Regional Co-digestion Facilities for Piggery Manure and Selected Industrial Waste

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Introduction

Regional digester facilities catering for a range of agricultural and food processing customers are quite common in Denmark, Germany and parts of Austria/Switzerland but have not yet found their way into New Zealand. They collect the waste such as pig manure from farms combined with industrial waste with a high content of non recoverable fat and protein and turn these materials, through anaerobic digestion with co-generation, into biogas (renewable electricity), heat (district heating) and value added organic fertiliser (digestate) (Al Saedi, 2000).

While regional digester facilities are successful and economically viable overseas, it would be risky simply to transpose costs and performance from these European examples into the New Zealand situation and design regional digester facilities following the examples from overseas. Different economic boundary conditions (power costs, fuel costs, transport distances, waste disposal costs) and New Zealand specific technical constraints (nature of industrial waste, farming practices, environmental regulations) suggest that it would be prudent to use an optimised New Zealand specific approach adapted to the local conditions. A detailed analysis of the technical and economic feasibility (feasibility study) under real conditions (case study, demonstration project) is then needed prior to commitment to investment.

Over the last 30 years, Waste Solutions, a division of CPG New Zealand, has designed, construction managed and supported their clients with operational assistance for a large number of industrial and municipal digester facilities in New Zealand, Australia, SE Asia and South America. This experience has led to technology options that produce biogas at lower costs than the systems available overseas (Europe, North America). This experience is thus likely quite useful in the design of digester facilities in New Zealand that have reduced construction costs while maintaining performance that is comparable to regional digester facilities overseas.

In 2008, the Energy Efficiency and Conservation Authority (EECA), in conjunction with the NZ Pork Industry Board (NZ Pork) and the NZ Department of Corrections, issued a request for the expression of interest from consultants for conducting a feasibility study for construction and operation of a regional digester facility treating piggery manure and primary processing and municipal/industrial waste/by-products in the greater Christchurch area (Christchurch Hub project). This regional digester facility would receive piggery manure and wastes/byproducts from primary processing, industrial and municipal sources. CPG New Zealand Ltd was chosen as the NZ consultants to conduct the regional digester facility feasibility study for the Christchurch Hub project.

Brief for the Christchurch Hub Feasibility study:

The feasibility study was structured into two components

> (i) a waste audit including analysis of the eco-efficiency of waste transport, the biogas yield and digestibility of the materials and the expected environmental compliance of digestate fertiliser application, and
> (ii) a conceptual level functional description of the facility operation and a rough order estimate of the cost effectiveness of digester facility construction and operation under realistic NZ conditions (Christchurch).

The feasibility study brief further specified that the regional digester facility was to be sited on a “large farm” next to the Christchurch Men’s Prison.

Motivation of the participants

In general, all generators of industrial waste contacted in the waste audit and all contacted pork farmers were very supportive of the underlying concept for a shared regional digester facility to take their waste and supply fuel, power and heat for the prison operation/national grid and fertiliser for the “large farm”.

Industrial waste generators supported the concept in expectation of a waste disposal cost reduction if delivering waste to the regional digester facility. A 20 % waste disposal cost reduction for industrial waste (relative to current costs) was built into the economic model for the feasibility study.

The willingness of the audited piggeries to participate in a regional digester facility scheme was found to be more complex. Piggeries were generally supportive of the underlying concept and the resulting reduced constraints on their piggery management (less site odour, environmental compliance risk, storage costs, and nutrient disposal constraints in wet conditions) when manure disposal to the regional digester facility would become available. However, a number of consulted farm managers specified that they would only choose to supply manure to a regional digester facility if there would be a clear monetary advantage for them in addition to intangible benefits for the operation of the piggery. Therefore, the economic model for the feasibility study had an in-built monetary incentive for piggeries by paying pig farmers for the actual nutrient content of the delivered piggery waste. This was justified because the digestate would be sold again after the digestion and the nutrient content of the digested waste materials is typically not destroyed during anaerobic digestion of organic materials.

Control of waste quality

Based on extensive experience (Hearn and Thiele, 2004; Thiele 2000; Thiele 2009) with the design and operation of digester facilities in New Zealand (Palmerston North) and other parts of the world (Sydney, Europe), CPG New Zealand understands that the commercial and technical success or risk of anaerobic digester facilities in all cases hinges mainly on

- a good understanding of the nature and seasonality of the waste material;
- a digester facility process design that is suited for the waste mixture under all operating conditions;
- a suitable size of the final digester facility operation (favourable economies of scale for the whole and all process unit operations);
- reasonable transport distance between the waste source and the location of the regional digester facility;
- a productive use for all digestion residues (ideally as fertiliser spread on land); and
- supply of all incoming feedstocks/waste at “zero” or “negative costs” (gate fees).

A crude chemical analysis of the quality/composition/digestibility of the various waste materials for the feasibility study was conducted in the laboratories of CPG New Zealand Ltd to provide a better understanding of the “nature of the waste”.
A further requirement for acceptance of the digestate fertiliser on the chosen “large farm” site was that all incoming material, including the pig manure, should be free of pathogens. This was a specific request by the host farm management. Thus the digester facility process design by CPG New Zealand Ltd specified the initial pasteurisation (70-80^{o} C, 1 hour) of all incoming manure and food industry waste with the purpose to sanitise the digester feedstock by destroying pathogenic bacteria, fungi and other microbial life. The pasteurisation is fuelled by the produced biogas. The net energy requirement for the heat treatment of the incoming materials is less than the heat needed for digester tank heating and the residual heat in the pasteurised materials per day is comparable to the daily heat required for maintaining the digester tanks at 35-37 ^{o}C. Thus, if well designed, the initial waste pasteurisation is not a “drain” on the energy production in the digester facility.

Figure 1: Example of a containerised module for pasteurisation of 100 t/day of incoming liquid waste in a digester facility.

Generally, the digestate from the regional digester facility was also required to meet the NZ Biosolids Guideline grade Aa for unrestricted use as agricultural fertiliser. A constraint on all incoming waste was thus the absence of significant levels of heavy metals in the combined waste materials. Many municipal biosolids in New Zealand have elevated levels of heavy metals disqualifying them as feedstocks for regional digester facilities that are designed to produce both, renewable energy and fertiliser as major value added products.

Evaluated waste supply scenarios:

Three different waste supply scenarios were tested in the feasibility study. Two scenarios modelled a scheme with participation of all contacted parties (Maximum scenario: 7 pig farms, 5 factories) and a scheme with participation of only the parties closest to the facility (Minimum scenario: 2 pig farms, 3 factories). The third scenario used for a conceptual design and costing including 5 factories and 4 pig farms.

Table 1: Key mass flow parameters for the three waste scenarios tested in the study

Scenario	Waste processed (t/day wet)	Methane produced (m^3/day)	Renewable Fuel Produced (GJ/annum)	Electricity Generation Potential (KWh per dayl)	Digester tank size ($m^{3)}$
Maximum	102	8,400	65,700	18,000	2 x 3,000
Minimum	52	4,400	35,100	9.500	2 x 2,000
Concept	100	7,100	55,640	15,200	2 x 2,000

All three scenarios resulted in a digester facility size where sound digester facility operation has been shown to be technically feasible. This technical feasibility has been proven by more than 10 years documented experience with the operation of over 20 Danish regional digester facilities using piggery manure and industrial waste (Al Saedi, 2000).

Waste transport cost and eco-efficiency

The transport costs and eco-efficiency for transport of the industrial waste materials and pig manure from selected factories/farms to the Christchurch Hub site were calculated in all scenarios based on the actual distance to the regional digester facility, two way transport distance and specific transport operating costs of 0.17 NZ$/t/ km. This cost was based on the assumption of the use of new vehicles, 50 % laden transport and includes capital, fuel, driver, repairs and other costs (Pearson, 2007). Although these costs were determined for transport with large trucks, a specific enquiry with a Canterbury pig farmer managing his own manure disposal arrived at average manure transport operating cost of 2.1 $/km for a 12 t payload (50 % laden transport assumed, = 0.175 $/t/km). Both values were in good agreement and exclude a contractor's profit margin and risk provision. For the purpose of determining waste transport costs in this feasibility study it was therefore assumed that the digester facility would operate the waste transport services under its own control.

Transport costs for the selected industrial waste materials to the regional facility were generally found to be less than 15 % of the digester facility gross revenue generated from gate fees, waste specific biogas sales and added nutrient value from digestion of the industrial waste.

For the eco-efficiency test of the transport of manure and industrial waste materials a specific transport energy use of 0.145 l diesel/t/km was used (Thiele, 2008b). Eco-efficiency ratios of industrial waste transport (biogas energy output/diesel energy input) were positive when using this fuel consumption figure and very significant for industrial waste materials with a biogas energy output/diesel energy input ratio ranging from 13 to 65.

Eco-efficiency ratios of piggery manure transport from piggeries were positive but lower (biogas energy output/diesel energy input: ratio of 1.5-16). Reduced eco-efficiency was caused by the higher water content in the piggery manure. Transport distances used in the eco-efficiency calculation were the actual distances to the Christchurch Hub site, while the biogas yield from the transported waste was derived using the actual waste composition as an input parameter.

Digester Process Constraints

One of the most important questions at the feasibility study level is whether the digester process will be stable and quantitative for a given waste mixture and whether the methane yield will be achievable. Typically, this risk is addressed at the design stage by conservative process module sizing (i.e. large hydraulic residence time) and conservative assumptions about the normally achieved volatile solids destruction in a digester with a given **H**ydraulic **R**esidence **T**ime (**HRT**).

The HRT in the maximum waste amount scenario with fresh waste fed at a 10 % TS consistency was 39 days at 35°C (6,000 m^3 digester working volume). This was designed to aggressively digest the loaded fat and protein materials in the industrial waste.

The digester sizing (39 days HRT in the maximum waste amount scenario) is conservative and uses larger tanks than typically employed for sewage sludge digestion. The conservative digester sizing is dictated by the fat and protein content of the feed materials and is aimed to maximise the methane production from the loaded industrial waste – especially waste materials with a high fat content (Broughton et al, 1998).

Renewable Biofuel Production Estimate

Two different methods were used to estimate the daily biogas production (60 % methane in the biogas) from the volatile solids of the processed waste. The results are shown below.

Table 2: Biogas production estimates for the three scenarios tested in the study

Scenario	Biogas (m^3/day) method 1	Biogas (m^3/day) method 2	Minimum renewable fuel production (GJ/annum; after process heat)
Maximum waste	8,400	8,500	51,900 GJ/annum
Concept Design Scenario	7,100	7,250	41,900 GJ/annum
Minimum waste	4,400	5,000	23,500 GJ/annum

Both methods for estimating the daily the biogas gave quite consistent results. It must be noted that each value above carries an inherent uncertainty of about +/- 25 % because only one waste sample was analysed for each factory/pig farm. The uncertainty can be reduced to +/- 10 % by confirming the waste sample composition data with analysis of a larger number of independent repeat samples of the waste materials sampled throughout the year at different dates and in different seasons

Seasonality of biogas production and use

A detailed analysis of the cost effectiveness of available options for the biogas end use from the farm based regional digester facilities showed that the sale of the biogas as a heating fuel substitute to a large institutional customer such as hospital, school complex, municipal buildings or correctional facilities would be the most cost effective option.

The seasonal characteristics for the preferred end energy use in the feasibility study is shown in Figures 2 and 3 with priority going to digester heating and waste pasteurisation (about 20 % of produced biogas) to guarantee the biogas production on an hourly basis. Limited biogas storage is provided in the digester tanks as a buffer (about 4 hours production as biogas storage). The “lion’s share” of the biogas is piped to the prison to replace diesel fuel and LPG use (Figure 2). Surplus biogas is sold as discounted fuel (1.3 c/kwh biogas) to operate a biogas genset to produce electricity. Electricity can be either sold back to the digester facility, the local utility company or to the prison operation (Figure 3). The produced electricity is valued at the marginal value of the power purchase price for large institutional electricity consumers.

It is likely there would be other preferred biogas use options at other regional digester facility sites in New Zealand, especially when natural gas pipeline connection is possible.

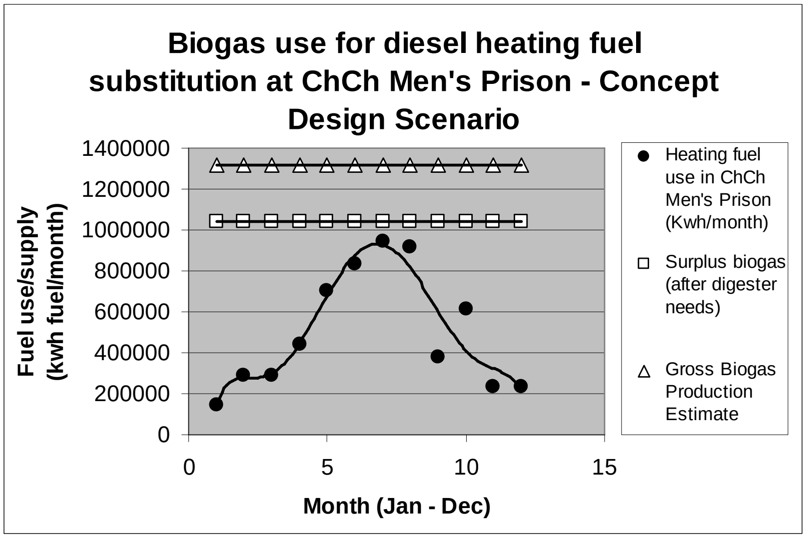

Figure 2: Biogas end energy distribution in the concept design scenario

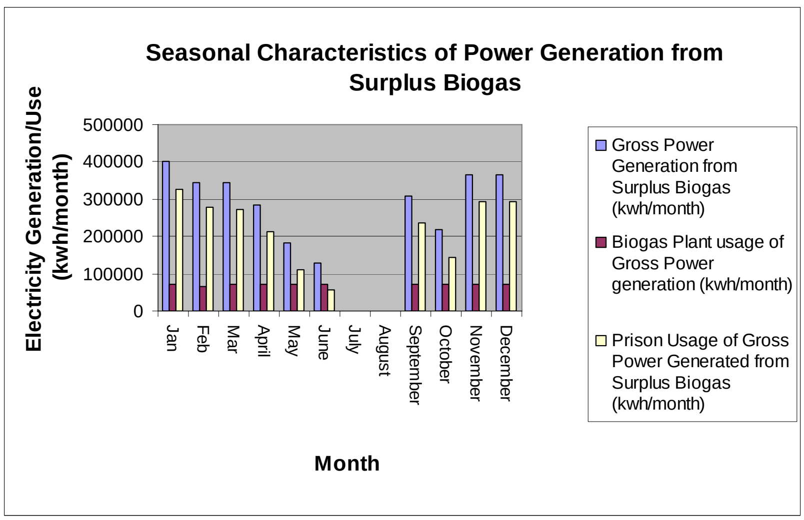

Figure 3: Electricity generation from surplus biogas in the concept design scenario

Digester Facility Revenue Stream Estimate

Based on the biogas end use infrastructure described above, the following digester facility annual gross revenue flow was estimated:

Table 3: Digester facility Upper Gross Annual Revenue Flow Estimate ($/annum)

Scenario	Biogas sales replacing diesel use as heating fuel @ 10 c/kwh ($/annum)	Sales of surplus biogas as genset fuel @ 1.3 c/kwh biogas ($/annum)	Gate Revenue industrial waste expected ($/annum)	Total maximum Gross Revenue expected ($/annum)
Maximum waste scenario	602,100	130,000	494,880	1,226,980
Concept design scenario	602,100	101,065	436, 582	1,139,747
Minimum waste scenario	527,900	34,562	420,823	983,285

Note: *Inherent uncertainty +/- 25 % due to uncertainty in underlying data*

Capital and operating cost estimate (CAPEX, OPEX)

The rough order construction costs estimate (+ 20 %, - 10 %) for a concept scenario digester facility was 5.2 million NZ$ (data not shown). The estimate included design fees, contingencies and contractors margin which may not always apply (for example for construction of multiple facilities using one common design).

The financial analysis after subtraction of estimated digester facility operating costs showed a simple payback period of 5.8 – 7 years at current fossil fuel (diesel/ LPG) and fertilizer prices.

Table 4: EBITDA analysis. (EBITDA: Earnings before Interest, Tax, Depreciation, Amortisation)

Item	**NZ$/annum**
Indicative operating expenditure	
Labour	
Digester plant operator (1.5 position), incl overheads	90,000
Waste Transport costs	
Piggery manure (piggery 1M, 3R, 4T and 5C; 32,000 t/annum)	108,956
Industrial waste (5060 t/annum)	15,590
Payment to nutrient content of delivered manure (122.2 t N/annum, 1.82 t P/annum, 43 t K/annum)	275,604
Energy	
Electricity use: 500,000 kwh/annum @ 0.11 $/kwh	55,000
Insurance and maintenance	50,000
Digestate carting costs	By fertilizer users
Total operating expenditure	**$ 605,150**
Indicative operating income	
Biogas sales as heating fuel (gross production: 19 million kwh/annum) 6 million kwh/annum @ 0.1 $/kwh diesel fuel	600,000
Gate fees for industrial waste (80 % of current disposal costs)	358,084
Fertiliser value of digestate	379,927
Payment received for waste transport services	124,546
Biogas sales to genset operator @ 1.3 c/kwh gas	110,000
Total operating income	**$ 1,572,557**
EBITDA	**$ 967,407**
Simple payback period: 5.8 years	

(EBITDA: Earnings before Interest, Tax, Depreciation, Amortisation)

Sensitivity Analysis of the EBITDA

Variation in waste characteristics: The input information available for the waste materials used to derive this EBITDA was collected with an inherent test uncertainty of +/- 25 % due to the small number of samples collected from each waste supplier contacted. The main reason for this uncertainty was the limited funding that was made available which prevented extensive testing. It would therefore be prudent to firm up this feasibility study with further waste testing during preliminary design before firmly committing to a construction project.

However, due to the fact that about 10 different waste suppliers and 7 different types of waste were combined in the digester facility feedstock in this feasibility study, the sampling risk has somewhat been reduced (law of averages), especially if different waste materials differ in seasonality.

Variation in construction costs: The rough order construction cost estimate was given with an inherent tolerance of – 10 % + 20 %. We estimate therefore that the EBITDA analysis will have an inherent combined uncertainty of approximately +/- 15 %. (i.e. about 1 year uncertainty in the payback period). Having therefore a simple payback period of 7 years in the minimum waste scenario and 5.8 years in the maximum waste scenario appropriately represents the range of financial investment uncertainty for this project.

Variation in realized fertilizer revenue: A significant additional uncertainty comes from the $ value used for the digestate fertiliser. Valued in the current analysis by its true chemical nutrient content (N/P/K), the actually realised market price could be well below that value (50 % or less – especially in the early years of facility operation and fertilizer application).

This would add an additional investment risk and it is therefore recommended to secure firm contracts for digestate fertilizer purchase before engaging in the investment and construction. Otherwise the regional digester facility payback period could be about 1-2 years longer than specified above. Expected fossil fuel and electricity energy price increases over the next decade would improve this position because fertilizer production is generally energy intensive.

Variation in realized energy sales revenue: It is unlikely that a risk exists for the biogas sales as diesel fuel substitute because the use of biogas in the heat market is a well proven and technically sound proposition. Expected fossil fuel and electricity energy price increases over the next decade would further improve the position.

Unavailability of the selected industrial waste materials: The incentive for industrial waste generators was a 20 % reduced gate fee when waste was delivered to the digester facility (compared to the alternative means of disposal i.e landfill).
A important hypothetical question addressed in the feasibility study report was: What would the financial performance of the regional digester facility look like if only piggery manure and no industrial waste was available? This was especially relevant as the gate fees for industrial waste contributed about 50 % of the Gross revenue stream for the digester facility (see Table 3, above).

A cursory market survey during the study identified the immediate availability of about 2 times the amount of suitable good quality and readily digestible industrial waste within the collection area (40 km collection radius) for the regional digester facility. Only strong competition by other regional digester facilities with overlap in the "collection radius" would be likely to cause a shortfall of available industrial waste

If the regional digester facility was designed for manure treatment alone, the construction costs would be reduced to about 4.3 million $ (+20 % , - 10 %). The biogas yield would be reduced from 8,400 m^3/day to 4,800 m^3/day. Biogas sold as diesel substitute for heating would remain about the same as in the Concept design/minimum scenario with some additional diesel heating fuel use in the peak winter months. Operation without industrial waste income would have a simple payback period of 13.6 years and thus be commercially unattractive.

This comparison illustrates clearly the underlying synergy of the co-digestion concept with sale of the total fertilizer and the additional gate fee income from acceptance of the industrial waste. This results are consistent with the Danish experience with operating regional digester facilities.

Main Drivers for Establishment of Regional Digester Facilities

The main operational drivers and issues identified for regional digester facilities in New Zealand from this analysis were the following:

- Quantitative sale of biogas, heat and power between the adjacent large heat user (industrial/institutional) and the regional digester facility and/or a third party involved in the cogeneration from the biogas. This includes the registration and marketing of cogeneration dependent suitably verified carbon credits in international carbon markets.
- Compensation of pig farmers for the fertiliser value of the contributed pig manure at a fair fertiliser (N/P/K based) price. Typically, that compensation value would be higher than the manure transport costs to the regional digester facility generating additional revenue to the contributing pig farmers.
- Payments to the digester facility for produced heating fuel at a price of at least 10 c/kwh fuel (1 $/liter diesel fuel equivalent). This would still maintain an incentive for the heating fuel user to substitute diesel/LPG use with the biogas.
- Agreement between the "large farm" and the digester facility on acceptance and utilisation of all produced digestate as farm fertiliser at a fair fertiliser (N/P/K based) price. Alternatively, negotiation of secure long term digestate purchase agreements with other parties outside the prison.
- Operation of the waste transport services by the digester facility itself to be able to offer attractive waste transport costs. If the waste transport were organised by outside contractors, the higher specific costs ($/t.km) including the contractors margin are likely to limit the amount of waste materials that can be economically accessed and thus limit the size and thus an attractive economy of scale for digester facility construction and operation.
- Auditing procedures for the incoming waste materials to guarantee high quality for the digestate fertiliser (low heavy metal content, NZ biosolids guidelines class Aa status).
- Auditing procedures for the incoming piggery manure strength/nutrient content to be able to determine a fair compensation for pig manure deliveries from individual farms.
- Digestate storage during the wet season for up to three months to be able to maximise the benefits from digestate use on the prison farm. Adequate facilities for digestate storage and rapid digestate tanker loading are also key for the effective sale of digestate fertiliser to other customers

Key conclusions from the study

The use of a rigorous and thorough waste composition and availability audit combined with an economic feasibility study for the Christchurch Hub regional digester feasibility study has demonstrated the following:

1. Regional digester facilities for piggery manure and selected food processing industry waste are proven technology and economically viable under NZ conditions if the biogas is sold for diesel/LPG substitution in the heat market.

2. It is expected that the simple concept can be repeated and is economically viable at numerous sites in New Zealand.

3. The size of potential regional digester facility opportunities in New Zealand, such as the Christchurch Hub project, provides additional options to add value to surplus

biogas by purifying the gas to pipeline quality bio-methane for use in CNG vehicles or natural gas substitute in reticulated gas systems.

4. The transport of waste materials within 40 km radius to the Christchurch Hub project is environmentally sustainable and cost effective for most of the analysed wastes.

5. The Christchurch Hub Digester Facility would require a digester sized 4,000 – 6,000 m^3 with a hypothetical electricity generation potential of 430 – 815 KW_{el} (uncertainty +/- 30 %). This size is a scale where digester and cogeneration system operation are considered at an economically viable scale.

6. It is very likely that the situation in Christchurch can be replicated in many other regions in New Zealand (Thiele 2007, Thiele 2008). The Christchurch Hub project can thus be seen as a demonstration facility for other dedicated regional digester facilities in New Zealand, particularly for co-digestion of piggery manure and selected industrial waste materials.

7. The construction costs for the Christchurch Hub type Digester Facility are expected to be in the order of 4.5 – 6.2 million NZ$ (2009 $).

8. The gate fees collected for treated industrial waste and a realistic fertiliser price for the sold digestate are key for a good financial performance of the digester facility.

9. The net revenue stream (EBITDA) for a maximum waste supply and a minimum waste supply scenario is expected to be in the order of 950,000 $/annum and 750,000 $/annum respectively.

10. The simple payback period for a Christchurch Hub Digester Facility is in the range of 6 - 8 years. This depends largely on the kind, quality, and quantity of industrial waste materials and piggery manure secured in firm waste supply contracts.

11. If only about 50 % of the value calculated from the N/P/K content of the digestate are realised, a regional digester facility is expected to achieve a 6 - 10 years payback period. This highlights the critical importance of the realised fertiliser value for regional digester facilities that are operated with piggery manure.

12. The renewable biofuel production from the waste treatment operation of the Christchurch Hub project is expected to range from 23,500 GJ/annum/site (minimum scenario) to about 52,000 GJ/annum/site (maximum waste scenario).

13. Practically all produced biogas, electricity and a portion of the by-product heat produced in the cogeneration from the surplus biogas can be utilised and sold back to other customers and the digester facility operation.

14. One key driver for the favourable economics of the Christchurch Hub project is the co-digestion of concentrated industrial waste materials with a high fat content (increased biogas production). CPG New Zealand developed unique fat digestion process technology in the 1990s enabling this process concept and since then has applied this technology in a number of regional digester facilities in New Zealand and Australia.

15. In comparison with other regional digester facilities in New Zealand and Australia, the Christchurch Hub project outlined in this feasibility study has the expectation of faster payback and improved environmental benefits mainly through additional income via use of the digestate residue as agricultural fertiliser.

16. The environmental co-benefits of the Christchurch Hub concept are significant. The co-benefits in addition to the addition of new power generation capacity are mainly

    - renewable energy/fuel production,
    - fossil fuel substitution in the heat and transport sector
    - odour emission abatement through effective treatment of raw pig manure,
    - nutrient run-off reduction through fertiliser storage at the facility,
    - methane emission abatement from piggeries and food industry waste

17. The manure transport costs to the digester facility (as a function of the distance and manure strength) are for most piggeries covered by the nutrient value credit paid back to farmers for manure delivery at the digester facility gate. Manure pre-thickening on farm prior to transport is advantageous but not required in most cases.

18. All analyses and test conducted so far in the feasibility study point towards the technical, economic and environmental feasibility of a regional digester facility at the Christchurch men's prison.

19. A future option for the regional digester facility would be the purification and compression of surplus biogas as fuel for farm vehicles and waste transport vehicles. This could improve the payback period to about 4.3 years in the maximum waste scenario. This option should be explored in a separate feasibility study.

20. The points above all demonstrate that shared regional co-digestion facilities can offer a significant benefit for the NZ Pork industry and the energy sector.

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