5	1,028,149	79	6,352,065	4,204,181	79,879	0.08	
Marlborough Region	45,900	39,558	34	40	3,178,053	1,589,026	30,192	0.03	5.6	5.0	449,448	35	2,776,760	1,837,828	34,919	0.03	
West Coast Region	28,500	30,300	25	24	1,881,188	940,594	17,871	0.02	3.3	3.0	266,042	21	1,643,650	1,087,867	20,669	0.02	
Canterbury Region	572,100	481,431	340	404	32,322,638	16,161,319	307,065	0.31	56.7	51.0	4,571,145	353	28,241,259	18,691,774	355,144	0.36	
Otago Region	202,700	181,539	162	181	14,470,676	7,235,338	137,471	0.14	25.4	22.8	2,046,478	158	12,643,463	8,368,209	158,996	0.16	
Southland Region	86,500	91,005	109	104	8,288,336	4,144,168	78,739	0.08	14.5	13.1	1,172,156	91	7,241,768	4,793,040	91,068	0.09	
Total South Island	1,040,900	906,756	742	852	68,141,621	34,070,811	647,345	0.65	119.5	107.6	9,636,752	744	59,537,379	39,405,441	748,703	0.75	
Total New Zealand	4,594,000	3,737,277	3,022	3,715	297,180,391.0	148,590,195	2,823,214	2.82	521.2	469.1	42,027,964	3,246	259,655,423.0	171,855,676	3,265,258	3.27	

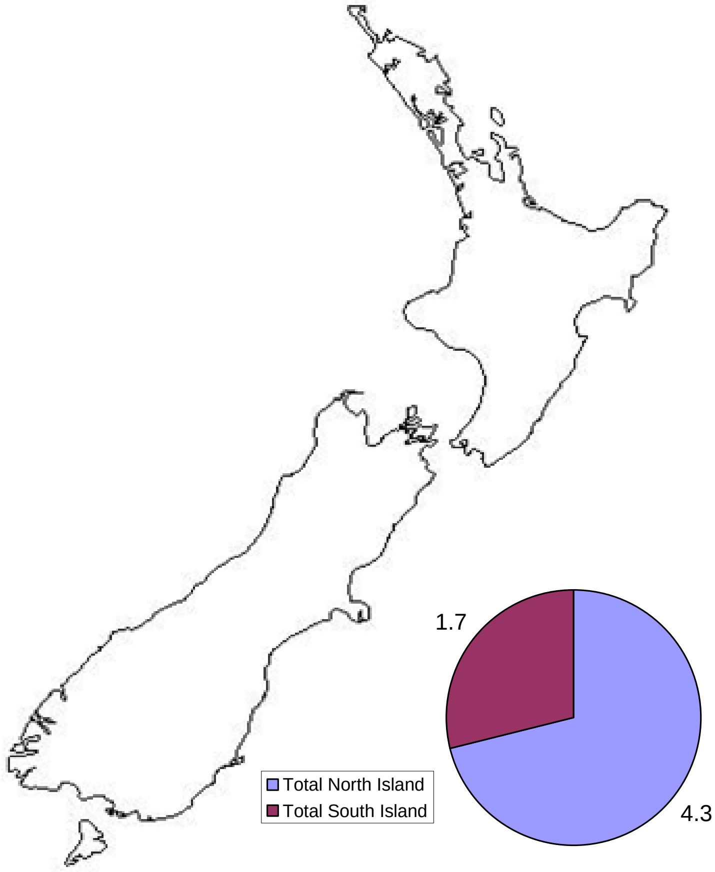
2.9 Wool Processing Wastewater Resource

- Actual effluent data from NZ wool scouring operations were commercially sensitive and not available for the report.
- A confidential estimate from a NZ industry expert suggested that the total wool scouring effluent bioenergy resource would be insignificant in comparison to the other processing industries (less than 0.5 % of total industrial processing waste resource) .
- Any solid waste from tanneries and wool scouring operations is currently deposited to landfill and thus already included in the landfill gas bioenergy estimates in section 2.8.

3.0 CONVERSION TECHNOLOGY (LOGISTICS, CONSTRAINTS, ECONOMICS)

Logistics and biogas bioenergy use

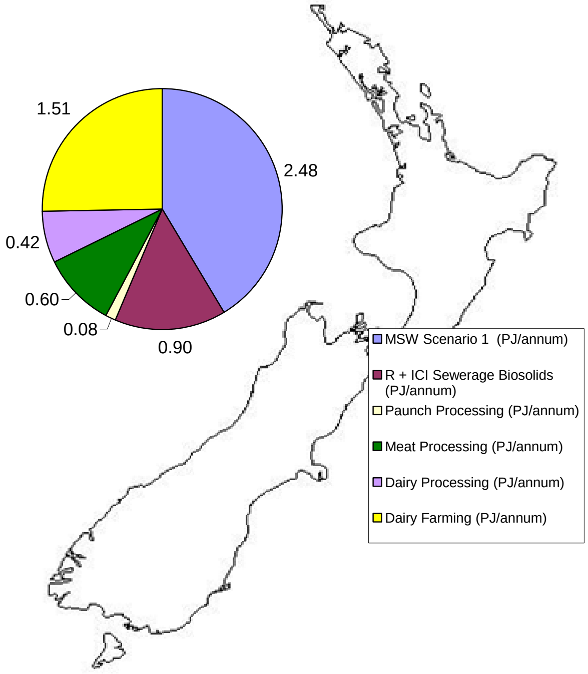
Details about the conversion technology characteristics are given elsewhere in detail (28-31) and examples are given in Appendix 1. The following maps/graphs give a summary of results obtained for the NETT usable biogas biofuel energy potential. NZ appears overall surprisingly bioenergy rich for industrial processing waste, animal manures, sewage biosolids and MSW. The figure of 6 PJ/annum biogas bioenergy is in addition to and complements the previously determined processing/farming waste derived bioethanol potential of 5.6 PJ (22) and needs to be seen with a relative uncertainty of about +/- 1 PJ. This uncertainty is due to the uncertainty in the input data and the assumptions made in the biogas bioenergy potential calculation.



Estimate of Nett National methane bioenergy potential from industrial processing waste (given in PJ methane biofuel/year; seperated for North and South Island)
Note: The processing energy requirement (heat, power) is assumed to be covered from the produced methane and is already subtracted

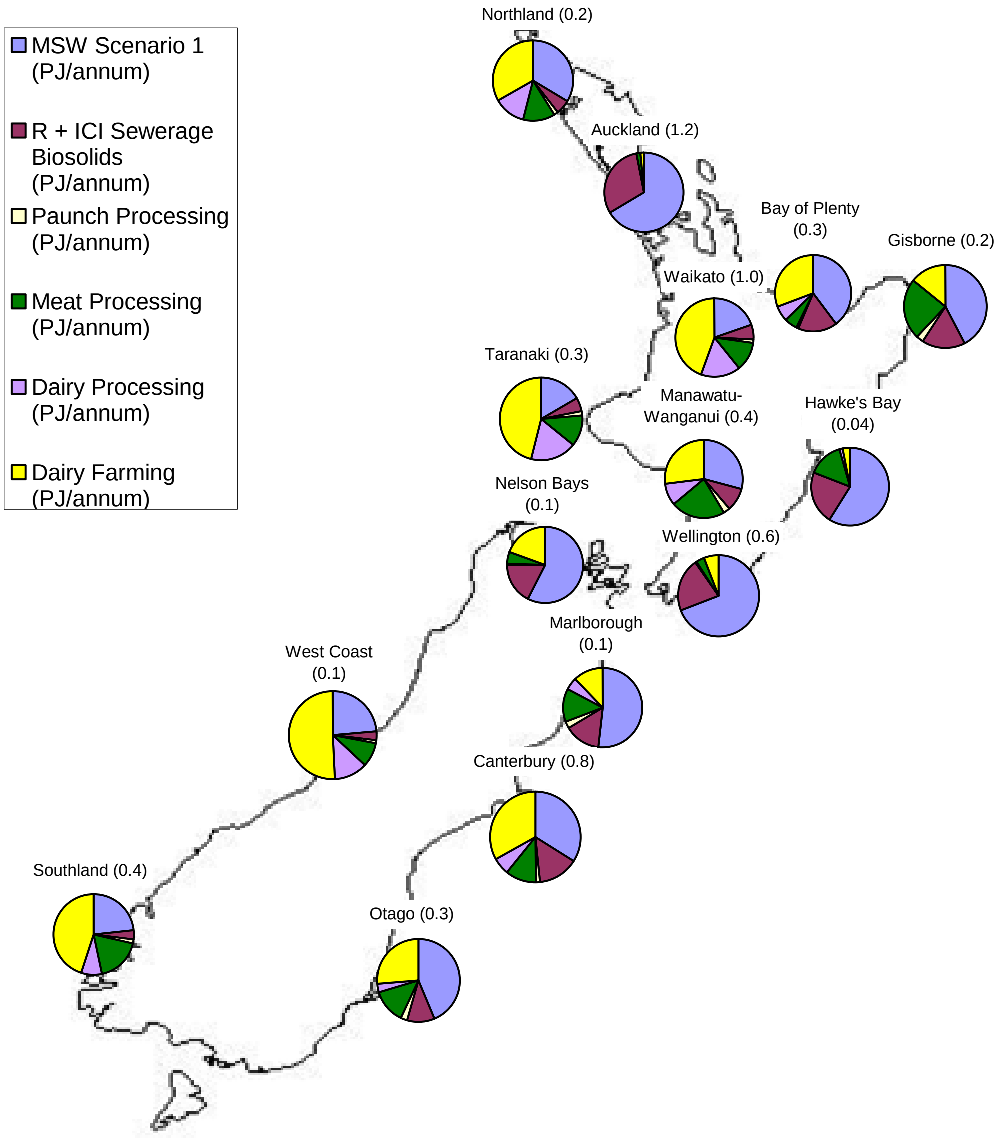
AD of processing waste and effluent from dairy and meat processing plant nationwide has a biogas bioenergy potential of about 1 PJ/annum. Sewerage biosolids digestion contributes approximately another 1PJ/annum and the majority of the NETT bioenergy is in the recovery of landfill gas from MSW. It is important to realise that nationwide both MSW scenarios (scenario 1 w/o source segregation an scenario 2 with a reasonable level of source segregation and high rate anaerobic digestion of segregated biowaste) deliver overall about the same amount of usable bioenergy within the inherent uncertainty of this assessment – thus the preferred solid waste management strategy discussion for NZ should be driven by landfill area, costs, environmental & aesthetic benefit and conservation criteria rather than bioenergy criteria.

A very interesting finding is the relative magnitude of the biogas biofuel potential from dairy farming. Based solely on the proven recoverable portion of dairy shed effluent manure in a fully assessed full scale application of the technology, the estimated figure of 1.5 PJ/annum of biofuel for milking shed operation is of some significance for the dairy farming sector. It is significant that only dairy farms with herds > 400 hd were considered here in order to allow for some economy of scale constraint on this component of the biogas biofuel potential. Clearly, more on farm AD technology development & demonstration work under NZ conditions and more research on improvements of the on-farm dairy shed effluent digestion economics (see below) are a priority if dairy farming manure digestion technology is to be adopted throughout the industry. Important is also that AD of all manure from pig farming (see section 2.2 above, data not shown) accounts nationwide for about 1/10th of the estimated biogas biofuel potential from treatment of dairy shed effluent manure from herds > 400 hd. Thus pig manure is of lesser importance for the national energy situation but of great importance for environmental reasons (odour).



Estimate of Nett National methane bioenergy potential from each sector (given in PJ methane biofuel/year)
Note: The processing energy requirement (heat, power) is assumed to be covered from the produced methane and is already subtracted

The regional breakdown of the biogas biofuel potential in NZ makes very interesting reading. Auckland is clearly biogas biofuel potential rich because of its MSW resource and the respective landfills.



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.

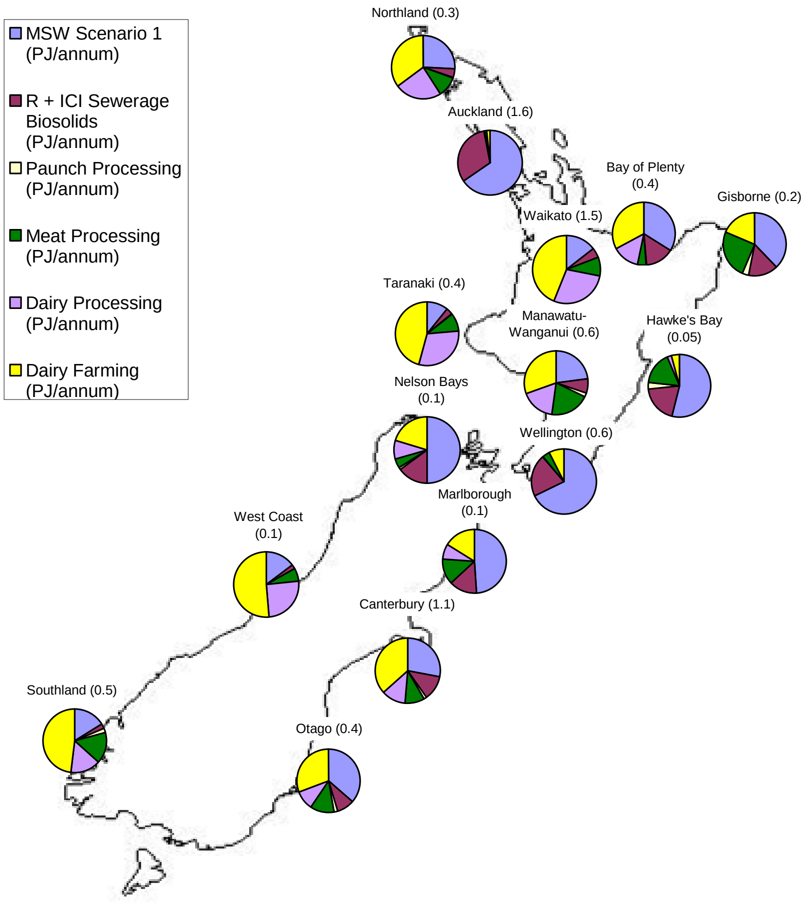
The estimated total recoverable methane energy value for each region is given in PJ methane/yr in parenthesis
Values were calculated using MSW Scenario 1 and biosolids processing from domestic sewage + ICI sewage.

Waikato, Canterbury, BOP, Manuwatu, Taranaki and Southland follow.

The biogas biofuel potential from processing waste from meat works and dairy processing plants in Waikato, BOP and Canterbury is combined in each area above 0.15 PJ/annum, whereas in all other regions this combined processing industry sector bioenergy potential was estimated below that threshold.

A biogas supply of 0.15 PJ/annum biogas biofuel potential is considered as the minimum technical biogas amount on a single site for commercial biomethanol production from biogas (under certain circumstances). As the dairy farm manure or farm manure digestion gas cannot be transported (too dilute) and as the primary processing industry biogas biofuel potential is spread over numerous plants in each region, it is very unlikely that the processing industry biogas biofuel potential in NZ will achieve sufficient local critical mass under current conditions (i.e. waste material concentration in one place to produce more than 0.15 PJ/annum biogas biofuel potential). This leads to the conclusion that a biomethanol production technology (29) will not be able to contribute to the NZ indigenous transport fuel production in the immediate future due to lack of sufficient localised biomethane production. This could be different if pipeline gas (biomethane, natural gas) are blended to meet the capacity requirements of a biomethanol production facility site.

This conclusion is further supported by the analysis of the expected GROSS biogas biofuel potential (below) for the year 2020, even if dairy industry sector growth (2 % p.a) and not yet materialised significant processing waste digester technology advancements are included (i.e., assumption that all produced biogas in one digester facility site is available for biomethanol production).



Expected GROSS bioenergy potential in 2020 in regional areas using MSW Scenario 1 and including Domestic and ICI Biosolids. Total Methane potential in PJ/yr is shown.

However, only the Waikato or Canterbury region could approach this critical biomethane mass concentration in 2020 (or earlier if natural gas is blended with biomethane) and thus a targeted case study would be very useful to assess this technology option in more depth in the NZ context. The biomethanol energy potential in Waikato in 2020 in one centralised facility could be in the order of 0.35 PJ biomethanol/annum which is about double the minimum critical mass for this potential transport biofuel production route and about the same order of magnitude as the current whey based ethanol production in NewZealand.

This conclusion leaves therefore the standard anaerobic digester process configuration with genset fuel use of the biogas in combined heat and power (CHP) production (see appendix), power use on site and/or for sales into grid via distributed generation and full heat use for digester facility operation as the preferred mode for biogas utilisation. Genset and digester sizes even for very small scale applications (400 hd dairy farm milking shed) or small piggeries are available on the market or are in the process of being demonstrated. This leaves therefore little remaining R&D for this particular aspect of the technology. However, biogas motor performance improvements and cost reduction at very small scale are needed and some targeted research for this aspect is in high demand. Low cost technology for biogas quality improvement at this scale (H_2S removal) is already available in New Zealand as is the appropriate digester technology. With the expected advent of electric car technology in about a decade, this biogas use for power production could free up/produce up to 6 PJ/annum of biofuel equivalents in the form transport energy without use of any additional land area in New Zealand. In some rare cases where the risks exists that the biogas may present high H_2S levels (occasional high sulphuric acid residues in captured/digested dairy processing industry DAF sludges), a suitable alternative would be biogas use as boiler fuel.

Possible Constraints

Energy balance: Most of the obvious technical constraints on the biogas production side were already discussed and eliminated by the choices made in the process design and assumptions used for the biogas biofuel potential estimate (see section 2 of this report). The digester process energy requirements (power) were fully met by the produced biogas for all examined industries and cases and were subtracted prior to the specification of the NETT biogas biofuel potential, Typically, the “energy balance” of the various digester processes is in the order of 10**:**1 to 5:1(overall electricity produced **:** overall electricity used) as the “low grade” genset waste heat is typically not saleable on industrial sites.

Waste strength and nutrient content: The COD (chemical oxygen demand) concentration in each of the processing industries and examples examined in section 2 and the COD biodegradability are in each case substantially higher than the minimum COD degradation and generator waste heat production needed to heat the digester and the incoming waste. All processing waste materials considered in this study provide sufficient nutrients for effective anaerobic digestion (see section 2). Thus there are no constraints from the waste composition on the technical or economic feasibility.

Seasonality: One important constraint for the specified biogas biofuel potential estimate in this report is the typical “seasonality” of many processing industries and dairy farming in New Zealand. This will require additional heat (storable fuel) demand during digester start-up in spring (season start) and this process heat must be provided by an additional fuel source (boiler on coal, natural gas or wood; hydroelectric). Digester start-up heat is normally provided by unrecoverable latent heat in the industry process wastewater if the effluent is warm. It is a potential issue in seasonal dairy farm digesters and typically requires some imported electricity (night tariff) or fossil fuel (diesel, petrol) use for generator operation for about 5-10 % of the total annual digester operating time. These details need to be decided on a case by case basis and were not allowed for in the biogas biofuel potential estimate in section 2 of this report.

Logistics, transport energy, nutrient transfer, odour issues: A key constraint that often applies to the use of solid biomass and solid biomass waste (such as forest processing residues) - i.e. additional waste collection energy, transport energy, waste collection costs and nutrient transfer - does not apply to the biogas biofuel potential determined here. All materials are converted to biofuel practically at their current site of waste generation. Pumping energy for waste conveyance into the digester module is virtually the same as in BAU (**B**usiness **A**s **U**sual) because anaerobic digester plants can be slotted into existing waste management operations as “bioenergy recovery modules” upstream of aerobic treatment steps. The digester effluent treatment is not more expensive or energy intensive than the BAU waste management and often less energy intensive (see section 2). AD of organic waste does not generate new nutrients and does not destroy significant nutrients, thus the nutrient load of a BAU waste management system with a “slotted in” AD module does not significantly change. All digester facility types and process configurations used here do not rely on or include the transport of other waste to an existing site – thus there are no waste treatment steps downstream of the digester that are additional and thus use additional energy or cause additional environmental constraints up and above BAU.

AD could generate some new odours which are contained in the biogas in the fully enclosed digester and gas handling system at each site and are destroyed during biogas desulfurisation and generator + boiler operation. Normally, the malodour in the digester effluent is less than the malodour in the solid waste or wastewater used as digester feedstock. Thus, none of these potential digestion process constraints create serious technical hurdles for AD technology implementation. Implementation is normally easily managed by practitioners in the industry and allowed for during routine site specific digester facility process design. A potential nutrient transfer from the import of nutrients with imported waste material as a potential constraint is not a consideration for the biogas biofuel potential because waste collection and transport beyond BAU are not used.

Digestion residue disposal: The digestion residue disposal is comparable to BAU if no water has been added the feedstock prior to digestion. This applies to all digestion technologies and industry sectors examined in this report. AD of source segregated putrescibles from municipal solid waste uses the intrinsic water from the waste 5-8 times prior to discharge to an aerobic treatment system. AD of sewage biosolids generates some effluent due to the improved biosolids dewatering qualities that are achieved in the process but treatment of these small amounts of additional effluent is normally easily managed in a standard waste water treatment plant. Hygienic issues with the digestion residues are typically less than from the treated waste materials if the digestion process is properly designed.

Mismatch between local biogas demand/supply (biogas flare): While there may be some rare occasions where short term mismatches between biogas demand and supply occur with the consequences of occasional biogas destruction in an emergency flare, these typically reflect process design issues that can be avoided up front by appropriate genset/boiler sizing. Using distributed generation as the default biogas utilisation (see above), all biogas bioenergy is normally utilised for power production and sales. Respective flexible legislation and import tariffs are key in this case. Overseas examples (Europe, 25) lead the way.

Other processing waste: The processing industry and municipal waste biogas bioenergy potential estimate in this report of 6 PJ/annum of biogas biofuel has not included the potential biogas production from pig manure, surplus whey disposal from cheese making in smaller dairy processing companies and wool processing industries because in comparison they were small. Although assessed in section 2, they were excluded from the presentation of the data in section 3 for the reason of clarity of the report. All available materials from these industries together would amount to less than 5 % of the biogas bioenergy potential estimate given herer and thus fall clearly within the uncertainty of the estimation procedure and approach . This is a partial shortcoming of this study but given the limited resources available for the research did not justify a more detailed treatment at this stage.

Economics and Integration into NZ infrastructure

The major factor controlling the economics of biogas production from industrial waste, manure and biosolids are the specific capital costs for the installed digester capacity ($/m^3 installed capacity) including biogas clean-up to genset quality. These costs show traditionally significant economies of scale with larger installed digester plants showing lower specific installed digester capital costs. WSL and its technology partners managed recently substantial successes in reducing these capital costs through innovative design and construction methods and are able to provide insulated digester plants for sludge, biosolids and industrial wastewater with biogas storage and H_2S management ability for very competitive costs at less than 500 $/m^3 installed capacity even at small scale (< 200 m^3).

With normally achieved digester biogas productivities of more than 1 $m^3_{biogas}/m^3_{installed\ capacity}$ / day, a 10 year lifetime expectation for the investment at current interest rates, this installed CAPEX figure equates to rough order biogas generation costs around 18 NZ$/GJ (+/- 30 %) which can be reduced to 9 NZ$/GJ (+/- 30 %) for new installations provided that the digester feedstock (wastewater) is provided “free of charge” and that the digester facility is credited the avoided costs for the avoided construction of alternative treatment works such as lined effluent ponds (avoided construction of alternative treatment works were valued about ½ of the low cost digester construction costs). If the credit for avoided alternative CAPEX costs is not easily calculated, typically a market rate “gate fee” for accepting waste materials for treatment in the digester facility can be used. Gate fees, energy sales and carbon credits are the income streams for commercial digester system operators. This commercial approach is very successful in all Asian examples for the WSL designed digester facility technology (see appendix 1, reference 32).

Carbon credits for the avoidance of methane GHG emissions in a BAU waste water management system at each site would be in the order of 15-25 NZ$/t avoided CO_2 emissions. The actual GHG emission avoidance benefit is only credited if the measure is “additional”- thus landfill gas (LFG) GHG avoidance credits would not be available (MSW scenario 1 and 2) because LFG capture is now legally required in the BAU case (proposed standard regulation for landfill management in NZ, 33).

Due to the high relative GHG emission factor for captured CH_4 (21 x CO_2), 1 GJ of avoided GHG methane emissions (i.e. "additional" methane capture from uncontrolled BAU emissions) could generate associated carbon credits of up to 0.42 t of CO_2 equivalent. The commercial value would be up to 10 $/GJ methane (at 25 $NZ/t CO_2 equivalent) making the AD option potentially a very attractive way forward - specifically with the new low cost digestion technology and high levels of abated methane emission in warm climates (appendix 1). However, normally the captured methane in a waste treatment digester in New Zealand is substantially more than the actually certifiable amount of avoided methane GHG emissions (i.e. certified methane emission abatement). This is so because in BAU waste management cases under NZ conditions a portion of the emitted methane is re-oxidised by aerobic bacteria before it leaves into the atmosphere and some of the waste carbon remains "refractory" in BAU scenarios, i..e. is deposited as residue into landfills with landfill gas capture or onto farm land without significant added methane emissions..

In this case the actual value of the carbon credits for avoided emissions from a digester installation could be substantially less than the 10 $/GJ methane (at 25 $NZ/t CO_2 equivalent) and less than any credits for avoided CAPEX costs for installation of alternative waste management systems (see above). Detailed cost comparisons are thus industry specific and site specific and usually cannot be generalised – thus this discussion needs to be validated on a case by cases basis.

A rough order installed digester CAPEX cost of Nett 9 NZ$/GJ (+/- 30 %) needs to be seen in the context that power generation equipment associated capital and operation costs were excluded in that figure (i.e. biogas used as boiler fuel and heat exchanger for digester heating included). Distributed generation costs at small scale (< 50 KW) are currently significantly higher than at industrial (> 200 KW) genset scale and significant cost reduction progress is expected at the small scale front in the next decade. Thus power sales into grid from biogas at 9 NZ$/GJ (+/- 30 %) may still not yet be competitive with wind or hydroelectric power at very small scale of generation even if a generator credits and avoided line charges are included.

The integration of the biogas technology into the NZ infrastructure and the realisation of the full bioenergy potential is thus expected to occur gradually if power purchase costs off the grid and carbon credit values increase, distributed generation is encouraged by pricing incentives and small scale genset CAPEX costs decrease due to mass production in NZ and/or import of low cost engine units from overseas. None of these expected developments currently carries commercial certainty and targeted RD&D is thus needed to reduce technology costs for certain adoption in the future.

Important drivers for implementation under current economic conditions are thus the demonstrable additional environmental benefits of improved effluent management, improved odour control, GHG capture, nutrient run-off management and the additional effluent storage capacity that gives farmers and primary processing industries more waste management flexibility for land application of treated effluent. Thus the crossover of synergies and benefits for energy security, improved efficiency of primary production and achievement of national environmental goals (clean & green image) via AD of industrial and municipal waste is thus significant and merits in detailed study on a RD&D level to guide national policy and energy industry planning.

4.0 CONCLUSIONS

In summary, this study has demonstrated that the biogas biofuel bioenergy potential from municipal biosolids & effluent, dairy factory, meat processing & wool processing waste and dairy farm effluent in New Zealand is significant. In order of decreasing importance landfill operators, dairy farms, sewage treatment plants, dairy factories, meat factories, piggeries and wool processors could make a measurable contribution to the national and regional energy security while improving their environmental performance at the same time. Achievement of environmental goals will be as important as energy security goals to be able to motivate the financial resources that are needed for a nationwide adoption of the anaerobic digestion technology advantages and benefits.

Taking into consideration a host of known technical and logistic resource constraints and after subtracting the bioenergy that is “lost” through the effect of those constraints, the research team estimates that an enduser bioenergy potential of NETT 6 PJ biogas biofuel is realisable in New Zealand with state of the art technology that is available on the market.

In addition to contributing a significant amount of indigenous bioenergy biofuel for the national economy, such a strategy would generate a nationwide technology platform to develop export grade environmental technology (see appendix 1) and synergies for improved efficiency of primary production and achievement of national environmental goals (clean & green image). The anaerobic digestion technology platform could also be used as a springboard and “real world playground” for development of elements for a future biofuel production bio-economy in NZ because many process technology elements, microbial biocatalysts and enzymes used in the process of anaerobic digestion are also useful for fermentation of agricultural feedstocks into liquid biofuel. Details of this aspect are known to WSL, were outside the brief for this study and should be explored in a separate study.

The biogas biofuel in NZ is available for power and heat production in CHP (combined heat & power) installation and partially as transport fuel through biomethane fuelled vehicles (bio-CNG, taxis, busses, trucks, commercial vehicles, see 25). The seasonality of 45 % of the biogas biofuel from primary production processing waste (2.6 PJ) fits well into the summer peak for the rural national power demand curve (dairy farm irrigation) and into the summer trough for hydroelectric power generation and also is most economically utilised in rural distributed CHP power generation. The balance (3.4 PJ; landfills, sewage treatment plant) is able to provide a mix of energy products ranging from medium and peak load power to vehicle fuel application for commercial and municipal services. Excellent examples for that are available in North America, throughout Europe (particularly Sweden) and in parts of Asia. The city of Christchurch has also some experience in that area.

Research gaps and priority energy research areas that need attention to facilitate this are:

- Research on improved on-farm dairy shed effluent digestion economics (innovative gensets and high performance digester systems, improved synergy, improved carbon capture)
- Biogas motor performance improvements and cost reduction at very small scale
- System dynamics research in the areas of crossover in synergies and benefits for energy security, improved efficiency of primary production and achievement of national environmental goals (clean & green image).
- Regional case study on use of biomethane as commercial transport fuel
- Regional case study on production of biomethanol

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Appendix 1

Waste Solutions
Biotechnology Group

Waste Solutions Ltd

Waste-to-Energy
Anaerobic Digestion Project Examples

1st Floor John Wickliffe House
265-269 Princes Street
Box 997
Dunedin
New Zealand

WASTE SOLUTIONS LTD

Waste Solutions Ltd is one of a group of three associated companies collectively called the Waste Technology Group. This group originated as a New Zealand Ministry of Agriculture & Fisheries team of scientists and engineers and has a thirty year history of research, development, and engineering of treatment technology for waste treatment. It is now owned by Downer Engineering Ltd., a large Australasian-based engineering company active in many industries.

The **Waste Technology Group Ltd** comprises:

- **Waste Solutions Ltd**, for consultancy, research, engineering and design
- **Total Construction Ltd**, for sub-system supply and small turnkey projects
- **Environmental Operations Ltd**, for the contract operation of treatment plants

The staff of the Waste Technology Group includes scientists, engineers, biotechnologists, and laboratory and instrumentation technicians who are among the best in their fields. They have in-depth experience of waste-to-energy process design and treatment plant design over a broad range of industrial wastes, sewage treatment and biological processes. Experience spans the range from “natural” treatment technologies for small-flows to combined physico-chemical and biological treatment for sophisticated waste-to-energy plants.

Typically Waste Solutions provides design all disciplines, project management, construction support, commissioning assistance, and automation. These services are provided in a flexible manner to suit individual circumstances, for example to a constructor, project manager, project operating company, local authority, government department, project developer or simply directly to a manufacturing facility.

A key feature that Waste Solutions can bring to an industrial waste treatment issue is vertical integration from laboratory work through to project implementation, commissioning and operation.

Waste Solutions Ltd has been accredited to the international quality standards ISO 9001 since February 1998.

Relevant Experience

The relevant experience of Waste Solutions Ltd may be classified in four categories:

1. Full-scale projects
2. Pilot scale, research and demonstration projects.
3. Consulting
4. Other

Waste Solutions has designed a large number of full scale waste-to-energy projects, and relevant examples are listed below. There is relevant pilot plant, laboratory and consulting work that is not mentioned.

Kitroonruang Waste to Energy, Mabtaphut, Thailand

This cassava waste processing facility has been completed by the Thai Bio-Energy Company as a BOOT project. The digester is designed to process 2800 m3 wastewater per day, with an average organic load of 15,000 mg/l CODt, and produce and 24,000 m3/day of biogas used for factory process heat and a 1.3 MW Jenbacher generator.

Thai Agro Energy Waste to Energy, Dan Chang, Thailand

Waste Solutions has designed a waste treatment facility to process the stillage from a molasses distillery producing transport fuel ethanol. The objective was to provide boiler fuel and produce a waste suitable for irrigation. 48,000 m3/day of biogas at 60% methane would be produced from this waste flow, delivered to 3 boilers.

The project was designed to process 1450 m3/day of waste at concentration of 90,000 mg/litre COD, although once operational the waste strength proved to be about 180,000 mg/litre COD. The project is technically demanding, with high concentrations of sulphates, refractory COD and monovalent cations. Waste Solutions was able through previous experience to develop an innovative yet cost effective lagoon process to manage these factors.

After anaerobic treatment, a Sequential Batch Reactor (SBR) is employed to reduce the BOD of the waste, although significant refractory COD, colour compounds and of course the mineral components remain. Refractory COD due to stable organic compounds is not amenable to biological processing.

Khorat Waste to Energy, Thailand

The project is located at Thailand's largest processor of cassava root. Sanguan Wongse Industries Ltd (SWI) produces 750 tons of native starch per day. WSL has designed Asia's largest anaerobic digester extracting more than 90,000m³ of biogas per day from SWI's daily discharge of more than 7,000m³ high-strength wastewater. The biogas replaces 7 million litres of heavy fuel oil used by SWI to dry starch and also will fuel an electricity generation plant that will provide over half of SWI's electricity demand.

The construction of a 3.0 MW electricity generation plant was completed in February 2004 with further electricity generation capacity to be added at a later stage. The project included all stages of development of a low-cost anaerobic treatment and biogas harvesting system for a flow of 300 m^3/h high strength industrial wastewater.

Camellia Waste to Energy, Sydney, Australia

This project is a commercial venture designed to recover energy and fertiliser from 51,000 tonnes/year of food wastes from supermarkets, restaurants and food industries. At full production of Stage 1 the facility will generate approximately 3.0 MW while utilising the waste heat to produce high quality organic fertiliser. Waste Solutions has been the designer from concept through to realization of this AUD 30,000,000 project. Waste Solutions conducted the plant commissioning and worked with the client to allow the introduction of the more highly contaminated wastes that are available to allow plant capacity expansion.

Fortex Silverstream, Mosgiel, New Zealand

The project involved primary treatment of high-strength abattoir wastewater, DAF float material and sheep droppings. The design, build and operate contract included a 120 m^2 DAF, 1,500 m^3 CSTR anaerobic reactor, solids handling facilities and variable speed pumping station servicing 12 km pipeline to an existing municipal WWTP.

Horotiu Anaerobic/Aerobic Treatment of Landfill Leachate, Hamilton, New Zealand

The project involved the design, construction, commissioning and operation of a two-stage system for combined anaerobic/aerobic treatment of municipal landfill leachate. This was based on the Covered In-Ground Anaerobic Reactor (CIGAR) concept using plastic materials for lining and cover of the ponds.

Tauranga Anaerobic Digester Upgrade, Tauranga, New Zealand

The project involved the upgrade of two anaerobic digesters including auxiliary plant at Chapel St Sewage Treatment plant. The project also included design and implementation of a new control system.

Anaerobic Digester Project, Portage La Prairie, Manitoba, Canada

The project is in a region with climatic extremes. The digester is designed for anaerobic digestion of pre-thickened Waste Activated Sludge at a municipal Waste Water Treatment Plant accepting waste from one of McCain’s potato processing facilities. The WAS is generated from SBR treatment of the wastewater, and in contrast to most municipal operations where mixtures of Primary Solids and WAS are treated, this is a pure WAS application. Special design and operational features were implemented to control foam production.

Key Staff

The following Waste Solutions Staff will have input into the process design and design review for Waste-to-Energy Projects.

Nathan Clarke - Process and Bioprocess Engineer, Manager, Waste Solutions Ltd

Nathan has a Bachelor of Technology in Environmental Engineering Degree from Massey University. He has MIPENZ membership, and has worked for Waste Solutions Ltd on a variety of projects in practical, design and consulting roles since 1996, including the KWTE project.

Martin Campbell-Board

Martin is a senior staff member of Waste Solutions Ltd. He has a Bachelor of Engineering, (Chemical and Process, Honours) from Canterbury University. He has been with Waste Solutions for 3 years in a project delivery and project development role, most recently focussed on projects in Thailand.
Previously Martin was a regional manager for a food engineering consultant in Australia, and a project manager and process engineer in the NZ dairy industry. Martin has 20 years experience in process engineering, project management and consulting.

Dr Chris Hearn

Chris has a Bachelor of Technology (Biotechnology) (Honours) from Massey University in 1983, and a PhD (Process and Environmental Technology) from Massey University in 1994. Since 1994 Chris has worked for Waste Solutions Ltd on a wide variety of Industrial Wastewater and Waste-to-Energy projects, including a leading role of the Camellia Waste-to-Energy project.

Dr Jürgen H Thiele

Jürgen has a PhD (Microbial Biotechnology) from the University of Tübingen, Germany and 27 years research experience in wastewater and solid waste treatment .He has led industrial and government funded process development projects in the USA, Germany and New Zealand (over 60 research publications and 4 patents) providing anaerobic process solutions including the bio-process design for the Camellia waste-to-energy project in Australia, and molasses distillery waste digesters in Thailand and The Philippines (thermophilic).

Henrik Harmssen

Henrik has a Degree of Engineering (Process Engineering) from the Technical University Clausthal, Germany and joined Waste Solutions Ltd in 2005. Henrik worked, for about 17 years at different German companies and the German Federal Research Centre for Agriculture mainly in the field of anaerobic digestion. Henrik is currently involved as a process design engineer in different digester projects (mesophilic and thermophilic) ranging from sewage sludge to piggery waste digesters.