Prepared for

Food Hawke's Bay

Bioenergy Assessment –

Fruit and Vegetable Residue to Energy

By

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Executive Summary

This report outlines the potential opportunity for investment in a fruit and vegetable processing waste fuelled bioenergy plant in the Hastings area.

The study was undertaken in order to provide an assessment of how additional value can be obtained from current supplies of fruit and vegetable waste by turning it into energy. The study was limited to using only anaerobic biodigester technology for the conversion of food waste into energy.

The study showed that despite the biodigester technology having been around for many years there are few international examples where food waste is processed in digesters. Internationally there are a greater number of digesters fuelled by farm stock waste (effluent), although the total number in this category is still very small. The emphasis on processing farm stock waste is driven principally by environmental objectives whereas fruit and vegetable waste is generally not a problem requiring a solution.

Producing methane gas from fruit and vegetable waste is anecdotally considered about three to seven times more efficient than using farm stock waste, or 50 m^3 per 150kg of dry matter.

The study considered three scenarios for processing Hastings area derived Fruit and vegetable waste:

- A small digester in the Omahu Rd area producing gas as a boiler fuel,
- A medium sized digester in the Omahu Rd area producing gas as a boiler fuel,
- A large digester based in the Whakatu area taking all fruit and vegetable waste from the Hastings area and producing gas and electricity.

The study summarises possible fruit and vegetable waste supply quantities from the Hastings area, and discusses the issues of adequacy of supply necessary for continuous digester operation.

Methane gas produced from a biodigester fuelled on fruit and vegetable waste is a suitable fuel for boilers and would be the preferable use in the Hastings area where large quantities of heat are used, rather than using the gas for electricity generation.

The study has shown that the production of biogas from fruit and vegetable waste is close to being commercially viable. It would appear that under certain scenarios biogas fuel could possibly be produced and delivered to boilers for heating at costs of 8 – 11 cents/kWh compared to natural gas supplied to commercial users at around 6.9 cents/kWh. Cogeneration of electricity from biogas was calculated at 17 cents/kWh compared to the marginal cost of grid-connected electricity at 11 – 13 cents/kWh. These costs are based on the best assumptions available, which in practice may vary significantly according to how the project were implemented. These results however indicate that given the level of confidence in the assumptions, that further work on the use of digesters for converting food and vegetable processing waste to energy (and the associated by-products), is justified.

The economics of each scenario also indicate that while gas production for use as a boiler fuel could theoretically be worth considering, the risk factors associated with feedstock, technology and hence energy supply would seriously affect investment decision making.

The study has identified that the use of anaerobic digester technology is in its infancy and as a result the data used has had to be adopted from international digester equipment suppliers and international applications

The location of digesters will be critical in minimising feedstock delivery costs and gas deliver costs. The size of any one waste producer (except for Heinz Watties) is too small to have a digester alone, or the waste from each is too variable in composition and quantity. In particular there is a potential waste supply over the spring period, which will have to be managed by import of waste from orchards or other sources. Any digesters would need to be operated as part of a waste-sourcing cluster. Co-location of a digester with a freezing works / wastewater treatment / waste combustion plant may be one strategy of managing the risk associated with feedstock availability.

The economics of digester operation is most significantly affected by the cost of fruit and food waste collection and delivery. The waste stream already has a positive value in that waste producers are receiving a payment for it or are at least getting it taken away for nothing. If the waste was to be used as digester fuel this would introduce collection and delivery costs that currently don't occur.

The study confirms that converting fruit and vegetable waste into methane gas for use in boilers is technically possible and can be economically a good investment. However the opportunity is most appropriate where the waste disposal is a cost and the waste producer is able to generate enough waste continuously for 12 months of the year. The continuous waste supply can be sourced from a cluster of waste producers.

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Comments:

1. Unless otherwise stated, all currency referred to within this document is in New Zealand dollars.
2. Tonnages for digester projects are quoted as "wet tonnage" for transporting, and "dry matter" for digester operation. This distinction is critical when accounting for transportation cost and gas yield.
3. An average net saleable biogas yield of $50m^3$ per 150kg of dry matter is assumed for this report. Process energy requirements (including feedstock conditioning, digester operation and substrate separation) of 15% have been deducted from gross gas yield to give this figure.
4. Where equipment is supplied from the United States of America, an exchange rate of US$0.60 : NZ$1.00 is applied to imported componentry and intellectual property.
5. Where budget estimates were supplied on a "total cost" basis, these were broken down with respect to publicly available budgets for projects of similar technologies.
6. In this report:

   Waste is considered as by-product of a process which is unused (e.g. by-products of from fruit and vegetable processing, packing and growing).

   Feedstock is considered as raw material (fuel) suitable for an anaerobic digestion process (e.g. waste from fruit and vegetable processing, packing and growing).

   Biogas (consisting of methane and carbon dioxide) is considered as the main product of the anaerobic digestion process.

   Substrate refers to the biological material within the digester and exiting the digester.

   Humus refers to the solid portion of the substrate by-product of the digestion process.

   Liquid Fertiliser refers to the liquid portion of the substrate by-product of the digestion process.

1 Introduction

Food Hawke's Bay has approached East Harbour Management Services with respect to evaluating the potential for a biogas digester project within the Hastings area. This report outlines the potential for anaerobic digester technology to produce energy, in comparison to the current situation of supplying processing waste as a feed for livestock.

Food Hawke's Bay has coordinated the study on behalf of the funding companies (Profruit, CSI Processors, Southmark Quality Foods, and Rakaunui Fruit Company).

The study was also financially supported by the Energy Efficiency and Conservation Authority in order that a waste-to-energy case study could be produced.

While the project was initiated by only some Hastings companies the scope of the study was to cover the whole of food processors in the Hastings area. Information was made available by most companies approached.

The study has identified that the use of anaerobic digester technology is in its infancy and as a result the data used has had to be adopted from international digester equipment suppliers and international applications. The three NZ based suppliers of digester equipment have provided useful assistance to the study.

2 Background

2.1 Status of Hastings Food Waste

There are a large number of food processors in the Hastings area each producing significant quantities of fruit and vegetable waste. Currently this waste tends to be picked up by farmers or others and trucked away for use as stock food. One party stockpiles the waste as silage for later distribution as stock food.

At the processor sites visited during the study the "farmers" removing the waste provided the bins or trucks in which the waste was deposited from the processing plant. This is generally at no cost to the waste producer and in some situations a fee was paid for the waste.

Fruit and vegetable growers also produce waste which could be used as an energy source. The study included apple growers as they have significant windfall or damaged fruit. They also have end of season fruit. Some of this fruit can be processed into juice while the rest is dumped or used by farmers as stock food. The collection of windfall fruit is becoming easier as mechanical retrieval equipment becomes available. Spring thinning of apple trees is considered as a potential contingency supply of feedstock during the otherwise low feedstock availability period (November to January).

Another source of suitable fruit and vegetable waste is from restaurants and supermarkets.

2.2 Anaerobic Digestion

An anaerobic digester is essentially a heated tank into which a wet organic substrate is fed. Oxygen is excluded to allow anaerobic bacteria to liquefy the organic compounds in the mixture and then convert the resulting simple organic acids into a methane rich biogas. Anaerobic conditions allow methane producing bacteria to flourish while inhibiting those that produce foul odours. The liquid residue is a nutrient rich fertiliser. Fertiliser that having lost much of its odour, can be used directly on land. Insoluble compounds such as lignified plant tissue may collect in the digester or pass through it unchanged. The undigested humus has not lost any nutrients and is suitable for storage and then land application, or for sale as stock feed (where appropriate) or as compost or soil conditioner [E.NZ-2004]. Anaerobic digestion does not produce any waste as all outputs have high value and can be used.

The biodigester is usually heated to provide optimal conditions for bacterial growth.

As anaerobic digesters rely on the action of micro organisms, which are temperamental to temperature fluctuations, inappropriate loading rates and retention times, pressure, agitation and contaminants within the feedstock, the digester requires good design and operational management. Modern digester technologies assist achievement of good bacterial growth through careful monitoring and control of digestion conditions. Inappropriate management will significantly affect the biogas yield.

2.3 Status of Digester Applications Internationally

Anaerobic digester technology has achieved significant advances over the last 25 years. This is largely due to the development of industry capability through providing solutions to environmental issues facing primary producers (dairy and pig farmer effluent processing), and sewage treatment. While the technology has advanced there has been a notable absence of other applications e.g. food and vegetable waste, using the technology. In fact world wide there are few specific reference examples (other than of dairy farm applications) that this study could refer to.

In New Zealand, large sewage treatment waste water processing facilities[1] have led the way in uptake of anaerobic digestion technology, using biogas produced from the processed waste to power the treatment plant, and with excess energy exported into the electricity network.

At a smaller scale, several New Zealand dairy farms [NZDE-4-2004] have been trialling anaerobic digesters to process effluent into low-pathogen fertiliser, and to generate electricity. In addition an award-winning engineering concept for a research project has been widely publicised as having the aim of combining small-scale digester and ice-bank and Stirling-engine technologies [E.NZ-2004].

2.4 Digester Suppliers in NZ

There are currently three suppliers of anaerobic digesters in New Zealand.

2.4.1 Waste Solutions

Waste Solutions Ltd (WSL) is a subsidiary of Duffill Watts & King and specialises in providing solutions for the collection, resource recovery, treatment, and disposal of waste streams. It has a particular expertise in handling waste streams with extremely high levels of organic pollutants and to produce concentrated fertiliser products from the digestion residue. Waste Solutions specialises in the provision of low costs digester systems for industrial waste waters (CIGAR, see below) and the specialist services for anaerobic digestion of high lipid waste (flotation foams, animal/plant fats), animal manure, food waste and protein/blood (slaughterhouse waste, fish processing waste).

Since 1975 as the MAFTech biogas group, the group has focused its research towards the development of anaerobic digestion technology in these various sectors including farm crops (grass, silage). This has produced the development of anaerobic digester technology for fats & oils (Figure 1), in ground covered lagoon and anaerobic baffled reactor technology for food industry waste water, high rate thermophilic digester technology for distillery waste and covered in-ground anaerobic reactor (CIGAR) technology for starch and fruit waste (Figure 2).

[1] North Shore City Water Treatment Plant, Christchurch Bromley Wastewater Plant and Hamilton Pukete Wastewater Treatment Plant.

Waste Solutions has undertaken projects based on advanced anaerobic digestion technology using organic waste:

- Solid fish waste – Dunedin; fish processing and packaging factory (2 x 400 m^3 digesters)
- Food residuals – Sydney; supermarket source segregated waste (2 x 5000 m^3 completely mixed digester, about 3 MW_e)
- High fat waste – Mosgiel, slaughtering and meat packaging plant (1 x 1500 m^3 digester)
- Hog waste – Bay of Plenty pig farm waste (covered lagoons)
- Food processing waste – Thailand, cassava starch processing (CIGAR), about 100,000 m^3, 30 MW gas currently converted to 10MW_{th} and about 3MW_e with future expansion to 5MW_e)

For food residuals with high levels of inert contaminants (plastic, glass, packaging, wood etc.), WSL use the patented BTA process, as utilised in 22 plants world wide, with four more under construction [BTA-W]. The process is described in Section 4.1.1.


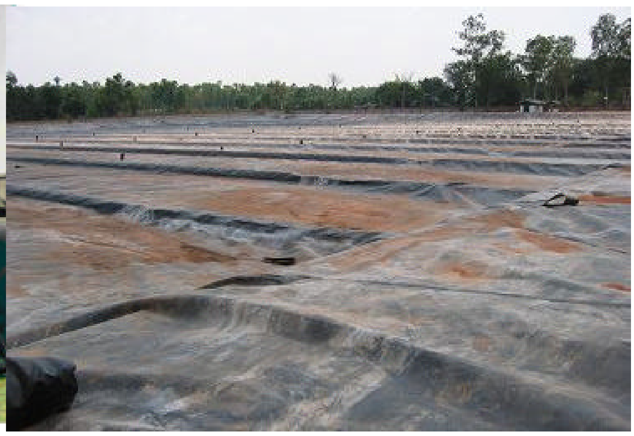

Figure 1 (Left). WSL completely mixed digester for food residuals and high fat waste.

Figure 2 (Right). WSL in ground Anaerobic Baffled Reactor for starch crops (cassava root).

2.4.2 Solwind

Solwind is involved in the design and development of remote area power and alternative energy systems, and is based in Whangarei. Solwind have developed a dual chamber batch-process anaerobic digester system for use on dairy farms (Figure 3).

Digester chambers are installed in-ground to minimise thermal fluctuations within the system. The chambers are made of roto-moulded polyethylene, and insulated from the ground with pumice. The digesters are gravity-fed (not pumped), and the chamber is totally flooded to expel oxygen. This technology is constrained to operation below 55°C, within the mesophilic temperature range.

A key factor that Solwind promote is their control system, which continuously monitors bacteria condition within the digester chambers.

Figure 3. Solwind Dual Chamber Polyethylene Digester System Shown "in-ground" [SOL-W].

2.4.3 Integrated Systems Engineers

Integrated Systems Engineers (ISE) has developed a stainless steel tank digester system that has been trialled on several dairy farms, including a three-digester configuration at *Orini Downs Station* in the Waikato (Figure 4). This technology is plug-flow in nature, and consists of a double skinned, insulated stainless steel enclosure. One benefit of this is that feedstock has potential to be varied without significant impact on chamber contents. The control system can be configured for use with multiple feedstock configurations i.e. apples may be configured to process slower than perhaps tomatoes.

ISE has been investigating the processing of Kiwi fruit waste into biogas, and has experience in developing digester applications on dairy and poultry farms within New Zealand. There are not perceived to be any significant issues in processing fruit waste with this system. An overview of ISE proposed fruit waste processing system is shown in Figure 5.

Some key variables related to fruit as a feedstock that will impact on gas production include:

1. The uniformity of the condition of the raw material.
2. The amount of moisture used.

ISE plant is modular in design, with each digester (54,000 or <u>84,000L</u>[2]) having its own control system (PLC[3]) to monitor and control the biological and gas production process.

[2] The '2.8' (2.8m in diameter), 84,000L unit is the device quoted in this report.
[3] Programmable Logic Controller.

Figure 4. Three ISE Digesters Producing Bacteria-Free Fertiliser and Biogas for a 53 kVA Generator (running for 7 hours/day) [ISE-2004].

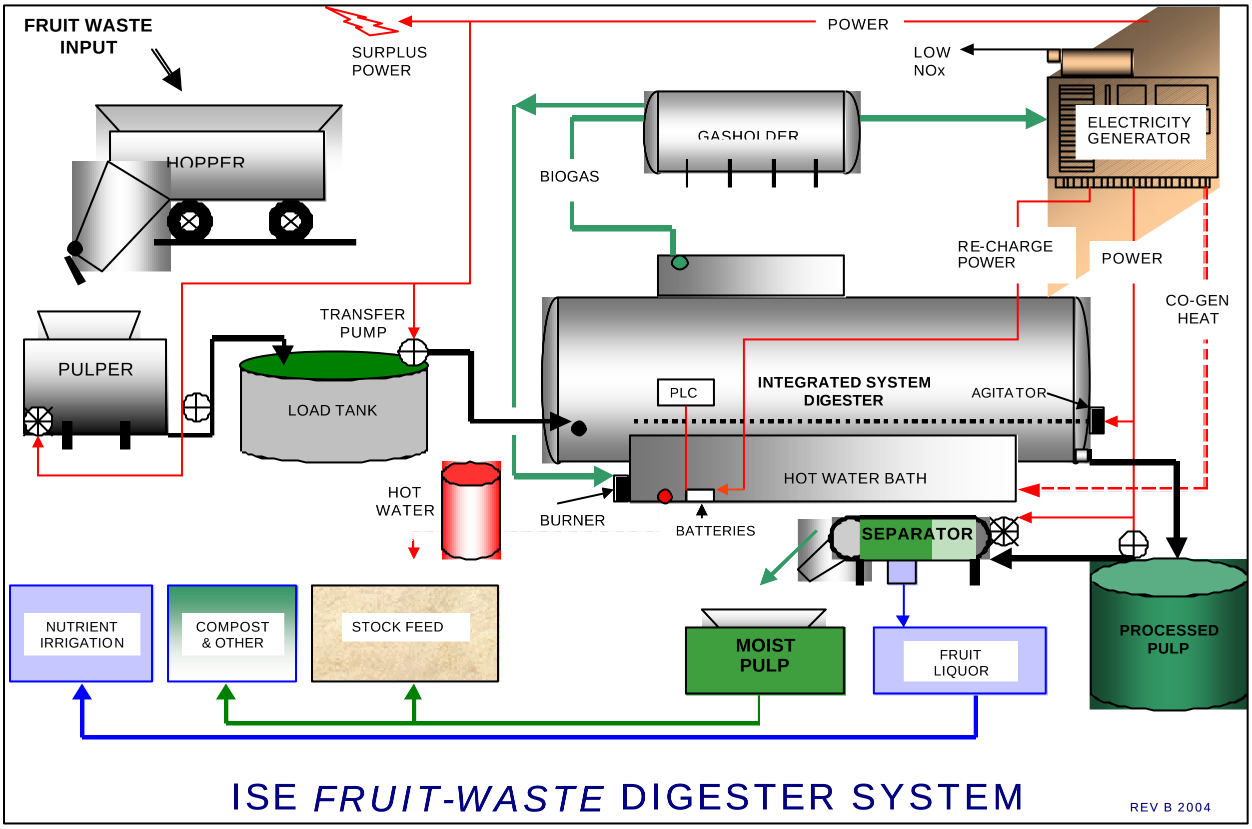

Figure 5. Integrated Systems Engineers Proposed Fruit Waste Digester System Overview [ISE-2004].

2.4.4 RCM Digesters

RCM Digesters (RCM) is an American based company that specialises in developing and commissioning farm waste digesters. RCM's marketing material suggests that almost half of the operating digesters in the USA are RCM digesters, and that RCM has constructed more than 35 digesters since 1982. RCM specialises in farm based digesters.

Digester technologies employed by RCM Digesters include:

- Covered Lagoons: For flush collected pig and dairy wastes in warm climates.
- Complete Mix Digesters: For scraped or pull plug pig or dairy wastes in cold climates.
- Heated, Mixed Covered Lagoon: For scraped or pull plug pig or dairy wastes in moderate climates where the goal is odour control rather than optimum gas production.
- Plug Flow Dairy Digester: For scrape-collected dairy manure in any climate

RCM has provided consulting services in Armenia, Belize, Chile, Colombia, Costa Rica, Ireland, Japan, Korea, Mexico, the Philippines, and Taiwan.

3 Digester Technology

Biogas is commonly produced by anaerobic digestion as part of the treatment of wet organic waste. This occurs in municipal wastewater and sewage treatment plants, industrial operations that have liquid wastes containing organic material (such as meat processing plant), and on farms where animals are kept or held in a small area, such as pig or poultry farms.

In many cases treatment of the waste to produce biogas is not economical in itself but is carried out for other reasons such as waste management (disposal), or reduction in greenhouse gas emissions. Also small-scale generation of biogas is rarely economic because of the high labour requirements and dilute nature of the waste stream (effluent) being treated.

Anaerobic digestion is the decomposition of organic matter in the absence of air to produce biogas. The biogas is a mixture of mainly methane and carbon dioxide with very small amounts of hydrogen sulphide[4] and other impurities. The methane content can range from 50% to 80% (on a volumetric basis).

Biogas from the digestion of crop materials is typically 55% methane[5], and from animal manures typically 65% methane.

The high amounts of carbon dioxide in biogas typically reduce the heating value to between 21 and 25 MJ/m^3 (GCV[6]) compared with natural gas typically around 40 MJ/m^3 (GCV). This means that approximately twice the volume of biogas is required to deliver the same energy as natural gas.

Unless biogas demand meets biogas production, storage may be needed or the biogas flared or vented. Low pressure storage can be in gasometers or butyl rubber bags, however gas has to be pressurised for direct use in boilers or in plant for electricity generation.

Biogas from anaerobic digestion can be used to produce heat for the digestion process itself, or process heat and electricity in other parts of the plant. It can also be upgraded to "natural gas" quality and fed into a local utility network.

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[4] Hydrogen sulphide is a common product of manure digestion. Fruit and vegetable waste digestion produces H_2S to lesser levels (depending on the feedstock).
[5] Methane specific volume (1.013 bar and 21°C) = 1.48 m^3/kg.
[6] Gross calorific value.

The biogas can be used as a fuel in a number of different types of plant such as reciprocating gas engines, mini-gas turbines, Stirling engines, and fuel cells or by direct combustion in boilers or other combined heat and power (CHP) plant.

Anaerobic digestion is a mature technology particularly when used for municipal waste water treatment. Here the scale of and requirement for treatment can justify the costs of installing and operating the equipment needed. However if the organic content of wet waste stream is too dilute, recovery of the energy content will be made more expensive. Excess moisture may also cause handling problems during utilisation. Biogas from anaerobic digestion is essentially a continuous process so it requires a reliable continuous feed of material.

3.1 Digester Design

A key aspect about digesters is that each appears to be specifically designed for each application. While there are similarities between applications there are specific types of design that will suit specific applications. This would be particularly the situation for digesters using fruit and vegetable waste from the Hastings area.

The digester design would require prior testing of the various component feedstocks and agreement on the feedstock recipes for which the digester would be designed.

3.1.1 Modular Plant

A waste-to-energy facility can consist of a large digester or a number of smaller modular digesters. One of the key benefits of modular digester configurations is the reduced effect of potential feedstock contamination. A modular digester configuration allows for an affected digester (one from a bank of several) to be cleared and returned to service (operating temperature) within a short period (days) whereas a large-scale digester configuration may result in considerable loss in operation (weeks or months at considerable energy requirement) due to potential for 100% of the operation being affected by contamination. A modular arrangement may also provide improved operation where there is a range of different feedstocks. Individual specific feedstock mixes may be set for each module.

The feedstock passes through a low-speed agitation process, allowing “fresh” material to be added continuously. This suggests minimal impact on digester performance due to changes in feedstock supply. As the feedstock scenarios within this project vary in content (apples to squash or corn etc) the speed of the flow can be adjusted to cater for varying ideal retention times in each separate module.

Modular digester plant (small-scale) is estimated to require up to one week to stabilise with fruit and vegetable waste, whereas larger digester plant may require several weeks before the operation is stabilised.

Modular plant design increases capital cost but reduces operating risk in variable non-homogenous feedstock situations such as would occur from the feedstock available in the Hastings area.

The development of a modular digester plant is incremental, with investment (or subsequent divestment) in equipment allowing the developer to vary the scale (and location) of plant employed.

3.1.2 Digester Life

Digester suppliers have commented on the reliability of digester equipment once the operators have established optimal plant design, feedstock mixes, and operating procedures. One supplier advised that they had one 1982 farm digester installation operating with no repair or maintenance for 17 years. Discussions with suppliers suggest expected lifetimes of up to 40 years, depending on technology and materials employed.

3.2 Operating Parameters

Anaerobic digesters are available in various configurations, depending upon the feedstock available, and the operating environment. Several key configuration variables are outlined [VERMA-2002].

3.2.1 Temperature

The efficient conversion of organic material into methane requires careful control of process temperature. This is to facilitate the growth of bacteria that operate at different stages of the anaerobic digestion process. The bacterial process itself produces some heat (exothermic), but to maintain the temperature of the reaction, some of the biogas produced is used as a heat source [EECA-1997].

Plant can be designed for mesophilic or thermophilic temperature operation. The mesophilic temperature range for methane production lies between 20 and 40°C, with the optimum temperature range is considered to be 30 to 35°C. The thermophilic temperature range is between 50 and 65°C, which generally results in reduced retention (processing) time. However, a trade-off exists between "quick" production of methane and the energy required to maintain a temperature of 50 to 65°C.

3.2.2 Number of Stages

One-stage digestion occurs where feedstock pulp is fermented within one single step in one mixed-fermentation reactor. This type of technology may be used effectively for comparatively small-decentralised waste management units [BTA-W].

A multi-stage digestion process is more appropriate for plants with a capacity of more than 50,000 tonnes of waste per annum. Pulp is separated into a solid mass from a liquid phase by using a dewatering aggregate. The liquid, already containing dissolved organic components, is pumped into a reactor, and remains there for methanisation over two days. The dewatered solid material, still containing undissolved organic components, is once more mixed up with water and fed into a hydrolysis reactor. After four days the mass is dewatered again and then the liquid is filled into the methane reactor [BTA-W].

3.2.3 Total Solid Content

Low total solids content (<15%) digesters have a large footprint. High solid content (15 – 40%) digesters require smaller footprint, however, operating in the thermophilic temperature range can have retention times in the region of 10-14 days.

3.2.4 Batch vs. Continuous Digesters

Batch reactors process feedstock in one discrete interval, after which digester products are discharged, and the digester is reloaded. These reactors require up to 10 times the footprint of continuous flow digesters [VANDE-2000]. The advantages and disadvantages of batch digester systems are outlined in Table 1.

Table 1. Advantages and Disadvantages of Batch Systems [VANDE-2000].

Criteria	Advantages	Disadvantages
Technical	• Simple • "Low-Tech" • Robust	• Clogging • Need for Bulking Agent • Risk of Explosion During Emptying of Reactors
Biological	• Reliable Process due to Niches and use of Several Reactors	• Poor Biogas Yield due to Channelling of Percolate • Small Organic Loading Rate (OLR)
Economical & Environmental	• Cheap, Applicable to Developing Countries • Low Water Consumption	• Very Large Land Acreage Required (Comparable to Aerobic Composting)

The operation of continuous flow digesters can be adversely affected by variations in feedstock and so require robust waste reception criteria.

3.3 Digester Outputs

The outputs of anaerobic digestion process are outlined, taking into account:

- Thermal energy
- Electrical energy
- Fertiliser or stockfeed
- Environmental benefits

3.3.1 Biogas Output

The yield of biogas varies significantly from one feedstock to another. This is due to the percentage of dry matter (DM or total solids), and in turn, the percentage of volatile solids (VS) within the feedstock. From conversations with digester suppliers [ISE-2004, SOL-2004], fruit and vegetable waste is considered as offering between three and seven times the yield of cow slurry. The net saleable biogas yield of fruit and vegetable waste is quoted as being between 36 and 48m^3/wet tonne of feedstock[7] [STEFF-1998]. Conversations with other suppliers [BIL-2004, WSOLN-2004] tend to suggest somewhat higher biogas yields (50 - 60m^3 per 150kg dry matter), primarily due to the use of decanter pomace as a feedstock.

For the purposes of analysis in this study, a gross biogas yield of 60m^3/150kg(dry matter) has been used which is in line with international data (Figure 6). This yield is based on conversations with suppliers (and previous suppliers) of biodigester equipment [BIL-2004, WSOLN-2004]. This results in a net saleable biogas yield of approximately 50m^3/150kgDM. A sensitivity of ±20% is used in the economic analysis, which takes into account the significant variation in net saleable biogas yields quoted by both equipment suppliers and literature.

[7] Assuming 15% of energy produced is used by the digester plant and feedstock processing equipment.

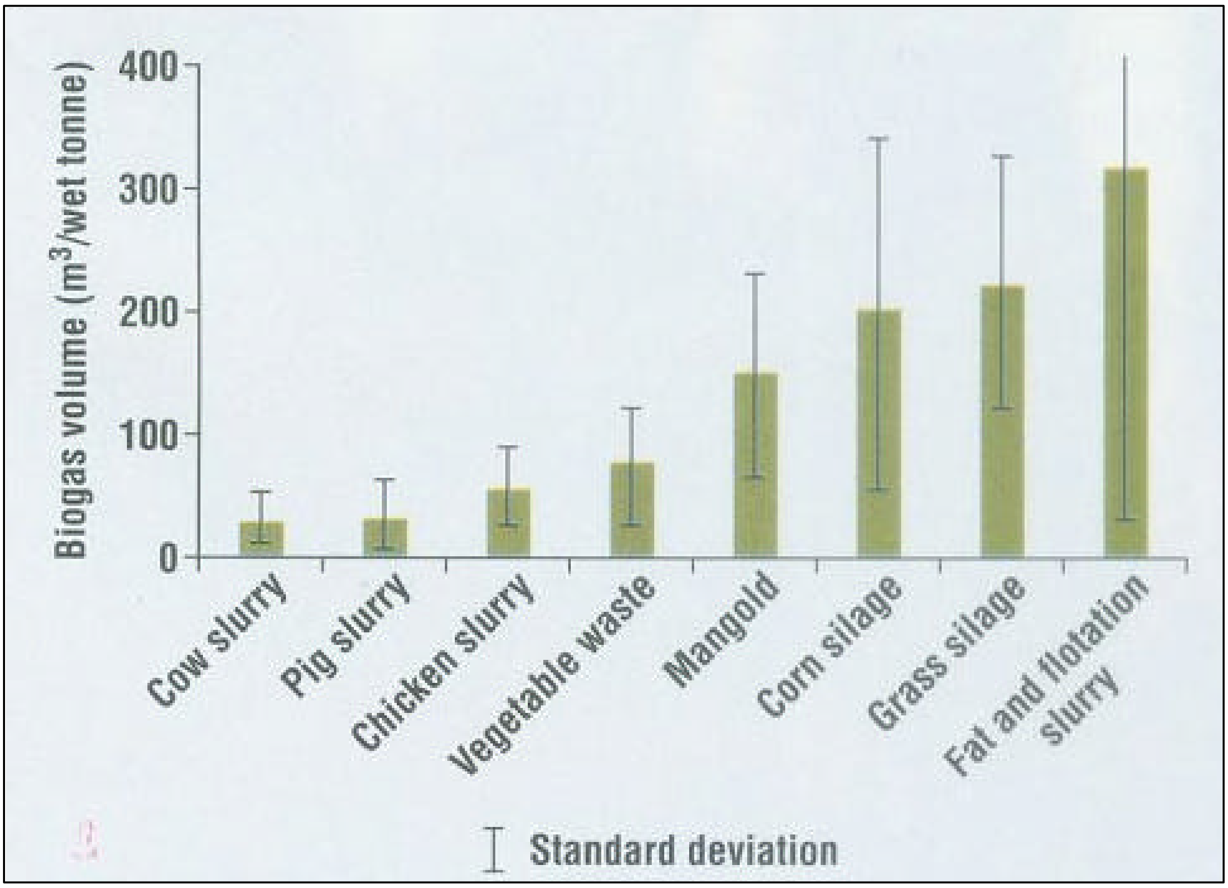

Figure 6. Average Biogas Yield per Tonne of Wet Waste for Some Possible Substrates (Showing Variance) [REWLD-2-04].

3.3.2 Gas Treatment

Biogas typically contains significant amounts of water, siloxane (silicate compounds) and CO_2. Water may have to be removed prior to compression and supply of the gas for cogeneration use. It may not have to be removed for direct use of gas in a boiler.

CO_2 may be problematic due to it mixing with water in the gas and forming carbonic acid which is detrimental to most process equipment. Several CO_2 treatment options are described in Table 2.

Table 2. Basic CO_2 Separation Operations [REWLD-3-04].

Basic Operation	Method	Separation Effect
Absorption	Pressurised water scrubbing	CO_2 dissolves in water
Chemical absorption	Scrubbing in a chemical liquid	Chemical reaction between CO_2 and liquid, such as a monoethanolamine bath (MEA)
Adsorption	Pressure swing adsorption (PSA)	CO_2 retention in a carbon molecular sieve
Membrane separation	Gas separation in extra-fine membrane	Differing membrane permeability for CO_2 and methane (CH_4)
Cooling	Low-temperature separation	Phase separation of liquid CO_2 and gaseous methane

Gas supplied to cogeneration equipment may also require filtration to remove any solid contaminants.

3.3.3 Direct Use of Gas

Biogas can be used directly in boilers for heating water. Because of its low calorific value, the volumes used are more than for natural gas, so pipe sizes have to be larger and pressurisation is required for transmission over long distances (i.e. 2 km).

Biogas does not require specific treatment if used directly in boilers but would require very specific treatment if it were to be reticulated for other uses including residential use. For the purposes of scenarios A and B of this study, it is assumed that biogas would only be used directly into existing boilers and thus no treatment is required. For the cogeneration option within Scenario C, treatment is assumed.

Biogas calorific values will fluctuate according to feedstock and digester operation so storage tanks are important in trying to ensure some uniformity of gas quality by mixing. They also provide a buffer for supply quantity, so may be conservatively sized unless security of supply is provided by natural gas. This would require dual firing capability.

Boiler controls are also able to deal with fluctuations in fuel quality.

3.3.4 Cogeneration

Biogas may also be used in gas turbines or gas engines for the production of electricity after only minimal treatment for removal of contaminants such as water and hydrogen sulphide. An advantage of gas engines is that they are also efficient producers of heat so are good for cogeneration applications. A gas turbine however requires a heat recovery boiler in order to recover the heat component.

In this study the cogeneration option is only considered for the large digester scenario as it would be unlikely that the cost of cogeneration equipment would be incurred when direct use of gas would be at a lower capital cost.

3.3.5 Fertiliser or Stock Feed

The solid waste (processed pulp) and fruit liquor removed from the biodigester after food waste processing is a very good fertiliser and can be used directly or dried for use as compost. It may also be fed to pigs as a meal. The material is clean of weed seeds as these will be destroyed during the digestion process. Other harmful bacteria are also generally destroyed. The specific make-up (Nitrogen/Phosphorous/Potassium) of fertiliser output is currently not known, this can be evaluated through testing, should a digester trial be exercised.

Discussions with Earthpower Ltd (owner/operator of the Sydney digester plant) indicate that the by-products of the digester process are dried using waste heat from its electricity generators [EARTHP-2004]. The water component is discharged to a sewer, while the solid component is pelletised and on-sold as organic fertiliser[8]. Through drying the fertiliser, transport costs are reduced. However, as the energy from a Hastings digester is likely to be used off-site for direct heat generation, it is likely that the fertiliser will be sold in liquid form. Once the make-up of the liquid fertiliser is known, it's suitability for application on adjacent orchards or dairy farms may be evaluated.

3.3.6 Environmental Benefits

It appears that environmental considerations have been the main drivers for most digester applications. This has been particularly the situation for the processing of farm stock waste, and factory waste disposal where the main synergy for biogas is between waste management and environmental controls.

[8] The pelletised fertiliser was mentioned as being similar in nature, if not slightly better than *blood and bone* [EARTHP-2004].

There are significant environmental benefits from waste digestion. These include reduced impacts of the effluents and solid waste disposal. Sludge (substrate) from the digesters can be returned to the soil as fertiliser, or in the case of food waste, may be fed to pigs [WSOLN-2004].

Production, collection and use of biogas reduce methane emissions to the atmosphere. Methane as a greenhouse gas has 21 more times greater effect than carbon dioxide. Hence, using biogas from a sustainable source is nearly carbon neutral. The energy from biogas will replace energy from other sources which may have come from non-renewable fossil based sources.

The benefits of reduced waste disposal costs often appear but the concept of making money out of turning waste into energy rarely appears in the literature.

4 International Digester Applications

The study has endeavoured to seek information on actual applications to supplement information provided from equipment suppliers. However there is a general shortage of information on actual applications relating to processing food waste into energy. There is significant information on processing waste from farm stock and there is general information on anaerobic digestion technologies.

The following examples of applications provide information that would be useful for implementation of a food-to-energy project in the Hastings area. The information on some farm digester applications has been included where there are issues that could also apply to a food feedstock application.

4.1 Fruit and Vegetable Waste Digester Projects

4.1.1 76,000 Tonnes/year in Sydney (Australia)

Earthpower Technologies[9] owns and operates a $17.7 million anaerobic digester at Camellia in western Sydney. The facility has been designed by NZ based Waste Solutions Ltd using the German BTA technology for waste pre-treatment and sorting and NZ based FloDry Ltd dryer technology for production of dried, granulated fertiliser product. The project is operated as a tolling operation by a private consortium [EARTHP-W] consisting of and associated with:

- **Environmental Infrastructure Limited**, an Australian public company that invests in the environmental services and renewable energy sectors.
- **Babcock and Brown**, an independent international investment banking firm that specialises in acquiring, managing, structuring and arranging finance for a target spectrum of "big ticket" assets, projects and other opportunities around the world.
- **Country Energy**, an energy trader who has signed a multi million dollar agreement with EarthPower Technologies Sydney Pty Ltd to secure electricity from the energy plant. Country Energy provides energy solutions to over 750,000 residential and business customers.
- **Paton Fertilizers** who are specialists in horticultural, turf and home garden fertilizers and will be marketing Earthpower organic fertilizer.
- **CMR** who creates, defines and implements projects across a wide variety of industries.
- **The Australian Greenhouse Office** is the lead Commonwealth agency on Greenhouse matters. Commonwealth Government funding through the Australian Greenhouse Office supports this project.
- **Sustainable Energy Development Authority** is an agency of the New South Wales Government, set up in 1996 to reduce greenhouse gas emissions associated with electricity generation.

[9] http://www.earthpower.com.au

The waste is taken from supermarkets but the plant has an ability to take food waste from other sources. The ability to vary the process was to enable the owners to adjust the process outputs to maximise market returns. However this has had its downside, as it is understood that the plant is being used to take waste outside its specification. The non-biodegradable wastes included in the waste stream affect the efficiency of gas production, and hence the economics of the operation. The digestion process is a variation of the patented BTA process (Figure 7) replacing the post composting of the digestion residue with thermal drying to granulated organic fertiliser.

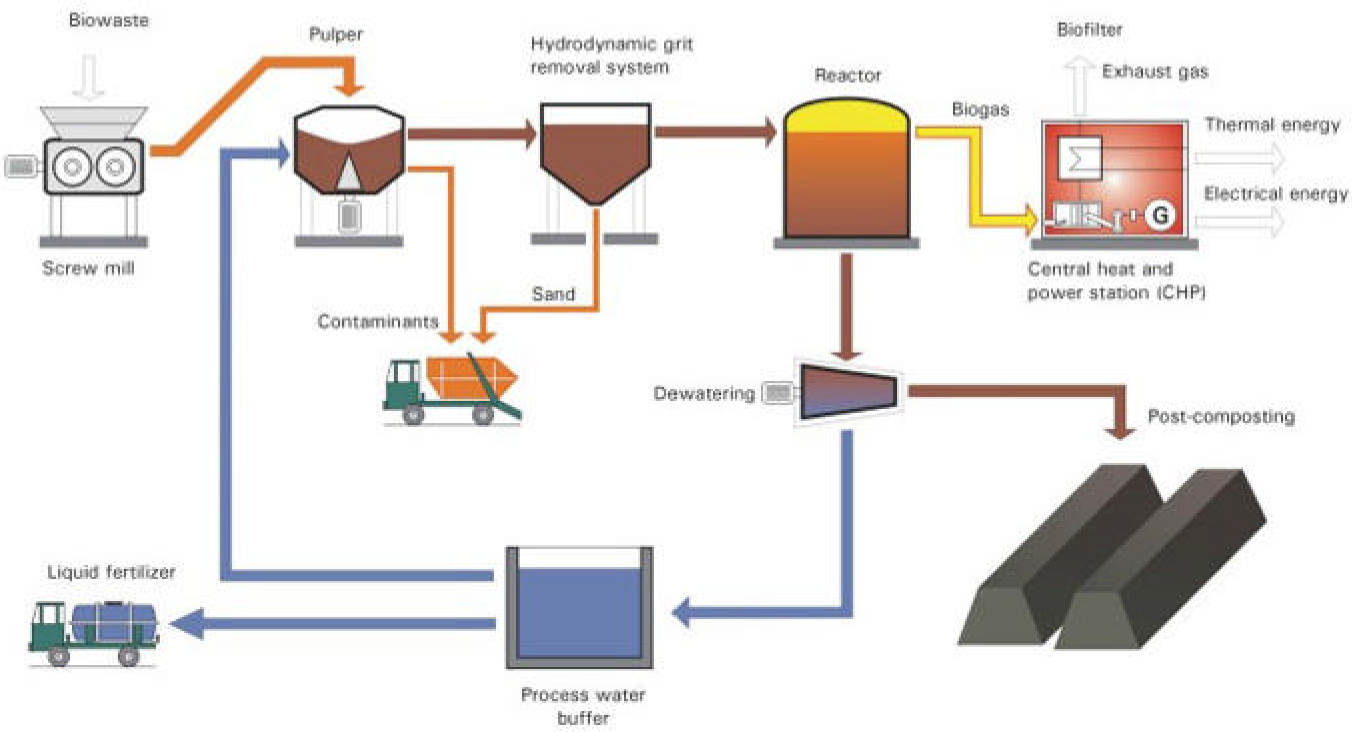

Figure 7. Schematic of the Single -Stage Solid Waste Anaerobic Digestion Process [BTA-W].

Information from the facility owner is that on an "as received" basis, one tonne of waste produces:

1.4GJ (110-130 Nm^3)[10] biogas energy
180Kg of dried organic fertiliser.
0.7 m^3 of treated water.

The first stage for development of the facility is to process 82,000 tonnes per year, with plans to expand to 140,000 tonnes per year. This project was completed 2001 and is designed to produce 3MW of exportable biogas (65% methane, 35% carbon dioxide). The prime contractor was McConnell-Dowell, with the AD technology supplied by Waste Solutions of New Zealand and BTA of Germany.

4.1.2 5,000 Tonnes/year in Anyang City (Korea)

In 1993, the Korea Institute of Energy Research in conjunction with the Ministry of Trade, Industry and Energy began a study into the processing of food waste into methane using anaerobic digestion. The resulting technology employs a two-phase anaerobic digester, capable of processing 5 tonnes per day of food waste (with a more recent model (1997) processing 15 tonnes per day). The capital investment required for this type of plant in Korea was estimated to be below US$125,000 per tonne/day for plant with a capacity of over 15 tonnes/day. The operating costs were estimated to be US$60 per tonne [CADDET#66].

[10] Biogas yield is calculated at "normal temperature and normal pressure". Note that due to difference in the feedstock, the yield for the Sydney plant is not considered as the yield for a Hawke's Bay biogas plant.

In a steady state operation the treatment of three tonnes of food waste produced about 100 kg of by-product (humus @ 70% moisture content), 230 m^3 of biogas (70% methane) and 2 tonnes of anaerobically treated wastewater. It is estimated that about 73% of degradable waste is converted into biogas.

In this application the first phase of the digester is required to remove heavy biodegradable waste such as bone and shells. This would not be necessary for a fruit and vegetable sourced waste stream.

This project demonstrated the importance of pre-treatment as fresh whole fruit was initially difficult to digest because of the skin.

4.1.3 AnDigNet Citrus Research Project (Greece)

The AnDigNet project is researching the potential for development of a citrus based anaerobic digestion technology in Europe. The consortium participants include:

- Centre for Renewable Energy Resources – Project Leader (Greece)
- Biotec Sistemi S.r.l – Member (Italy)
- University of Cologne (Germany)
- Antonios Zacharopoulos S.A. (Greece)
- Liverta S.A. Fruit Processors (Greece)
- Christodoulou Bros. S.A. (Greece)
- Impax Capital Ltd (United Kingdom)

The key driver of this work is European Union solid waste management goals to reduce the organic matter that is landfilled. Other attempts have been made to utilise citrus waste as animal feed, with limited success due to the low nutritional value of citrus peel.

4.1.4 Nara City (Japan) Food Waste

The Nara City project is a food waste fed digester, with a capacity of 1500 tonnes per annum. The pre-treatment of the plant is designed using the BTA process. The plant was scheduled to start its operation in April 2003. BTA has provided engineering works, delivered particular components and assists during start-up. Information on this project is limited.

4.1.5 Biogas Harvesting from Food Processing Waste (Thailand)

This project in Thailand is a treatment/resource recovery project for very high-strength wastes from the processing of cassava. It has been commissioned in 2003 by Waste Solutions Ltd and delivers 10 MW_{th} thermal energy (boiler fuel). In 2004 stage II was commissioned which generates an additional 3 MW_e (electricity) with a future upgrade to 5 MW_e. The project will return approximately 50 hectares of land, currently used for an aerobic lagoon treatment system, to productive use. The project is suggested as repaying the initial capital cost from energy sales alone within three years and thereafter producing a financial return.

4.2 Effluent Digester Projects

4.2.1 Dairy Farm Digesters (New Zealand)

Integrated Systems Engineers (ISE) has commissioned a dairy farm digester project at Orini, northeast of Hamilton [NZDE-4-2004]. Three digester modules (stainless steel construction, see Figure 8) convert effluent from a 2000 cow feed-pad and dairy into biogas, which in-turn fuels a 6-cylinder engine to generate up to 53kVA of electricity for seven hours a day (plant factor 0.29). Discussions with ISE suggest that this technology is currently being evaluated for use with fruit waste to supply electricity to a North-Island kiwifruit pack-house [ISE-2004].

Figure 8. Two of Three ISE Digesters Producing Bacteria-Free Fertiliser and Methane Gas at Orni Downs Dairy Farm [ISE-2004, NZDE-4-2004].

4.2.2 Tohoku Pig Farm (Aomori, Japan)

RCM Digesters have developed a complete mix digester for a 30,000 head pig farm in Japan Figure 9. This is based on their covered pit design. The initial driver for this project was odour reduction. Manure is collected at the facilities via mechanical scrapers, and flows to a mixing tank before it is sent to the digester. The digester consists of two separate concrete tanks each covered by an inflatable cover. The effluent from the digester flows to a high-density polyethylene lined basin prior to land application. The primary benefit experienced is waste treatment and electricity generation. The electricity generated is used on farm and to power aeration treatment.

Figure 9. Pig Farm Application of Complete Mix Digester by RCM Digesters [RCM-W].

4.2.3 MEAD Project (Oregon, USA)

Tillamook County (Oregon, USA) is a working example of distributed digester technology. Concerned about the quality of surface and groundwater (from over 30,000 dairy cows in the county), the local electricity supplier (retailer/distribution) and soil and water conservation organisations joined together to pursue the MEAD (Methane Energy and Agricultural Development) project.

The MEAD project committee was initially considering development of a large-scale anaerobic digester facility. However, this has since been scaled back. The capital outlay required for a single large facility (to processes manure for up to 9,000 dairy cows) was not feasible. In 2000, MEAD project proponents sought support for a smaller scale facility to demonstrate the technology and feasibility of collecting and digesting dairy waste at a central site. A demonstration facility designed to process manure from 2,000-3,000 cows could lead to future construction of several more distributed facilities of a similar size (Figure 10). A network of strategically placed digester facilities might finally address the manure management needs of local dairy farms.

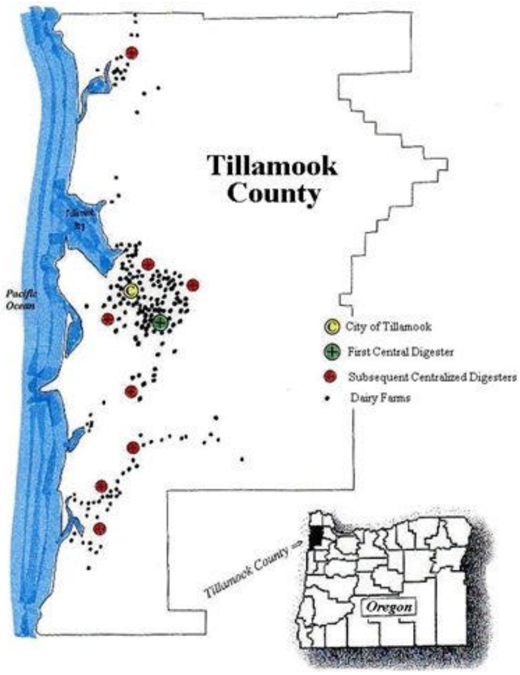

Figure 10. Map of Tillamook County Showing Distribution of Digester Plant [TILLAM-W].

4.3 Status of Hastings Fruit and Vegetable Waste (Feedstock)

For the purposes of this study, feedstock is considered as any off-cut or reject material from the growth, packing and processing of fruit and vegetables, with the exclusion of materials not normally recovered[11] in the process of harvesting and processing fruit and vegetables.

The feedstock available in the Hawke's Bay region is segmented by sequential process stage:

1. Growers
2. Packers and Processors

A map of waste output per process stage is outlined in Figure 11.

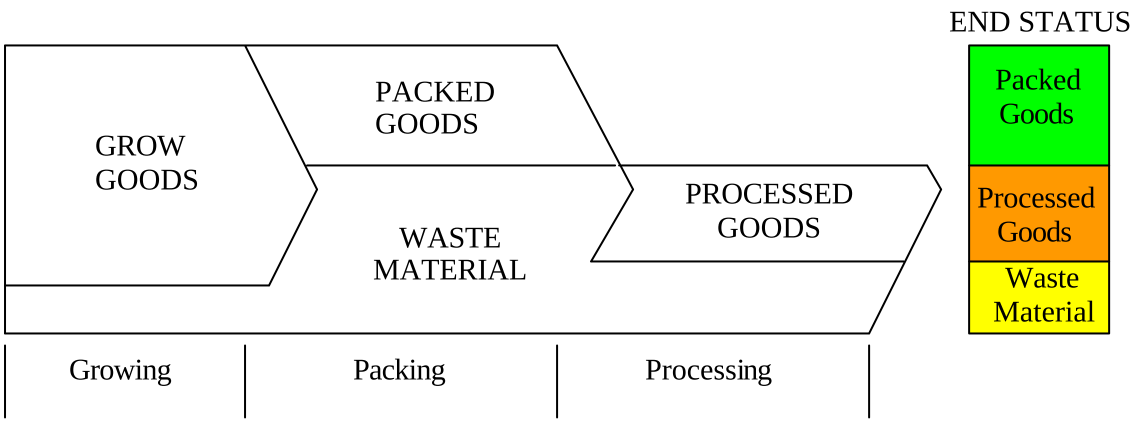

Figure 11. High-Level Hawke's Bay Fruit and Vegetable Process Outline.

[11] During periods of low waste availability, alternative waste will be considered for use, such as thinning apples and other materials not normally collected during fruit and vegetable processing.

4.3.1 Measured Waste (Feedstock) Potential

The feedstock potential (wet tonnage) of Hawke's Bay fruit and vegetable processors is sourced from a previous study [FHB-2003]. Other contributors are evaluated at a high level, and summarised in Table 3.

Table 3. Summary of Hastings Biogas Plant Waste Stream[12] Assessment (Net Tonnes).

Supply Stage	Estimated Annual Waste Volume (Net Tonnes)								TOTAL
	Fruit				Vegetables				
	Apple	Kiwifruit	Summer	Grape	Potato	Squash	Corn	Green	
Growers Subtotal[13]	12,900	4,125	225	100		211	0	5,540	**23,101**
Processors Subtotal	15,900	2,750	150			1,900	4,500	11,180	**36,380**
Supermarket / Restaurant Subtotal									
TOTAL WASTE	**28,800**	**6,875**	**375**	**100**		**2,111**	**4,500**	**16,720**	**59,481**

Note: Apple thinnings are excluded from this table, and are considered at up to 500 tonnes per month over the November to February period.

Information from the feedstock possibly available from growers proved difficult to get because some growers feed the waste to stock while others return it to the land by digging it in.

The data for processing and supermarket/restaurant waste from within the Hastings area also proved difficult to obtain because there are so many different sources. This is an area where further work is required.

Innovation in waste processing is already present in the Hawke's Bay region, where fruit and vegetable waste are further processed for juice, animal consumption (silage) and fertiliser application.

Waste from one stage of the product may feed into the processed goods stage (such as apple juice production), or alternatively be used as animal feed. This has a non-linear effect on the waste stream, as waste at the start of the process may not equal overall waste less waste produced at later stages of the fruit and vegetable manufacturing process, with the addition of wash-down water.

Apples and other fruit often go to waste during the period of growing and picking. Some of this will be thinnings, reject quality fruit, windfall or end of season fruit. Estimates were attempted on how much may be available for use in a digester but the range of alternative uses was so great that it was difficult to quantify. It is apparent however that because some of the fruit such as apples have a reasonably long storage period they could be used to meet shortfalls in waste supply from other sources.

4.3.2 Seasonality of Waste (Feedstock) Supply

While the quantities of waste have been established it has proven difficult to establish monthly profiles of waste. This is necessary before any consideration of a digester were considered further. For the purposes of evaluation within this study waste profiles have been established for each scenario and are summarised in Section 5.

[12] For this report, "base supply" of digester feedstock is assessed from previous Food Hawke's Bay investigation [FHB-2003]. Contingency feedstocks are applied to compliment the base supply.
[13] From waste flow diagrams in Appendix A.

4.3.3 Fruit and Vegetable Waste Solid Content

Previous investigation initiated by Food Hawke's Bay into the make-up of fruit and vegetable waste [FHB-2003] has been used to evaluate the total solid (TS) concentration of the feedstocks. The total solid concentration for each scenario is calculated as being between 17.5% and 18.8%.

For the purpose of this report, the volatile solid (VS) content of dry material (from fruit and vegetable waste) is considered as 90% of total solids [BOUAL-2001].

4.3.4 Feedstock Contingency

Anaerobic digesters require consistency in supply of dry matter to ensure steady operation. Several options are explored with a view to covering periods of low dry matter availability. These include ensiling fruit and vegetable waste from periods of over-supply, as well as using thinned fruit from orchards.

Fruit and Vegetable Waste Silage

Currently waste from some sources is collected and stored as silage for later use as stock feed. The silage form of storage would be appropriate also for storage of fruit and vegetable waste to be used in a digester, given the potential feedstock over-runs during the March-April period for Scenarios B and C.

Assuming a delivered cost of $25 per tonne, and the indicated biogas yield (Figure 6) being approximately two to three times that of fruit and vegetable feedstock, silage is considered as a primary level contingency feedstock.

Fruit Tree Thinnings

During the November to February period, apples orchards thin their trees to optimise the number of fruit drawing nutrition from the trees. This is considered as a potential contingency feedstock for a Hastings digester operation.

Initially, a price of 15c/kg ($160/tonne delivered) was quoted for apple thinnings [RAKA-2004], however this is greater than that which is "paid" to orchards for season apples (7c/kg, $80/tonne delivered), suggesting that it may be more cost effective to purchase and ensile market apples "in-season" (somewhat inappropriate for a waste processing plant). For this report, the value of apple thinnings is estimated at 3c/kg ($40/tonne delivered).

Potential Feedstocks

Given the price premium of apple thinnings for use as a contingency feedstock, alternative sources of feedstock that may be available during or ensiled prior to the November to January period should be explored. The cost per tonne delivered will determine the appropriateness of such contingency feedstocks, and greatly affect the economics of operation.

4.3.5 By-products (Liquid Fertiliser and Pulp Stock Feed)

Digester feedstock is converted into a substrate, which (upon separation) consists of a low moisture content, nutrient rich pulp for use as stock feed, as well as a high nutrient liquor, suitable for application on orchard or farm land.

The value of the humus is enhanced through reducing transport and storage costs to the farmer, however, the value of reduced moisture content in the stock feed may require further consideration.

5 Three Digester Scenarios

Three potential digester scenarios are outlined, with respect to operating within the Hastings area. These scenarios were chosen for analysis based on the availability of waste from various sections of the Hastings fruit and vegetable processing sector, with contingency adjustment during periods of low feedstock availability. Wet tonnages are selected to produce a consistent dry mass content on a monthly average basis (see Appendix C for monthly wet tonnages). This is a key factor in ensuring the continuous (efficient) operation of a digester system.

To test out the possibility of digester size and economics three scenarios have been assumed. The scenarios cover three different sized digesters, and the concept of localised small digesters compared to a large Hastings area digester.

It should be noted that the quantities and timing of waste availability is likely to vary considerably over time. The quantities used in each scenario should be taken as indicative only. Before any consideration of investment in a waste-to-energy plant were undertaken, improved data collection would be required.

5.1 Scenario A – 10,000 Wet Tonnes/Year Digester @ Omahu Road

The operation of a medium-scale on-site digester on Omahu Road (Pro Fruit site) is outlined.

5.1.1 Location

The location of the "Omahu Road" digester is optimised through a tonnage-distance calculation for the supply of waste sourced in the Omahu Road area. (Appendix B). The best location for a digester at Omahu Road (given the assumptions above, and based on distance calculation) is either on or nearby the Profruit site (Appendix B). It should be noted that no specific site was identified rather the principle of a local digester near the waste generators was assumed.

5.1.2 Feedstock Supply

Feedstock requirement of scenario A in equivalent dry tonnes is outlined in Table 4.

Table 4. Equivalent Dry Tonnage[14] for Scenario A Hastings Biogas Plant.

	Apple	Kiwifruit	Decanter Pomace	Squash	Onion	Apple Thinnings	From Silage	Digester DM Input
Jan	0	0	0	0	1	160	0	**161**
Feb	0	0	0	88	1	70	0	**158**
Mar	41	0	21	88	1	0	-55	**160**
Apr	41	0	21	88	1	0	-55	**160**
May	41	0	21	88	1	0	-55	**160**
Jun	41	53	21	0	1	0	-20	**160**
Jul	41	53	21	0	1	0	-20	**160**
Aug	41	53	21	0	1	0	-20	**160**
Sep	41	53	21	0	1	0	-20	**160**
Oct	0	53	0	0	1	0	110	**163**
Nov	0	0	0	0	1	65	95	**161**
Dec	0	0	0	0	1	120	40	**161**
Total	**285**	**262**	**150**	**350**	**10**	**415**	**0**	**1923**

Note: No information was available from McCain Foods which is a source of waste that would be considered if a digester was sited at this location.

[14] Note that tonnages shown in these tables are subject to rounding error (i.e. sum of individual values may not equal total tonnage).

The dry matter (DM)[15] profile of this scenario is outlined (Figure 12) with excess feedstock ensiled and apple thinnings used to augment limited "base waste". The red dotted line indicates the estimated level of dry matter required for continuous operation of the digester (160 tonnes DM/month). Originally, the wet tonnage of feedstock was estimated at 13,000 tonnes p.a., however refinement of the scenario model has resulted in reduction of feedstock to 10,000 tonnes p.a.

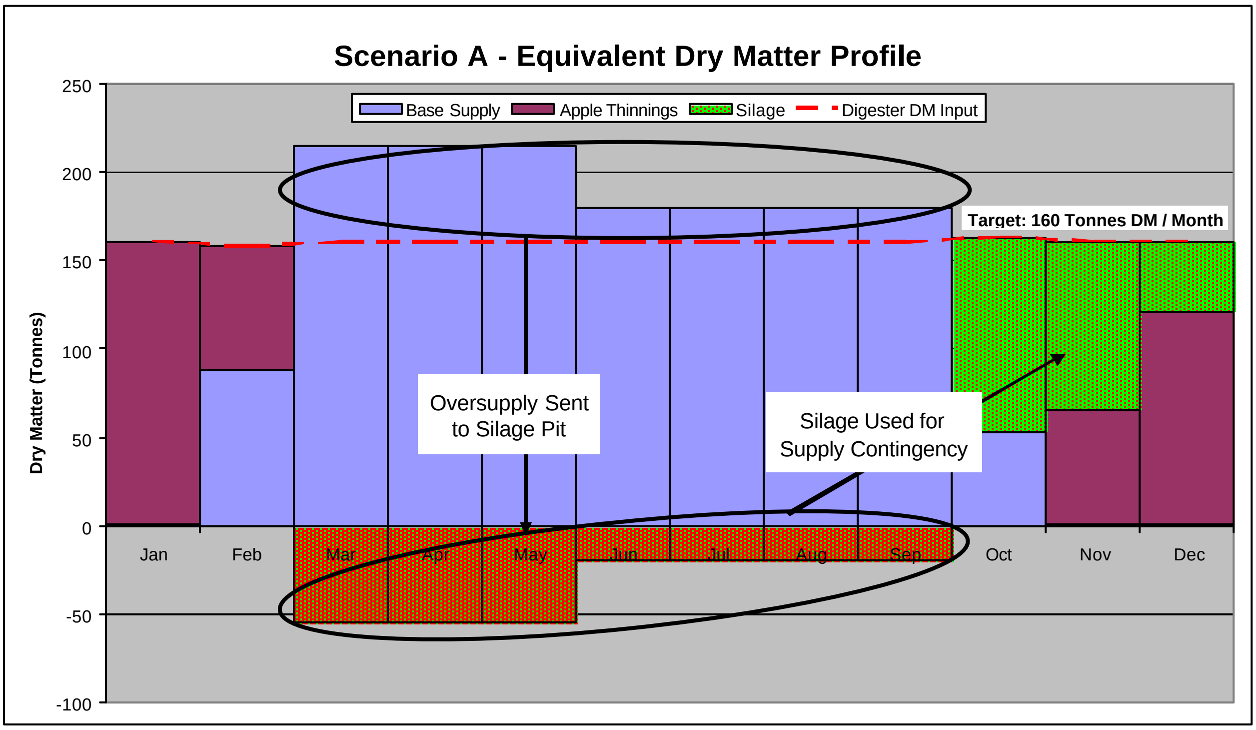

Figure 12. Equivalent Dry Matter Monthly Waste Profile for Scenario A Hastings Biogas Plant.

5.1.3 Digester Plant

Solwind

Solwind advise that for an installation using Hastings feedstock, two large sealed insulated underground concrete buildings would be required. It has been derived that each would hold approximately 500 tonnes (0.5M litres) of a 70:30 solid to liquid mix and run for a 28 day cycle on an alternating basis. This is a larger scale project in comparison to their existing dairy farm and domestic product offerings.

The potential biogas yield is estimated at between 7 and 10 times that of processing dairy effluent (per tonne of feedstock) depending on operating conditions.

Integrated Systems Engineers

ISE advise that for an installation using Hastings feedstock, two large 2.8m diameter stainless steel "plug flow" digester units would be required, each holding approximately 86 tonnes (86k litres) of a 85:15 solid to liquid mix and run on a continuous feed basis. This is a modular technology that allows for addition of digester units as the plant grows. This is of a similar scale (number of digester units) to existing ISE plant configurations.

The potential biogas yield of three times that of dairy farm biogas production is indicated, depending on operating conditions.

[15] A dry matter equivalent profile is used rather than wet feedstock, as the volatile solid gas yield is related to the dry matter content of feedstock.

Waste Solutions

Waste Solutions advise that for an installation using Hastings feedstock, a completely-mixed digester would be required. Two small tanks will be required, holding in total approximately 1,000 tonnes of a 30:70 waste feedstock to liquid mix and run on a continuous basis. Depending on ground conditions, digester tanks can be simple, in-ground anaerobic baffled reactors.

Waste Solutions advise that the net saleable biogas yield[16] (digester heated with biogas) of 50-55 m^3 per tonne wet feedstock (15 % w/w dry matter assumed), equivalent three to four times that of dairy farm biogas production is indicated, depending on operating conditions.

RCM Digesters

RCM Digesters advise that for an installation using Hastings feedstock, a complete-mix digester would be required. It has been derived that two concrete tanks will be required, each holding approximately 400 tonnes of an 85:15 solid to liquid mix and run on a continuous basis.

RCM related literature suggests potential biogas yield of four times that of dairy farm biogas production is indicated, depending on operating conditions.

5.1.4 Operating Model

The key features of the operating model for this solution are outlined:

- Contributors include:
    - Profruit
    - Horticulture Marketing
    - CSI Processors
    - Circle Pacific
    - ENZA Foods
    - Heinz Watties
    - James and Son (NZ) for silage management
    - Hastings apple growers for apple thinnings (November to January)
    - Possibly other feedstock sources (November to January)
- Small site with storage and dedicated feedstock processing plant (mashing/shredding) and two 0.5 equivalent full-time operators and occasionally contracted tradespeople.
- On or off-site silage pit(s) to store excess capacity for contingency (approximately 1,500 – 2,000m^3)
- Digester has priority for receiving waste produced by contributors.
- Existing transport operator ships feedstock from Omahu Road processors to the feedstock storage and processing stage.
- Excess feedstock is provided to silage operator in preparation or recompense for silage buffer availability.
- Silage provider manages and/or delivers previously ensiled overcapacity feedstock based silage during periods of low feedstock availability.
- Feedstock is sorted by type (wet / dry), and mashed/shredded accordingly before being fed into in feedstock preparation tanks.
- 200m gas line to Profruit boilers – potential consumer of biogas product.
- Staff and contractors use dedicated amenity facilities (toilet / washroom / tearoom).
- Digester substrate is separated (liquid / pulp) and on-sold as liquid fertiliser and humus for land application.

[16] Given the baseline gas yield assumption of 46m^3 per wet tonne of feedstock @ 15% average dry matter content, a 20% sensitivity is applied to incorporate the Waste Solutions estimate of biogas yield.

5.2 Scenario B – 45,000 Wet Tonnes/Year @ Omahu Road

The operation of a large-scale on-site digester on Omahu Road (Pro Fruit site) is outlined.

5.2.1 Location

The best location for a digester at Omahu Road (given the previous assumptions) is either on or nearby the Profruit site.

5.2.2 Feedstock Supply

Feedstock requirement of scenario B in equivalent dry tonnes is outlined in Table 5.

Table 5. Equivalent Dry Tonnage for Scenario B Hastings Biogas Plant.

	Apple	Kiwifruit	Summer	Decanter Pomace	Squash	Corn	Carrot	Green	Onion	Beetroot	Tomato	Apple Thinnings	Silage	Digester DM Input
Jan	0	0	0	0	0	0	0	28	1	15	0	656	0	**700**
Feb	206	0	0	0	238	200	88	28	1	15	0		-80	**695**
Mar	247	0	60	86	238	500	88	340	1	0	53		-910	**701**
Apr	247	0	0	86	238	200	88	340	1	0	60		-560	**699**
May	247	50	0	86	238	0	88	130	1	0	0		-140	**699**
Jun	247	103	0	86	0	0	88	130	1	0	0		45	**699**
Jul	247	103	0	86	0	0	88	130	1	0	0		45	**699**
Aug	247	53	0	86	0	0	88	28	1	0	0		200	**702**
Sep	247	53	0	86	0	0	88	28	1	0	0		200	**702**
Oct	0	53	0	0	0	0	0	48	1	0	0		600	**701**
Nov	0	0	0	0	0	0	0	48	1	0	0	165	490	**704**
Dec	0	0	0	0	0	0	0	48	1	0	0	540	110	**699**
Total	**1935**	**412.5**	**60**	**600**	**950**	**900**	**700**	**1326**	**10**	**30**	**113**	**1361**	**0**	**8397**

The dry matter profile of this scenario is outlined (Figure 13) with excess feedstock ensiled, and apple thinnings used to augment limited "base waste". The red dotted line indicates the estimated dry matter level required for continuous operation of the digester (700 tonnes DM/month). Originally, the wet tonnage of feedstock was estimated at 50,000 tonnes p.a., refinement of the scenario model has resulted in reduction of feedstock to 45,000 tonnes p.a.

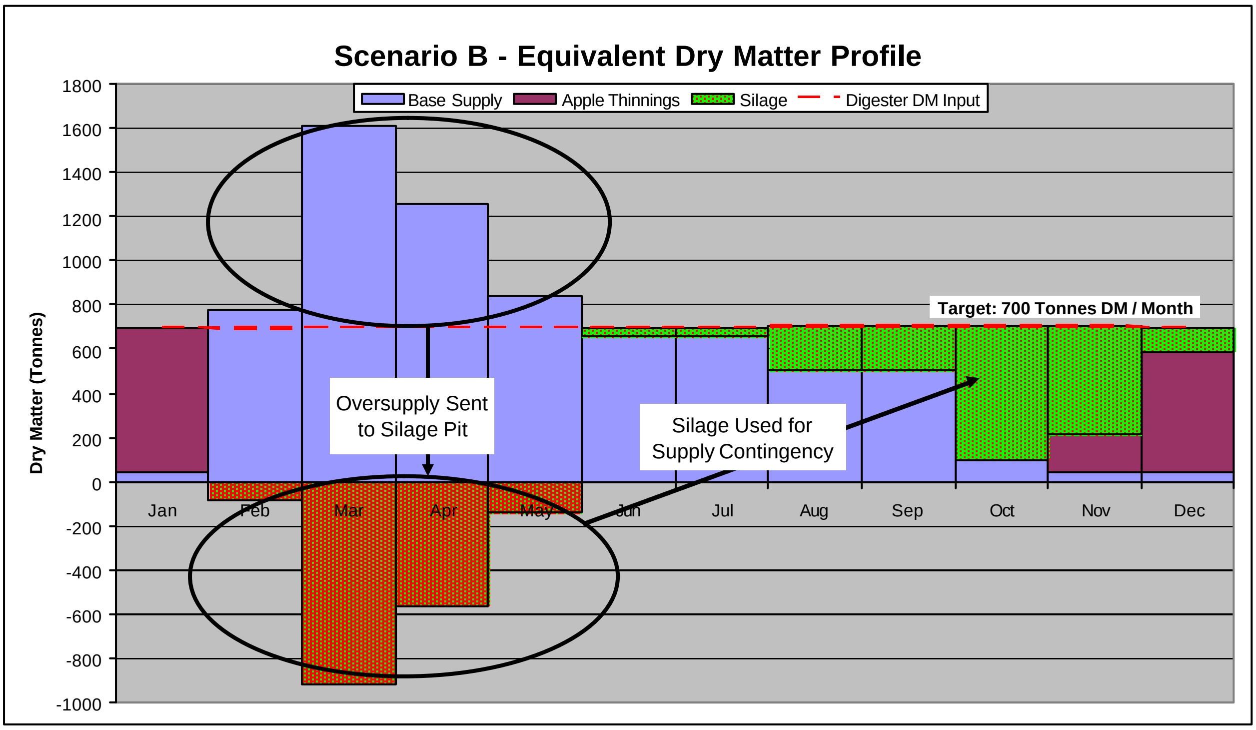

Figure 13. Equivalent Dry Matter Monthly Waste Profile for Scenario B Hastings Biogas Plant.

5.2.3 Digester Plant

Solwind

Solwind advise that for an installation using Hastings feedstock, two large sealed insulated underground concrete buildings would be required. It has been derived that each would hold approximately 2,000 tonnes (2M litres) of a 70:30 solid to liquid mix and run for a 28 day cycle on an alternating basis. This is a larger scale project in comparison to their existing dairy farm and domestic product offerings.

Integrated Systems Engineers

ISE advise that for an installation using Hastings feedstock, ten large 2.8m diameter stainless steel “plug flow” digester units would be required, each holding approximately 86 tonnes (86k litres) of a 85:15 solid to liquid mix and run on a continuous feed basis. This is a modular technology that allows for addition of digester units as the plant grows. Digester units may be added or relocated to cater for future variance in feedstock availability.

Waste Solutions

Waste Solutions advise that for an installation using Hastings feedstock, a completely-mixed digester would be required. Two digester tanks will be required, holding in total approximately 3000 tonnes of a 30:70 waste feedstock to liquid mix and run on a continuous basis. Depending on ground conditions, digester tanks can be simple in-ground anaerobic baffled reactors.

RCM Digesters

RCM Digesters advise that for an installation using Hastings feedstock, a complete-mix digester would be required. It has been derived that two concrete tanks will be required, each holding approximately 1400 tonnes (1.4M litres) of an 85:15 solid to liquid mix and run on a continuous basis.

5.2.4 Operating Model

The key features of the operating model for this solution are outlined:

- Contributors include:
  - Profruit
  - Horticulture Marketing
  - CSI Processors
  - Circle Pacific
  - ENZA Foods
  - Heinz Watties
  - James and Son (NZ) for silage management
  - Hastings apple growers for apple thinnings (November to January)
  - Possibly other feedstock sources (November to January)
  - Various summer fruit and green vegetable growers.
  - Possibly other feedstock sources (November to January)
- Large sized site with storage and dedicated feedstock processing plant (mashing/shredding) and two equivalent full-time operators and occasional contracted tradespeople.
- On or off-site silage pit(s) to store excess capacity for contingency (approximately 8,000 – 8,500m^3)
- Digester has priority for receiving waste produced by contributors.
- Excess feedstock is provided to silage operator in preparation or recompense for silage buffer availability.
- Existing transport operator ships feedstock from Omahu Road processors and orchards to the feedstock storage and processing stage.
- Excess feedstock is provided to silage operator in preparation or recompense for silage buffer availability.
- Silage provider manages and/or delivers previously ensiled overcapacity feedstock based silage during periods of low feedstock availability.
- Located adjacent to a significant heat load at Profruit – potential customer for heat output.
- Feedstock is sorted by type (wet / dry), and mashed/shredded accordingly before being fed into in feedstock preparation tanks.
- 200m gas line to Profruit boilers – potential consumer of biogas product.
- Staff and contractors use dedicated amenity facilities (toilet / washroom / tearoom).
- Digester substrate is separated (liquid / pulp) and on-sold as liquid fertiliser and humus for land application.

5.3 Scenario C – 80,000 Wet Tonnes/Year @ Whakatu

The operation of a large-scale digester site/farm at Whakatu Industrial site is outlined. This scenario differs from the others, in that waste is assumed to be taken from within any part of the study area. The digester plant would also not necessarily be located adjacent to a direct heat load but gas could be piped to boilers at Heinz Watties or other large gas users. In this scenario the biogas is also assumed to be adequate for a small cogeneration operation embedding supply of electricity to nearby users.

It should be noted that no specific site was identified and the plant location is general rather than specific.

5.3.1 Feedstock Supply

Feedstock requirement of scenario C in equivalent dry tonnes is outlined in Table 6.

Table 6. Equivalent Dry Tonnage for Scenario C Hastings Biogas Plant.

	Apple	Kiwifruit	Summer	Grapes	Decanter Pomace	Squash	Corn	Carrot	Green	Onion	Beetroot	Tomato	Apple Thinnings	Silage	Digester DM Input
Jan	0	0	0	0	0	0	0	0	42	1	23	0	1100	0	**1165**
Feb	413	0	0	0	0	264	200	131	42	1	23	0	100	0	**1173**
Mar	494	0	150	25	86	264	500	131	510	1	0	79	0	-1070	**1169**
Apr	494	0	0	25	86	264	200	131	510	1	0	90	0	-640	**1161**
May	494	125	0	0	86	264	0	131	195	1	0	0	0	-130	**1166**
Jun	494	256	0	0	86	0	0	131	195	1	0	0	0	0	**1163**
Jul	494	256	0	0	86	0	0	131	195	1	0	0	0	0	**1163**
Aug	494	131	0	0	86	0	0	131	42	1	0	0	0	280	**1165**
Sep	494	131	0	0	86	0	0	131	42	1	0	0	0	280	**1165**
Oct	0	131	0	0	0	0	0	0	72	1	0	0	0	960	**1164**
Nov	0	0	0	0	0	0	0	0	72	1	0	0	770	320	**1163**
Dec	0	0	0	0	0	0	0	0	72	1	0	0	1100	0	**1173**
Total	3870	1031	150	50	600	1056	900	1050	1989	10	45	169	3070	0	**13990**

The dry matter profile of this scenario is outlined (Figure 14) with apple thinnings augmenting limited "base waste", and silage used as a back-up feedstock. The red dotted line indicates the estimated dry matter level required for continuous operation of the digester (1160 tonnes DM/month).

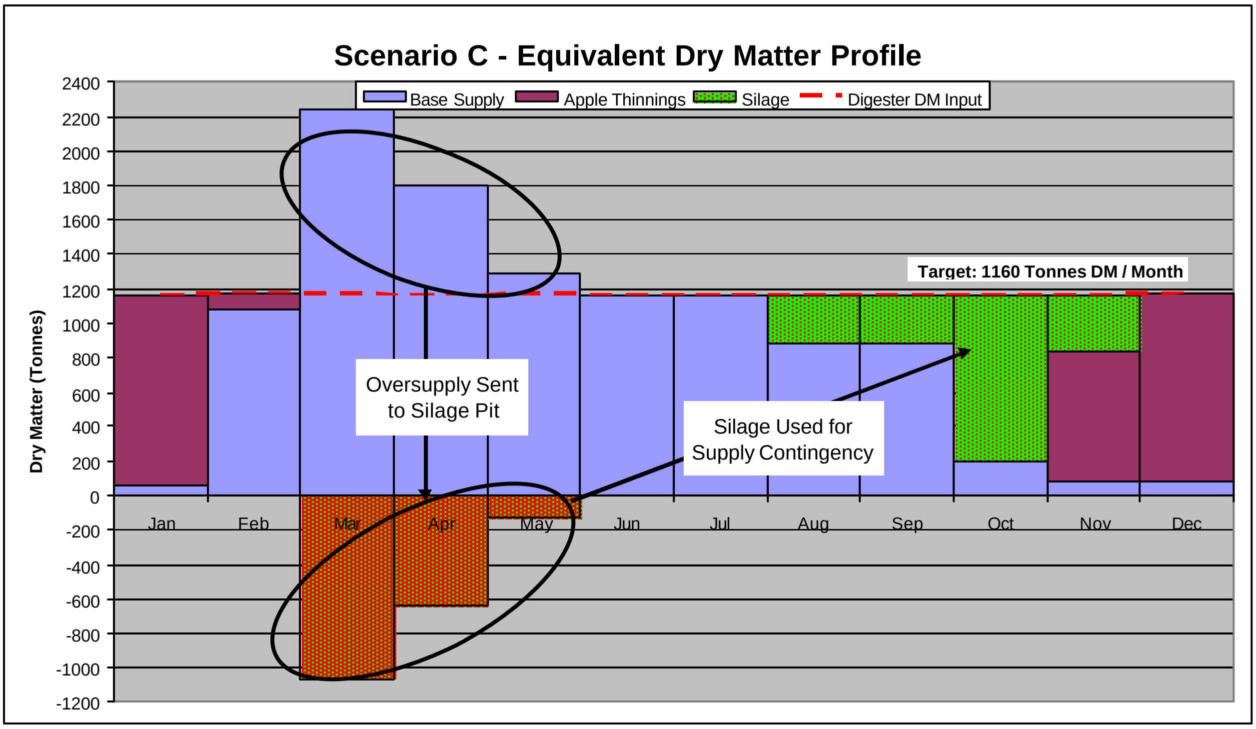

Figure 14. Equivalent Dry Matter Monthly Waste Profile for Scenario C Hastings Biogas Plant.

Solwind

Solwind advise that for an installation using Hastings feedstock, two large sealed insulated underground concrete buildings would be required. It has been derived that each would hold approximately 3,800 tonnes (3.8M litres) of a 70:30 solid to liquid mix and run for a 28 day cycle on an alternating basis. This is a larger scale project in comparison to their existing dairy farm and domestic product offerings.

Integrated Systems Engineers

ISE advise that for an installation using Hastings feedstock, 15 large 2.8m diameter stainless steel "plug flow" digester units would be required, each holding approximately 86 tonnes (86k litres) of a 85:15 solid to liquid mix and run on a continuous feed basis. This is a modular technology that allows for addition of digester units as the plant grows. Digester units may be added or relocated to cater for future variance in feedstock availability.

Waste Solutions

Waste Solutions advise that for an installation using Hastings feedstock, a completely-mixed digester would be required. Two digester tanks will be required, holding in total approximately 6000 tonnes of a 30:70 waste feedstock to liquid mix and run on a continuous basis. Depending on ground conditions, digester tanks can be simple, in-ground anaerobic baffled reactors.

RCM Digesters

RCM Digesters advise that for an installation using Hastings feedstock, a complete-mix digester would be required. It has been derived that two concrete tanks will be required, each holding approximately 2,500 tonnes (2.5M litres) of an 85:15 solid to liquid mix and run on a continuous basis.

5.3.2 Operating Model

The key features of the operating model for this solution are outlined:

- Contributors include:
  - Profruit
  - Horticulture Marketing
  - CSI Processors
  - Circle Pacific
  - ENZA Foods
  - Heinz Watties
  - Hastings wide orchards
  - Various summer fruit and green vegetable growers[17].
  - James and Son (NZ) for silage management
  - Hastings apple growers for apple thinnings (November to January)
  - Possibly other feedstock sources (November to January)
- 1-2 km gas line to Heinz Watties large boilers – potential consumer of biogas product.
- Large sized site with storage and dedicated feedstock processing plant (mashing/shredding) and two equivalent full-time operators and occasional contracted tradespeople.
- On or off-site silage pit(s) to store excess capacity for contingency (approximately 9,000 – 9,500m^3)
- Digester has priority for receiving waste produced by contributors.
- Excess feedstock is provided to silage operator in preparation or recompense for silage buffer availability during periods of otherwise low feedstock availability.

[17] Grower waste tonnage supplied (23,000 wet tonnes p.a.) is estimated at zero cost (plus transport), based on interpolation of waste flows in Appendix A.

- Existing transport operator ships feedstock from Omahu Road processors and orchards to the feedstock storage and processing stage.
- Excess feedstock is provided to silage operator in preparation or recompense for silage buffer availability.
- Silage provider manages and/or delivers previously ensiled overcapacity feedstock based silage during periods of low feedstock availability.
- Feedstock is sorted by type (wet / dry), and mashed/shredded accordingly before being fed into in feedstock preparation tanks.
- Staff and contractors use dedicated amenity facilities (toilet / washroom / tearoom), larger than that of scenarios A & B.
- Digester substrate is separated (liquid / pulp) and on-sold as liquid fertiliser and humus for land application.

5.4 Scenario Summary

Assumed digester biogas output quantities are given in Table 7. This assumes that 15% of energy produced is used by the plant to warm the reactor, process the feedstock and separate the output substrate.

Table 7. Calculated Net Energy Yields of Hastings Food Waste Digester Scenarios.

Scenario	Feedstock Dry Matter (T/year)	Biogas Yield (m^3/year)	GJ/year		
			@ 17MJ/m^3	@ 21MJ/m^3	@ 25MJ/m^3
Scenario A	1900	641,000	10,900	13,500	16,000
Scenario B	8400	2,800,000	47,600	58,800	70,000
Scenario C	14000	4,663,000	79,300	97,900	116,700

Plant capacities are calculated for upper and lower assumed gas energy yields (Table 8). Plant capacity is a function of gas yield (energy) and time that plant capacity is utilised. A larger capacity plant will require greater capacity for gas storage.

Table 8. Calculated Capacity of Plant per Scenario and Gas Yield.

Gas Yield MJ/m^3	Energy Yield (Net GWh_{th} p.a.)			Boiler Plant Capacity (kW_{th})								
				@ 24 h/day			@ 16 h/day			@ 8 h/day		
	A	B	C	A	B	C	A	B	C	A	B	C
17	3.0	13.2	22.0	350	1500	2500	520	2300	3800	1000	2700	7500
21	3.7	16.3	27.2	430	1900	3100	640	2800	4700	1300	5600	9300
25	4.5	19.4	32.4	510	2200	3700	760	3300	5500	1500	6600	11000

Note: Energy yield per year (GWh) accounts for 15% of energy produced for "own use" by the plant.

The scale of boiler considered for economic analysis ideally operates for 16 hours per day, 365 days per year. However, an additional plant factor of 90% (of 16 hours/day) is assumed. This accounts for maintenance, statutory holidays and other events that are likely to impact the day-to-day consumption of biogas from a digester plant in Hastings.

6 Digester Investment Economic Drivers

6.1 Cost Assumptions

6.1.1 Capital Expenditure

The capital investment required for digester equipment is summarised based on budget estimates received from equipment suppliers to the New Zealand market. Where technologies were not represented by estimates, these were derived from scaled publicly available information.

Table 9. Digester Plant Capital Cost for Hastings Biogas Plant.

Technology	Scenario A *(10,000 T/y)*	Scenario B *(45,000 T/y)*	Scenario C *(80,000 T/y)*
Complete Mix Digester/biogas storage	$ 575,000	$ 885,500	$ 1,380,000
Integrated Modular Digester/biogas storage	$ 333,500	$1,667,500	$ 2,501,250

The base digester capital cost assumed for each scenario is taken as the highest of the costs in Table 9. The cost includes for the cost of the digester, biogas storage vessel, and construction and project management costs.

To establish an accurate capital cost would require detailed design and feedstock testing. To provide costs for the analysis in this study costs were analysed for both modular and complete mix plant.

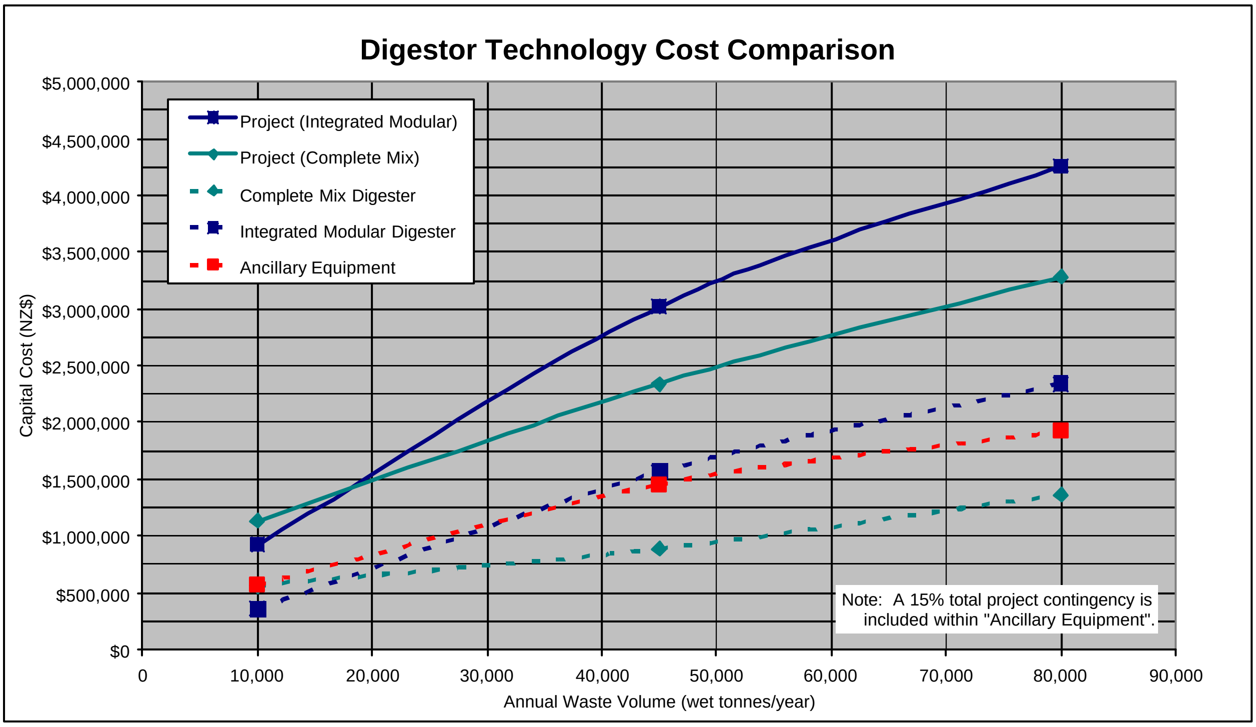

Figure 15. Capital Expenditure[18] Requirement of Technologies for Hastings Biogas Plant.

[18] Capital costs include digester (commissioned), while Ancillary Equipment costs include feedstock storage and pre-processing (mashing) plant, gas distribution and by-product processing, as well as a project contingency of 15%, based on total cost of project for each scenario (assuming technology of greatest cost).

As can be seen from Figure 15, modular technology has a distinct advantage at low scale (<20,000 Tonnes per annum), however the replication of control and other equipment at larger scale, reduces its cost effectiveness (on a purely capital basis). The separate processing of various waste streams spreads the risk of feedstock contamination across a number of plant. This reduces the potential for negative affects from feedstock and environmental issues to upset digester micro organisms and thus reduce gas yield. A single large digester does not have this diversity in design. Feedstock contamination is considered more likely where a wide variety of feedstocks and sources are used, as with a Hastings fruit and vegetable processing sector unless good feedstock delivery controls are established.

For comparison purposes the capital cost of an organic fraction municipal solid waste digestion technology (OFMSW) such is operating in Sydney is approximately ten-fold greater than those shown in Figure 15. This indicates the cost increase that could occur if feedstock is not controlled and inorganic waste is accepted in the feedstock stream. An OFMSW plant is significantly more costly (even excluding cogeneration or boiler plant [BECK-2004]), due to the plant having to deal with a multiple waste stream requiring sorting of inorganic from organic matter, separation of plastics from biodegradable materials. The plant is also more likely to be within a confined municipal area with tighter environmental controls, whereas in a rural environment there is more space for low-cost processing. Hydrogen sulphide is likely to be another factor affecting the cost of an OFMSW plant, through increased requirement for gas treatment.

A dedicated fruit and vegetable waste biogas plant in Hastings will not require this level of functionality so the lower cost estimates are assumed.

The total plant capital cost is made up of the cost of digester plant (Table 9) plus the cost of ancillary equipment needed for feedstock storage and handling (Table 10). The cost of ancillary equipment is estimated for each scenario. These costs are based on budget estimates.

Table 10. Hastings Biogas Plant Ancillary Equipment Capital Cost Estimates.

Ancillary Equipment	Scenario A ($000's)	Scenario B ($000's)	Scenario C ($000's)
Feedstock Storage Building	120	240	260
Feedstock Storage Odour Control	80	160	120
Feedstock Processing Unit	40	80	100
Gas pipeline	20	60	305
Post Digester Substrate Separator	80	400	450
Site Services	40	80	80
Staff Building	40	40	50
Project Contingency (15%)	148	394	556
TOTAL	**568**	**1,454**	**1,921**

Feedstock Storage and Processing

The feedstock storage building houses the feedstock (short-term prior to processing), and associated pre-digester and post digester processing equipment. A biofilter is installed external to the building to process any undesirable odours produced by the facility. Omahu Road is located near a residential area, hence the cost per scale (tonnes of feedstock processed) of biofilter required is considered greater than that of the Whakatu industrial area.

Feedstock processing involves mechanical mashing or shredding the raw feedstock into a pulp. This improves the consistency of feedstock and thus efficiency of the digester. The feedstock processing unit cost estimates based on the assumed local availability of existing mashing or shredding plant and expertise from fruit and vegetable processors in the Hastings area. The cost of this process is subject to process consideration, as addition of air via shredding may affect the biogas yield.

Gas Pipeline and Plant

The gas pipeline cost estimate allows for biogas distribution from the biogas storage vessel (at 3 barg to travel 2km in Scenario C) to the location of biogas use. The cost of easements or land access is excluded from the cost estimate. Rail crossings and roadways are likely to affect the time and cost of the pipeline.

In Scenario C it is assumed that a compressor will be required to move the large volume of gas through reasonable sized pipes. The cost of a gas compressor is estimated at $100,000 for Scenario C, and is built into the estimate for pipeline cost. Scenarios A and B require minimal compression, due to the short distance (some 200m) to the heat load. Any road and railway crossing of gas-lines will significantly affect the cost of gas pipelines above those assumed here, as will the cost of easements.

Digester Substrate Separation

The capital cost of equipment for post digester substrate separation is based on the plant required for separation of solid from liquid digester output. The cost of storage and removal of solids from the digester is assumed as an operating cost.

Site Services and a Staff Building

Site services required of a waste processing facility are estimated and include; stormwater, sewage, electricity, telephone and vehicle parking features. The staff building is considered to be equivalent to a kitset garage, with more features for the Whakatu site (Scenario C).

6.1.2 Feedstock Transportation

Several options are available with respect to transporting feedstock from producers and processors. The options are outlined for each scenario in Table 11. Should a specific scenario be developed further, the transportation method may be further reviewed. For the Omahu Road scenarios (A & B), this may include pumping of feedstock material down a pipeline [BIL-2004]. This opportunity has not been explored in depth within this report. However assuming the cost per tonne would be between $0 and $10 (less than trucking), the effect of such a process on the unit cost of gas is considered within the sensitivity analysis.

Table 11. Feedstock Transportation Cost Estimates for Hastings Biogas Plant.

Transport Option:	Feedstock Cost $/Tonne	Annual Cost ($000 p.a.)		
		Scenario A	Scenario B	Scenario C
Existing 450kg Bins (bins returned)	$12.22	125	556	984
Existing Waste Transport Operator (rough estimate)	$10.00	102	455	805
Free of Charge	$ 0	0	0	0

Transport Estimate

The estimate of $10 per tonne for transporting fruit and vegetable processing waste was provided by a local supplier of transport services. This is within 20% of the existing 450kg plastic bin transport service. The estimate was based on the following assumptions, across two location scenarios.

Scenario A:

- Approximately 7 sites contributing an average total of 5,000 tonnes per month of feedstock.

- All within approximately 1-2km (by road) away from the digester plant.
- Half of the sites are likely to contribute 80% of the feedstock.

Scenario B:

- Approximately 10 – 20 sites contributing an average total of 7,000 to 10,000 tonnes per month of feedstock.
- All will be on average approximately 10km (by road) away from the digester plant.
- Half of the sites are likely to contribute 80% of the feedstock.

A high-level analysis of the $10 per tonne cost estimate for feedstock delivered indicates that this could be reduced depending on the availability of similar work within the region for trucks and drivers contributing to this process [JDSOUN-2004].

6.1.3 Contingency Feedstock

The use of silage storage of over-supply is considered, as well as the potential supply of apple thinnings. However, a collection cost is considered for apple thinnings, which adversely affects the economics of energy production. Further investigation into the availability and costs of alternative "spring" feedstocks is required. The cost of contingency feedstock alone (Table 12) may have potential to reduce the cost to equal or better that of existing commercial gas supply.

Table 12. Feedstock (Fuel) Cost Estimates Including Silage and Apple Contingency Options.

Feedstock Category	Scenario A ($000 p.a.)	Scenario B ($000 p.a.)	Scenario C ($000 p.a.)
Feedstock Transportation at $10/T	102	455	805
Level 1 Contingency* (Ensiling Excess)	41	211	230
Level 2 Contingency** (Apple Thinnings)	111	363	819
TOTAL FUEL COST	**254**	**1,029**	**1,854**

Note: * Cost of ensiling excess feedstock is considered at $25/tonne delivered (ensiled offsite).
** Apple thinnings are evaluated at a price of 3c/kg ex orchard ($40/tonne delivered).

6.1.4 Operational Expenses

Operational expenses such as labour, maintenance, and quality assurance are outlined (Table 13).

Table 13. Operational Expenses for Hastings Biogas Plant.

Expense	Scenario A ($000 p.a.)	Scenario B ($000 p.a.)	Scenario C ($000 p.a.)
Quality Assurance / Testing	5	15	15
Site Services	10	15	30
Operations Staff	36	92	110
Management / Overhead / Training	25	50	55
Maintenance	10	60	70
O&M TOTAL	86	232	280

Quality Assurance and Testing

Quality Assurance / Testing cost is based on a cost of $100 per test on a weekly basis, depending on scale and exposure to potential feedstock issues. This is in addition to any quality control programmes that may be required of staff and management / overhead / training costs. Scenarios B and C are considered as requiring more tests than scenario A.

Site Services

Site services are estimated and include rates and levies regarding stormwater, sewage, electricity connection, telephone line services to the premises.

Operations Staff

Operations staff requirement is estimated on full time equivalent (FTE) basis, assuming dual operators may be required to ensure safety and process quality:

Scenario A, 2 * 50% FTE, at rate of $18 per hour,
Scenario B, 4 * 50% FTE, at rate of $18 per hour,
Scenario C, 4 * 50% FTE, at rate of $18 per hour.

Management and Training

Management / Overhead / Training includes staff and asset management time as well as a training allowance. Training is considered essential with respect to ensuring the viability of the digester process.

Plant Maintenance

Maintenance is an approximate estimate, based on the physical size and cost of the plant. The ratio of maintenance cost to capital declines with respect to capital employed.

6.2 Potential Revenue Streams

A biogas processing plant in the Hastings area has potential to gather revenue through several channels:

- Biogas
- Fertiliser/Stock feed
- Carbon Credits (Promissory Notes)
- Digester expertise (possible consulting opportunity depending on scale)

The three scenarios outlined were analysed with respect to determining the unit cost of gas produced. This analysis is based on cost assumptions for:

- Capital expenditure
- Feedstock transportation
- Operational expenses (labour, energy, maintenance, quality assurance)
- Fertiliser/stock food sale value

6.2.1 Base Assumptions for Unit Cost Sensitivity Analysis

Table 14. Baseline Assumptions Used for Unit Cost Sensitivity Analysis.

Unit Cost Baseline	Pessimistic Sensitivity	Optimistic Sensitivity
Highest CAPEX budget estimate for each scenario	- 15%	+ 30%
Monthly average biogas (net saleable) yield baseline is 50 m^3 per 150kg of Dry Matter	± 20%	
Monthly average biogas calorific value baseline is 21MJ/m^3	± 4	
Weighted average cost of capital (WACC) baseline is 10%	± 5%	
Operations and Maintenance (O&M) cost is as per Table 12	± 25%	
Revenue from liquid and solid by-products is baseline $5 per tonne of dry matter	± $5	
Transport cost is $10 per tonne (wet matter)	± $10	
Spring contingency feedstock cost is $40 per tonne for apple thinnings / $25 per tonne for ensiled feedstock (on-site or delivered)	± 100% (Apples) - 100% (Silage)	

6.2.2 Unit Cost of Biogas Production

The unit cost of gas produced by a biodigester plant in the Hastings area is:

11.4c/kWh for Scenario A,
8.8c/kWh for Scenario B, and
8.5c/kWh for Scenario C.

This takes into account the capital, operational, and tax costs, as well as revenue potential from the sale of fertiliser/stock food over the lifetime of the plant.

The unit cost of producing gas for each scenario is calculated in terms of base assumptions provided in Section 6.2. The sensitivity of the unit cost to a range of variations to the base assumptions is calculated and shown in Figures 16-18.

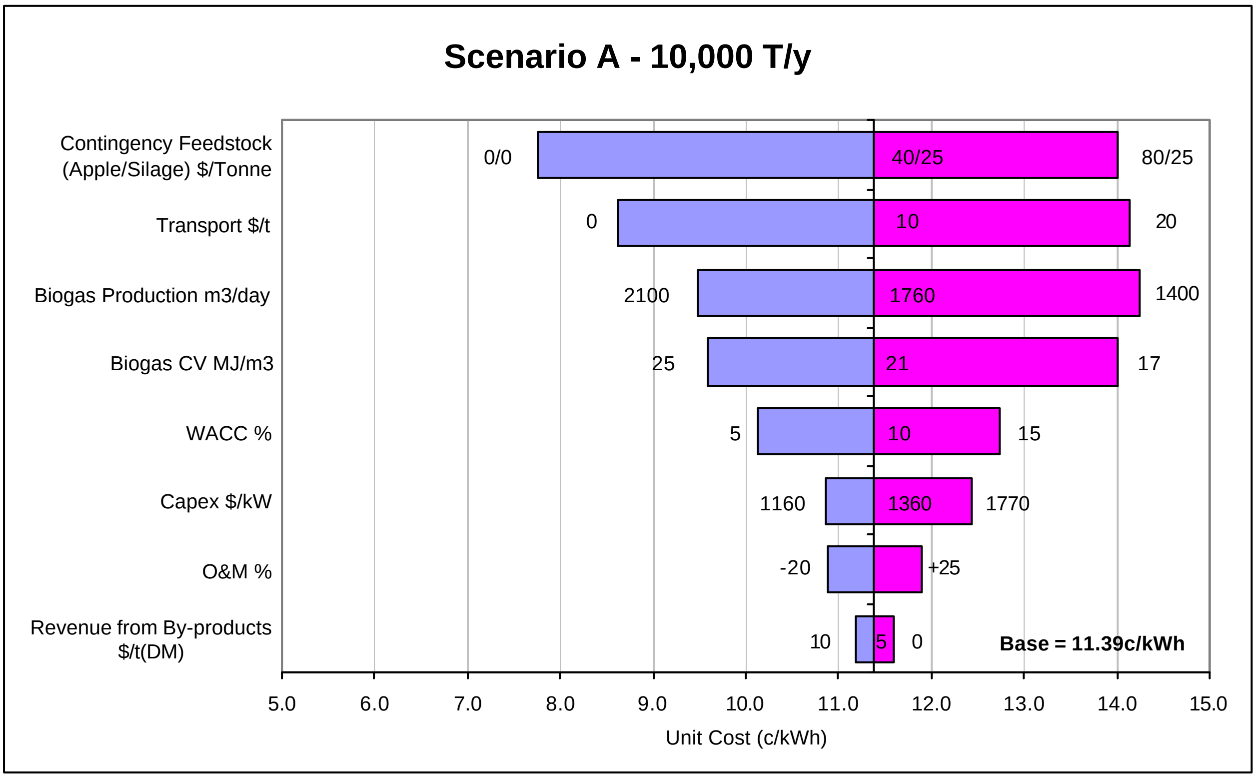

Figure 16. Sensitivity Analysis of Scenario A.

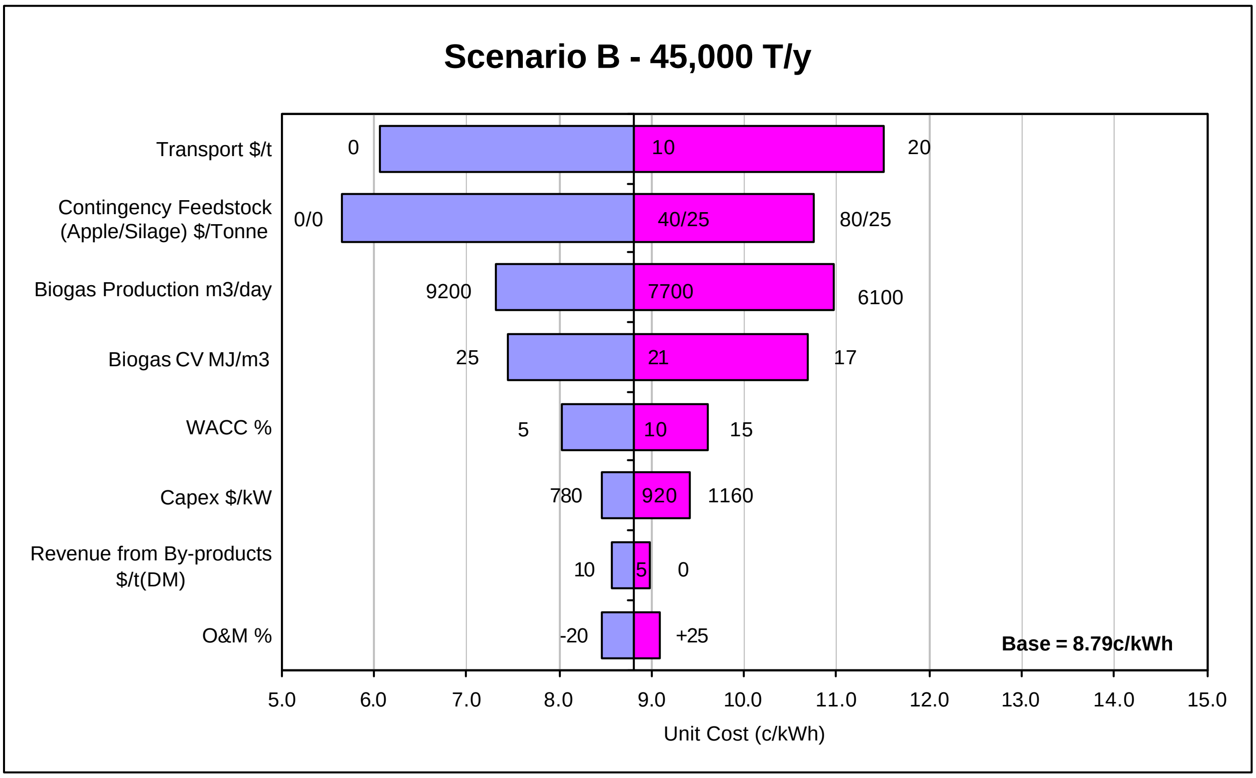

Figure 17. Sensitivity Analysis of Scenario B.

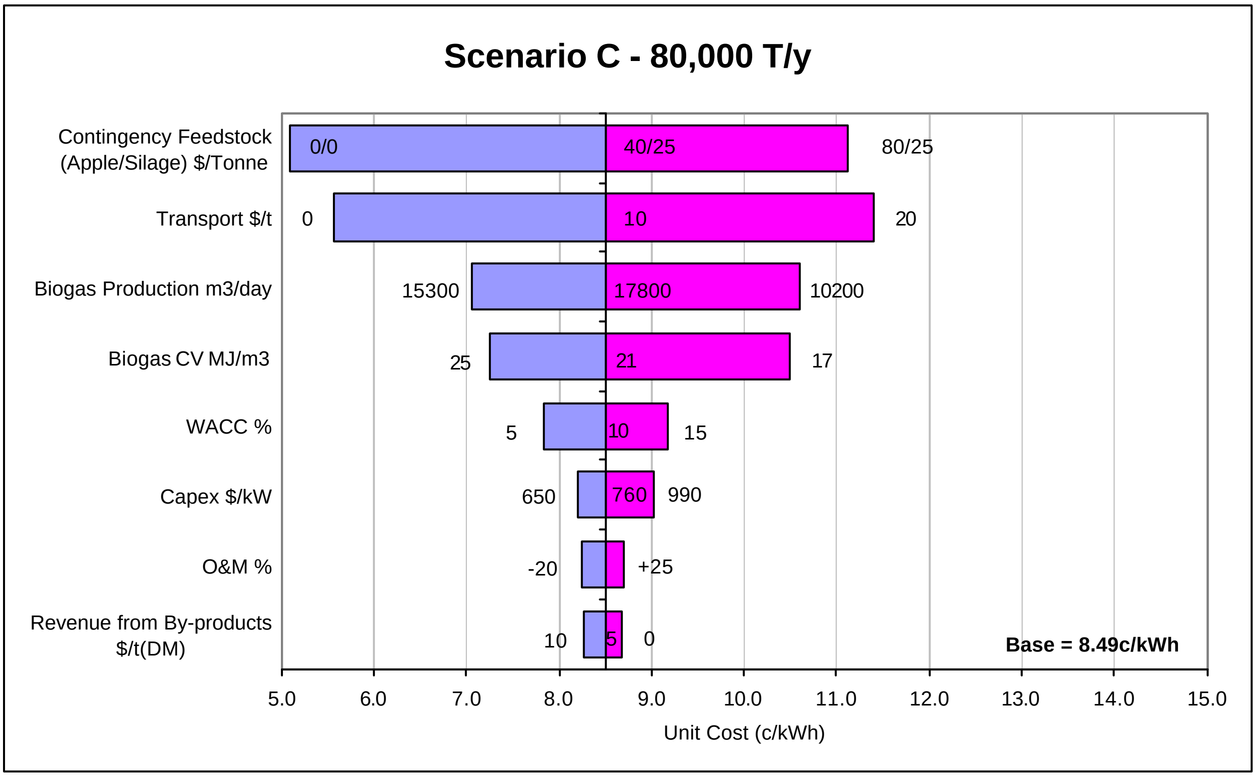

Figure 18. Sensitivity Analysis of Scenario C.

6.2.3 By-Product (Liquid Fertiliser / Humus) Revenue

By-products of digester operation (sludge or substrate) are separated into liquid and solid pulp. These are considered (at this stage) as a high-nutrition liquid fertiliser and dry matter suitable for application to land. The marginal value of this may be considered as:

- Reduction in stock feed liquid content transported from processor to the farm (through separation process).
- Concentration of nutrients and potential reduction of stock methane emissions.
- Potential for liquid component application as nutrient-rich liquid fertiliser.

The liquid by-product of the digester process is considered as a nutrient rich fertiliser. The value of this is yet to be determined, but conversations with suppliers and users [ISE-2004, BIL-2004] of liquid products of anaerobic digester processes and fertiliser supplier [FLANDS-2004] suggest that the value should not be underestimated. This has not been quantified, however testing of feedstock suitability for digestion is likely to give a reasonable indication as to its value.

If the liquid residue is suitable for application to apple orchards, it may be used to negotiate a reduced cost transfer of apple thinnings during the spring contingency feedstock period.

The value of the solid by-product of anaerobic digestion (humus) is roughly estimated at between $5 and $10 per tonne of equivalent dry matter. A “dry-tonnage” basis for pricing is due to the digesters requirement for operating with a specific dry matter content, rather than the variable feedstock wet tonnage supplied to the digester.

6.2.4 Cogeneration

The assumed cogeneration electricity outputs if all biogas were put only to the cogeneration function are:

- Scenario A – 100 to 210 kW_e
- Scenario B – 420 to 930 kW_e
- Scenario C – 700 to 1,500 kW_e

A cogeneration plant would operate 24 hours per day, at an electrical conversion efficiency of approximately 39%. The marginal cost of operating a 1.4MWe biogas cogeneration plant was evaluated at 17.1 cents/kWh_e for scenario C (using fuel cost of 8.5c/kWh_{th}). Thermal energy recovered from the cogeneration plant would be used to warm the digester and process the digester by-products into alternative forms. Solid fertiliser pellets could be produced with on-site heat. Cogeneration options for scenarios A and B are not evaluated as they are smaller and considered more expensive to operate.

Given the existing electricity costs of between 11 and 13 c/kWh_e, a cogeneration plant at 17.1 c/kWh_e is not a commercially viable proposition.

6.2.5 Carbon Credits

Biogas (methane and carbon dioxide) is a greenhouse gas, of which the methane component has 21 times the effect of CO_2. A biogas plant has potential to have a net greenhouse gas benefit. Government promissory notes may add further value to this project. However this is speculative and therefore is not considered at this stage of investigation.

6.2.6 Digester Expertise / Consultancy

The potential for a Hastings area digester project operator to engage in consulting or operation of other plant may at some later stage provide additional revenue (or a national benefit) attributable to the project. However, the value of this is difficult to quantify and is not considered at this stage of investigation.

7 Digester Risk Profile

A high-level assessment of the risks associated with digester operation is presented, with a view to determining the key areas likely to impact on the economic operation of a fruit and vegetable processing waste to energy plant in the Hastings district.

7.1 Risk Assessment Methodology

Risk = Probability * Consequence

The risk of a biogas project success is subject to a wide range of effects. These are assessed at a high level, with respect to probability and consequence on the project operation. The operation of a biodigester plant is assessed using probability and consequence ratings (Table 15). The resultant risk factors are summarised in Table 16.

Table 15. Measures of Risk and Consequence Used for Operational Risk Assessment [adapted from RISKMG-W].

Factor	Probability Description	Consequence Description
1	**Rare** – May occur only in exceptional circumstances.	**Minor** – No measurable operational impact to the organisation.
2	**Seldom** – Could occur at some time but would require remotely possible coincidences.	**Significant** – Minor degradation of operations or service delivery. Impact to a single area of the organisation. Local management intervention required, with locally available resources.
3	**Possible** – Might occur at some time. Chosen sequence or coincidence unusual.	**Serious** – Substantial degradation of operations or service delivery. Impact to multiple areas of the organisation. Substantial management intervention required, may need some external assistance.
4	**Likely** – Will probably occur in most circumstances.	**Major** – Substantial degradation of operations or service delivery. Impact to multiple and diverse areas of the organisation threatening the viability of the organisation. Significant senior management intervention required with mobilisation of resources including external assistance.
5	**Almost certain** – The most likely and expected result if the chosen sequence or scenario takes place.	**Catastrophic** – Widespread and total degradation of operations or service delivery. Impact across critical functions of the organisation threatening immediate viability and significant long term doubt about sustainability of the organisation. Immediate senior executive and Board intervention required.

7.2 Feedstock

The identification of feedstock for processing is the first stage of a quality operation of the digester. The consequence of incorrectly identifying feedstock for biogas production includes the potential for significant performance degradation (reduced gas production) for an extended period and increased operating costs.

7.2.1 Homogeneity of Feedstock

The uniformity of feedstock composition is a critical aspect to the efficient operation of digester plant. The consequence of poor homogeneity of feedstock can range from slightly reduced performance to extended periods of diminished performance (gas production). The seasonality of food production in the Hastings area is also likely to affect the performance of digester plant with different fruit and vegetables being delivered daily. The management of feedstock transitions is important with respect to minimising the potential impact on gas production.

The experience of plant operators with digesters and quality assurance processes is likely to be a key factor to the successful operation of digester plant. This may be backed up through training in the operation of digesters and availability of expert operational advice.

Probability = 4, Consequence = 3

7.2.2 Consistency of Feedstock Supply

The consistency of feedstock is subject to seasonal variance in fruit processing. Within digester loads there is likely to be variance in feedstock consistency. This is countered through use of mechanical mashing or shredding prior to feeding the digester and storing and mixing prior to injection as much as possible.

Probability = 5, Consequence = 2

7.2.3 Pesticides, Garden Chemicals and Detergents in Feedstock

The presence of pesticides may have a negative impact on digester productivity. This will be subject to advice from the digester manufacturer.

Probability = 4, Consequence = 3

7.2.4 Transportation of Feedstock

The use of feedstock transportation vessels for transportation of other materials exposes the digester to feedstock contamination and subsequent reduction in performance.

Several options are available to minimise exposure to the efficient operation of the digester plant:

1. Dedicated feedstock transportation containers – implies additional capital expenditure.

2. Traceability across the feedstock supply chain – implies additional operational expenses.

Probability = 3, Consequence = 3

7.2.5 Storage of Feedstock for Processing

The storage of digester feedstock should be considered with respect to:

- Allowing feedstock to aerobically degrade – reduces gas yield and thus the return on investment.
- Attracting insects and animals – potential negative impact on adjacent fruit and vegetable processors.
- Cross-contamination of the feedstock with other incompatible feedstocks – potential to reduce gas yield and thus the return on investment.

The key consequence of poor handling (storage) of feedstock is the possible reduction in digester performance. This implies that feedstock be processed as soon as it arrives at the plant, or be stored in an air-free environment (vacuum sealed bags or possibly under water).

Probability = 4, Consequence = 2

7.2.6 Feedstock Supply Availability

The operation of digester plant requires careful consideration of feedstock operation. It is prudent to consider the size of buffer, which may be required to ensure consistent operation. A local silage operation may be a suitable buffer for digester feedstock. During periods of peak supply of feedstock, over-run feedstock may be ensiled (on or off-site) by a local silage operator. In return, during periods of low feedstock availability, previously stored silage could be purchased (at an estimated cost of $25 delivered from off-site) to support digester operation. Co-location of a digester with a freezing works / wastewater treatment / waste combustion plant may be another strategy of managing the risk associated with feedstock availability.

Probability = 5, Consequence = 3

7.2.7 Conditioning of Feedstock Prior to Processing

The conditioning of waste prior to digestion is critical to the efficient operation of the digester, as well as the quality of liquid fertiliser and humus by-products. Conditioning processes include shredding, screening and metal/combustibles separation are utilised to remove inorganic matter prior to digestion. Mechanical chopping and mashing can improve subsequent processing. Special consideration must be made for the feedstock processing methodology, as unwanted air may be introduced to the feedstock depending on processing technique.

Probability = 5, Consequence = 2

7.3 Digestion Process

7.3.1 Conversion of Feedstock into Energy and By-Products

The conversion of feedstock into energy is performed within a digester. Efficiency of digestion relies upon close monitoring of biological conditions within the digester plant. The monitoring of the digestion process enables the operator to adjust plant variables to provide a more consistent long-term supply of biogas from the plant. The consequences of undesirable operation of the digester plant are substantial, with some events resulting in extended process downtime (months).

Probability = 3, Consequence = 4

7.3.2 Temperature

The operating temperature of the digestion process determines the rate of gas production, while a drop in temperature can result in diminished performance, and take significant energy (heat input) to recover from.

Probability = 3, Consequence = 2

7.3.3 Digester Safety

Digesters are generally a safe operation but as with any processing plant accidents can occur. Several digester projects in the United States of America have result in loss of life:

- A Spokane Wastewater Treatment Plant employee died in May 10, 2004 when a 2,000,000 gallon sewage tank erupted and its roof collapsed.

- An Aurora city sewage plant had an explosion when an empty sludge line allowed methane gas to leak into a control building, where electrical equipment is thought to have sparked the explosion.

Probability = 2, Consequence = 5

7.3.4 Storage of Gas

The storage of biogas produced by the plant is critical, with respect to the economic and safety performance of the plant. The consequences of faulty gas storage are substantial, perhaps resulting in plant destruction, whereas the consequence of gas leakage is likely to affect the economic performance of the plant. Adherence to gas codes of practice, and hazardous goods regulations is recommended.

Probability = 2, Consequence = 5

7.4 Use of Digester Output

7.4.1 End Use of Gas

As the digester is likely to use gas for its own use, risk associated with the use of gas is considered within the scope of this report. The combustion of gas to produce heat is considered as standard practice. The risk associated with energy usage in biogas plant is similar to that normally associated with gas use.

The New Zealand Gas Codes of Practice will apply to gas related parts of a biogas project. Standards relating to the use of gas for food processing will apply.

Probability = 2, Consequence = 5

7.4.2 Fertiliser / Humus Output

The feedstock output of the digester (substrate) consists of liquid fertiliser and humus are considered suitable for land application. Guidelines relating to the safe application of biosolids to land will apply.

Probability = 1, Consequence = 4

7.5 Risk Summary

Based on the probabilities and consequences outlined, a ranking of risks related to the operation of a biogas plant in the Hastings area is summarised in Table 16.

Table 16. Summary of Hastings Biogas Plant Operating Risks.

Operation Factor	Probability	Consequence	Risk Factor
Feedstock Supply Availability	5	3	15
Conversion of Feedstock into Energy and By-Products	3	4	12
Homogeneity of Feedstock	4	3	12
Pesticides, Chemicals and Detergents in Feedstock	4	3	12
Consistency of Feedstock	5	2	10
Conditioning of Feedstock Prior to Processing	5	2	10
Digester Safety	2	5	10
Storage of Gas	2	5	10
End Use of Gas	2	5	10
Transportation of Feedstock	3	3	9
Storage of Feedstock for Processing	4	2	8
Temperature	3	2	6

Feedstock related processes require the most attention from a risk management perspective. The success of a biogas plant in the Hastings area will be dominated by ensuring the quality and availability of the feedstock throughout its operation.

7.6 Digester Ownership

The ownership and operation of the digester plant will have a bearing on risk management. The digester facility is dependant on feedstock being supplied from a number of sources. Other than Heinz Watties there is probably no single company that has a sustained continuity of feedstock supply. This applies to both the small and large sized digesters. The digesters are also a specialist technology that lends itself to third party ownership and operation.

The advent of third party ownership is becoming common where an independent party contracts to supply heat to industry heat users. Examples of this within NZ are the contracted supply of heat by Meridian Solutions to the Blue Mountains Lumber sawmill in Tapanui, Dunedin Hospital, and Winstones Pulp Mill in Ohakune.

7.7 Integration with Other Energy Plant

The digester operation would lend itself to integration with the operation of other heat plant. Not only would the biogas be able to be used as fuel into the other heat plant but the risk associated with contracted energy supply can be better managed.

There are separate opportunities for the establishment of heat plant facility fuelled on wood waste or a combination of woody biomass and gas or coal. Co-location with a digester facility would provide synergies of operation.

8 Conclusions

8.1 Fruit and Vegetable Digester Technology

The study shows that despite the biodigester technology having been around for many years there are few international examples where food waste is processed in digesters. Internationally there are a greater number of digesters fuelled by farm stock waste, although the total number in this category is still very small. The emphasis on processing farm stock waste is driven principally by environmental objectives whereas fruit and vegetable waste is generally not a problem requiring a solution.

8.2 Suppliers to New Zealand

This report covers four suppliers of digester technology to the New Zealand Market. These include:

- Integrated Systems Engineers – Stainless Steel Plug Flow Technology
- Waste Solutions – Complete Mix / In Ground Baffled Reactor / BTA Single-Stage Technology
- Solwind – In Ground Passive Batch Technology
- RCM Digesters – Complete Mix / Plug Flow / Heated / Covered Lagoons

8.3 Food Waste (Feedstock)

Fruit and vegetable waste supply (feedstock) quantities from the Hastings area are aggregated by type on a monthly basis. These are segmented by supplier, and applied to three scenarios. The dry matter content is required to remain consistent on a monthly basis. During months where feedstock is in short supply (i.e. spring), the dry matter content may be supplemented through either ensiling of previous excess supply, or collection of fruit thinnings. These two options are complementary, as supply of apple thinnings is limited to November through February, whereas silage availability is dependent upon storage of previous feedstock.

8.4 Scenarios of Digester Operation

Producing methane gas from fruit and vegetable waste is considered by digester suppliers as perhaps three to seven times more efficient as using farm stock waste, giving a biogas yield of 50m^3/150kg(dry matter).

Three scenarios were considered for processing Hastings area derived Fruit and vegetable waste:

a) Small digester in the Omahu Road area producing gas as a boiler fuel.
b) Medium digester in the Omahu Road area producing gas as a boiler fuel.
c) Large digester based in the Whakatu area taking all fruit and vegetable waste from the Hastings area and producing gas and electricity.

8.4.1 Scenario A

The operation of a small scale biodigester at Omahu Road has been assessed. A fruit and vegetable feedstock capacity of 10,000 tonnes per annum is estimated to net 640,000 m^3 of biogas (13,000 to 16,000 GJ). This is enough gas to fire a 640kW boiler for 16 hours per day year-round, at a cost of 11.4c/kWh.

8.4.2 Scenario B

The operation of a mid sized biodigester at Omahu Road has been assessed. A fruit and vegetable feedstock capacity of 45,000 tonnes per annum is estimated to net 2,800,000 m^3 of biogas (60,000 to 70,000 GJ). This is enough gas to fire a 2,800kW boiler for 16 hours per day year-round, at a cost of 8.8c/kWh.

8.4.3 Scenario C

The operation of a large biodigester at Whakatu as a generic representative area has been assessed. This would be fed by feedstock from the wider Hastings area. A fruit and vegetable feedstock capacity of 80,000 tonnes per annum is estimated to net 4,600,000 m^3 of biogas (100,000 to115,000 GJ). This is enough gas to fire a 4,600kW boiler for 16 hours per day year-round, at a cost of 8.5c/kWh.

Given biogas at a cost of 8.5c/kWh, the cost of generating electricity 24 hours per day was evaluated at 17c/kWh_e. This is not competitive with existing on-grid electricity supply at 10-12 c/kWh.

8.5 Economics of Operation

The study has shown that the production of biogas from fruit and vegetable waste is close to being commercially viable. It would appear that under certain scenarios biogas could possibly be produced and delivered to boilers for heating at costs of 8 – 11 cents/kWh compared to natural gas supplied to commercial users at around 6.9 cents/kWh. These costs are based on the best assumptions available but which in practice may vary significantly according to how the project were implemented. These results however indicate that given the level of confidence in the assumptions, that further work on the use of digesters for converting fruit and vegetable waste to energy is justified.

Methane gas produced from a biodigester fuelled on fruit and vegetable waste is a suitable fuel for boilers and would be the preferable use in the Hastings area where large quantities of heat are used, rather than using the gas for electricity generation. Biogas from Whakatu industrial area could be supplied to Heinz Watties or other large heat users in the area.

The marginal cost of electricity from a cogeneration plant (for scenario C) is calculated at 17.1 c/kWh_e. This is not a commercially viable proposition, given the existing on-grid electricity costs of between 11 and 13 c/kWh_e.

The value of digester (liquid fertiliser and humus) by-products is as yet unknown. However, an interim value of $10 per tonne (on a dry matter tonnage basis) has been applied for the liquid and solid components. Further research is required to determine the true value of the liquid and solid by-products.

8.6 Operational Risks

A wide variety of anaerobic digester technologies are available, with varying options to manage the risks associated with the conversion of feedstock into energy.

The economics of each scenario indicate that while gas production for use as a boiler fuel could theoretically be worth considering, the risk factors associated with feedstock, technology and hence energy supply could seriously affect investment decision making.

The study has identified that the use of anaerobic digester technology is in its infancy and as a result the data used has had to be adopted from international digester equipment suppliers and international applications.

The location of digesters will be critical in minimising waste delivery costs and gas deliver costs. The size of any one waste producer (except for Heinz Watties) is too small to have a digester alone, or the waste from each is too variable in composition and quantity. In particular there is a potential waste supply over the spring period, which will have to be managed by import of waste from orchards or other sources. Co-location of a digester with a freezing works / wastewater treatment / waste combustion plant may be one strategy of managing the risk associated with feedstock availability. Any digesters would need to be operated as part of a waste-sourcing cluster.

The economics of digester operation is most significantly affected by the cost of fruit and food waste collection and delivery. The waste stream already has a positive value in that waste producers are receiving a payment for it or are at least getting it taken away for nothing. If the waste was to be used as digester fuel this would introduce collection and delivery costs that currently don't occur.

8.7 Summary

The study confirms that converting fruit and vegetable waste into methane gas for use in boilers is technically possible and can be economically a good investment. However the opportunity is most appropriate where the waste disposal is a cost and the waste producer is able to generate enough waste continuously for 12 months of the year. The continuous waste supply can be sourced from a cluster of waste producers.

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Appendix A – Waste Flow Diagrams

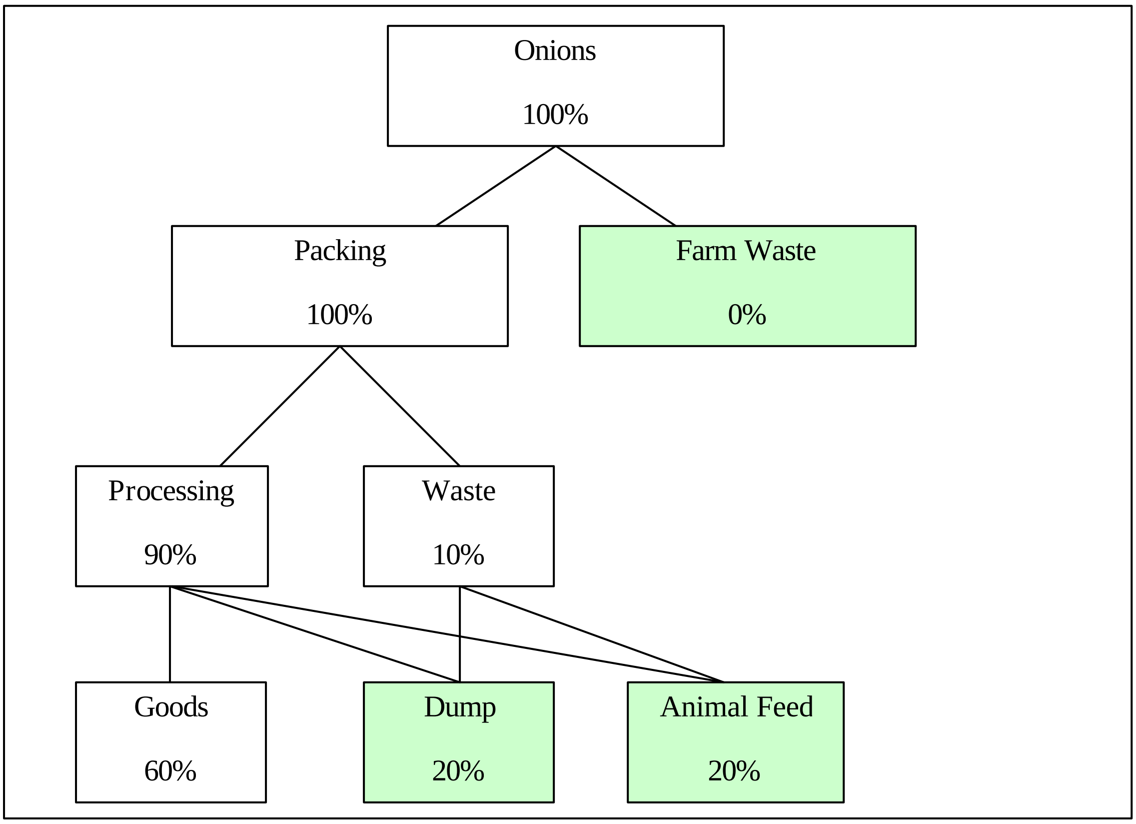

Figure 19. Tree Diagram of Waste from Grow, Pack and Process Stages of Processing.

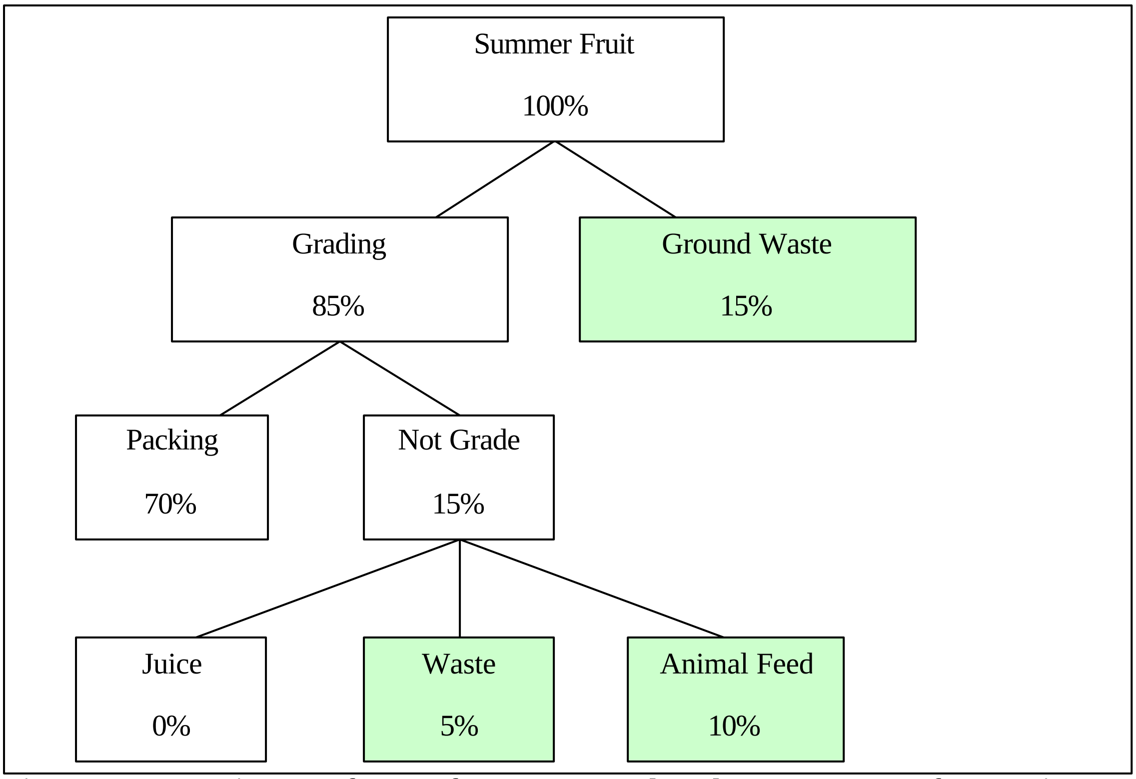

Figure 20. Tree Diagram of Waste from Grow, Pack and Process Stages of Processing.

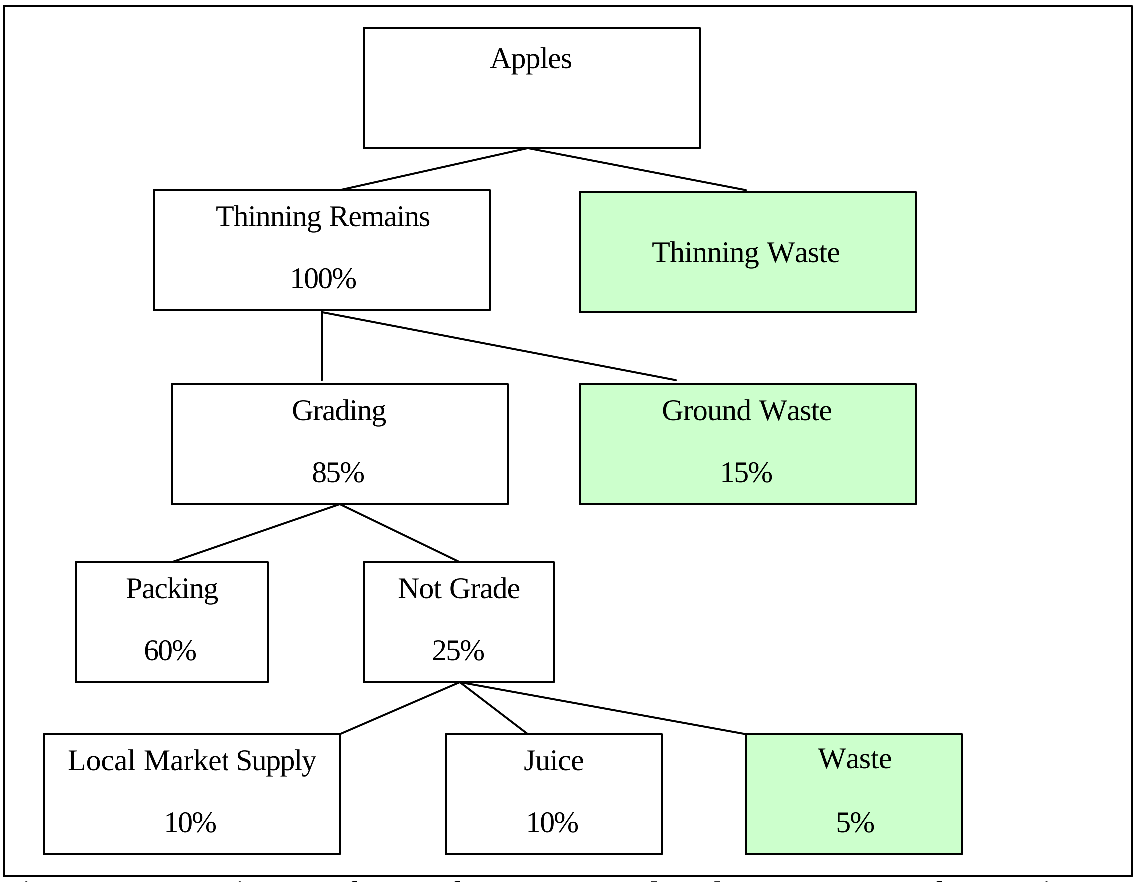

Figure 21. Tree Diagram of Waste from Grow, Pack and Process Stages of Processing.

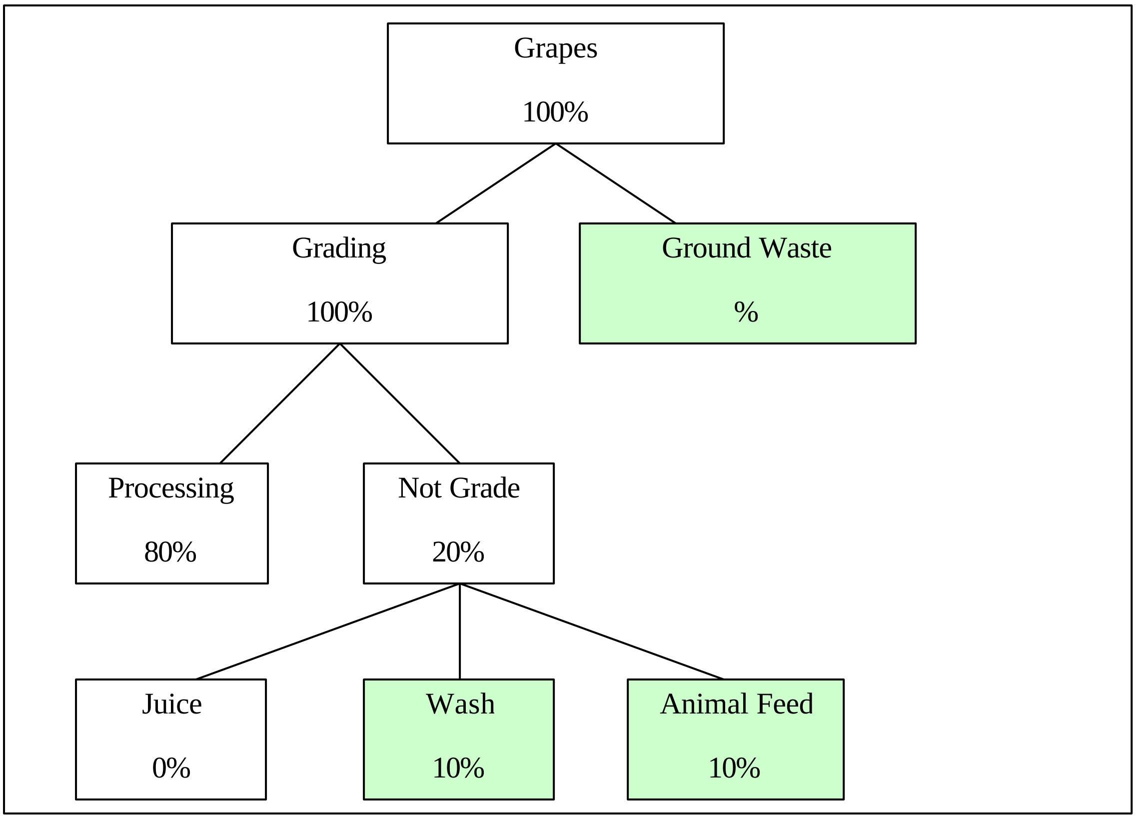

Figure 22. Tree Diagram of Waste from Grow, Pack and Process Stages of Processing.

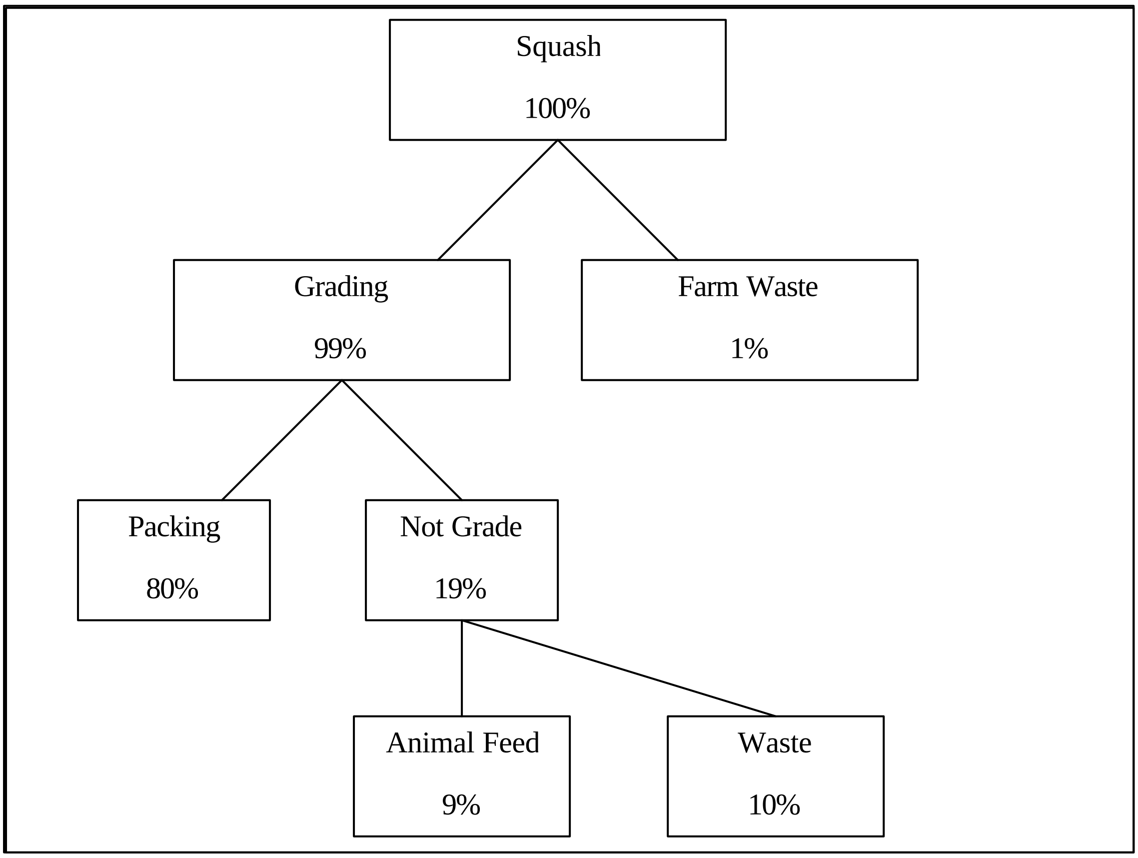

Figure 23. Tree Diagram of Waste from Grow, Pack and Process Stages of Processing.

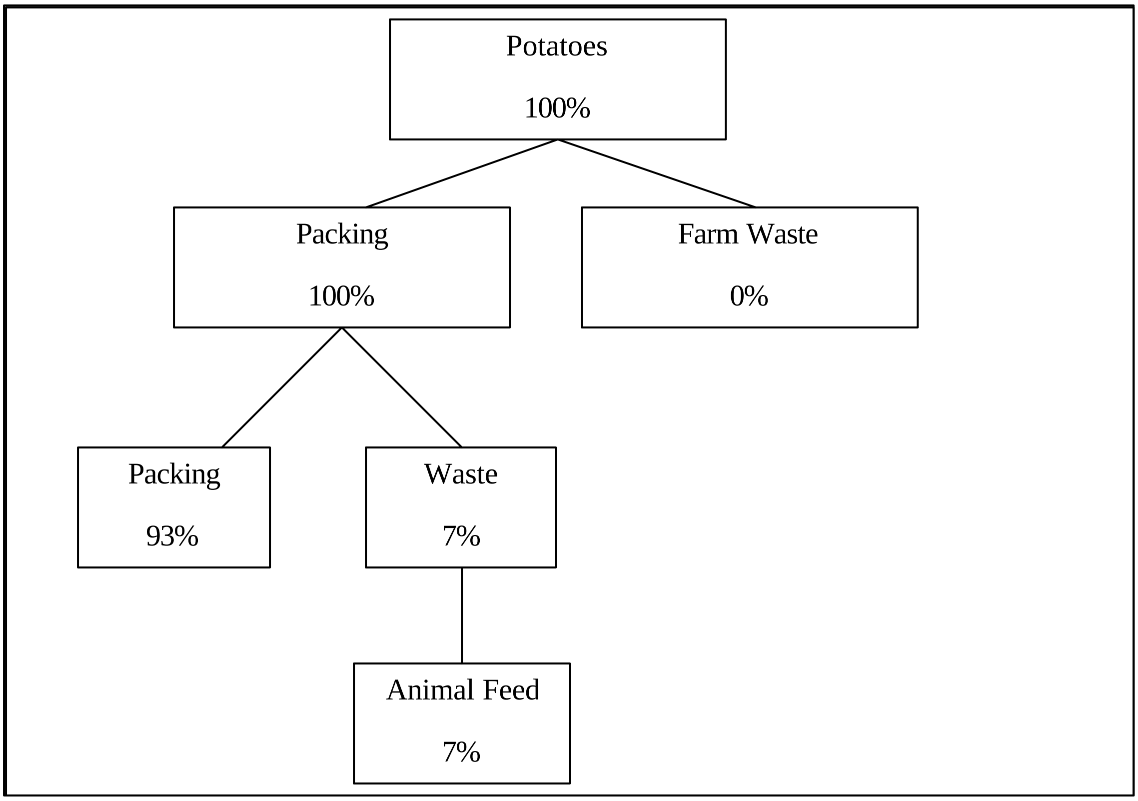

Figure 24. Tree Diagram of Waste from Grow, Pack and Process Stages of Processing.

Appendix B – Distance Calculations

Table 17. Approximate Distance (in metres) Between Omahu Road Processors.

From / To	Profruit	McCain Foods	Horticulture Marketing	CSI Processors
Profruit	20*	500	1200	1350
McCain Foods	500	20*	900	1000
Horticulture Marketing	1300	900	20*	100
CSI Processors	1350	1000	100	20*

* Note: Assume 20m distance from within processor site to an on-site digester.

Table 18. Aggregate Waste Tonnage-Distance per Potential Omahu Road Digester Location.

Month	Tonne-km to Profruit	Tonne-km to McCain Foods	Tonne-km to Horticulture Marketing	Tonne-km to CSI Processors
Jan	11	8	1	0
Feb	239	166	4	18
Mar	253	516	844	963
Apr	253	516	844	963
May	253	516	844	963
Jun	32	533	1,261	1,418
Jul	32	533	1,261	1,418
Aug	32	533	1,261	1,418
Sep	32	533	1,261	1,418
Oct	18	183	421	473
Nov	11	8	1	0
Dec	11	8	1	0
ANNUAL	**1,178**	4,055	8,004	9,050

Appendix C – Waste Information

During October-February, it may be possible to source:

1. Apple tree thinning waste is considered to be readily available from the end of November to January, the quantity during this period is though to be significant (estimated at 200,000 tonnes of apples within the Hastings area).

2. Silage (from stored fruit and vegetable processing waste to maintain feedstock supply). Silage is stored under plastic wrap, with an initial aerobic process, and later an anaerobic process occurring. At this stage we are uncertain as to the potential for silage to be used as a feedstock during periods of low waste supply. There is currently a 5000 Tonne silage pit. It may be possible to exchange significant excess capacity during the March-April period for contingency purposes.

Moisture Content

Table 19. Moisture Content of Waste Streams.

Waste Source	Moisture Content		
	Low	High	Figures Used
Apple	10%	20%	15%
Kiwifruit			50%*
Summer Fruit	10%	70%	60%
Grapes			50%*
Apple Decanter Pomace	90%	95%	95%
Squash	50%		50%
Corn	80%		80%
Carrot	80%		80%
Green Vegetables	70%	90%	80%
Onion	85%	90%	90%
Beetroot	80%	85%	85%
Tomato	80%	90%	85%
Silage	77%	90%	80%[19]
Apple Thinnings	85%		85%

* Note: Where no Low or High figures are listed, figure used is best guess.

[19] Note: Silage has a higher volatile solid content than average fruit and vegetable waste. Therefore, a DM figure of 20% is considered conservative (see Figure 6).

Annual Waste Profiles

The wet tonnages of feedstock are outlined at a high level. Where "Base Supply" is below an ambient level, apple thinnings (directly from orchards) are relied upon to maintain a relatively consistent level of DM. Where apple thinnings are unavailable, a local supply of silage[20] is considered as a suitable back-up feedstock. It is thought that during times of digester "overload", unused feedstock may be stored in silage, while being drawn upon during the spring period, where feedstock is scarce. Conversation with "Jason and Son Ltd" [JASON-2004] suggests a price of approximately $25 per tonne delivered would be paid for silage stored off-site. This appears to be competitive on a dry matter content basis.

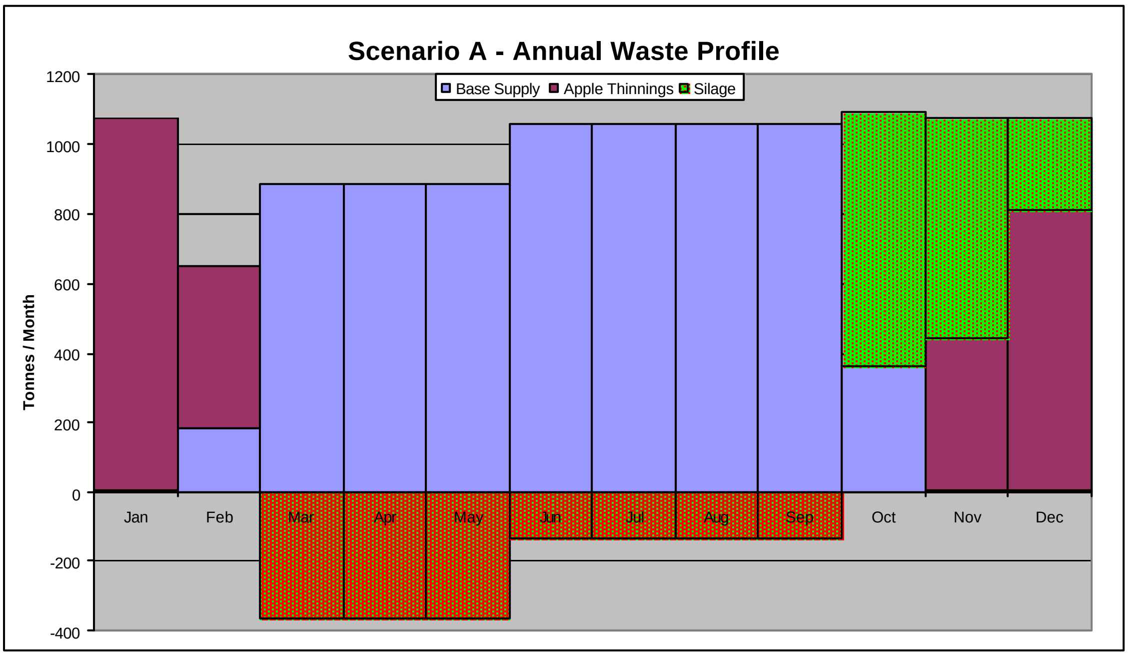

Figure 25. Estimated Annual Waste Profile for Scenario A (Wet Tonnes).

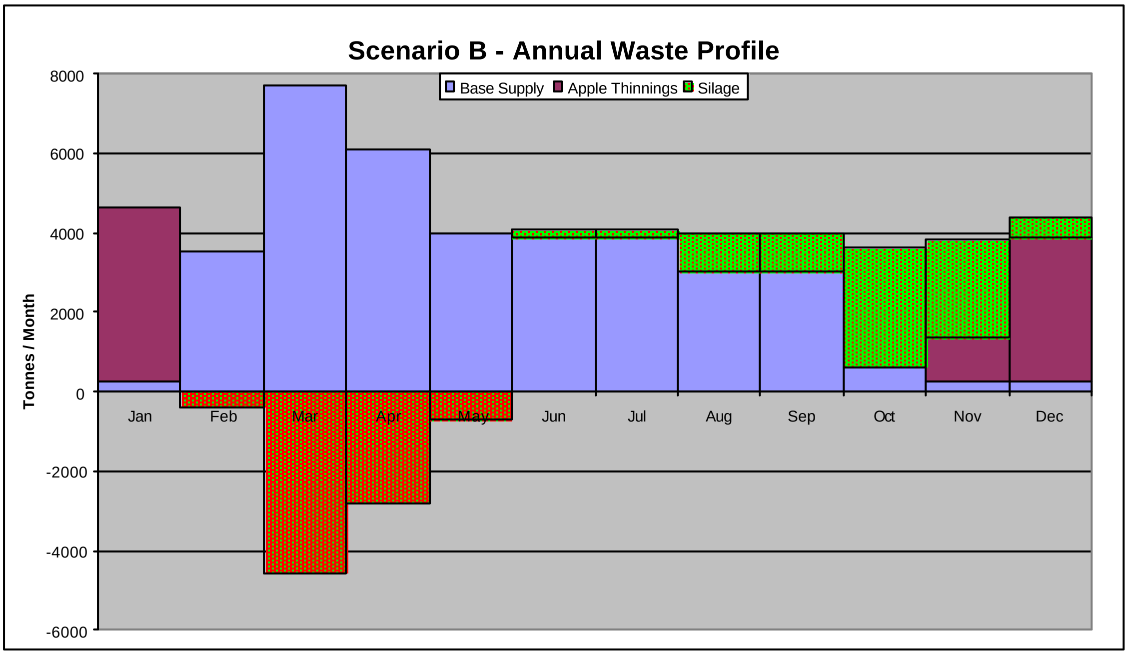

Figure 26. Estimated Annual Waste Profile for Scenario B (Wet Tonnes).

[20] See Figure 6 for an indication of the biogas yield from silage materials.

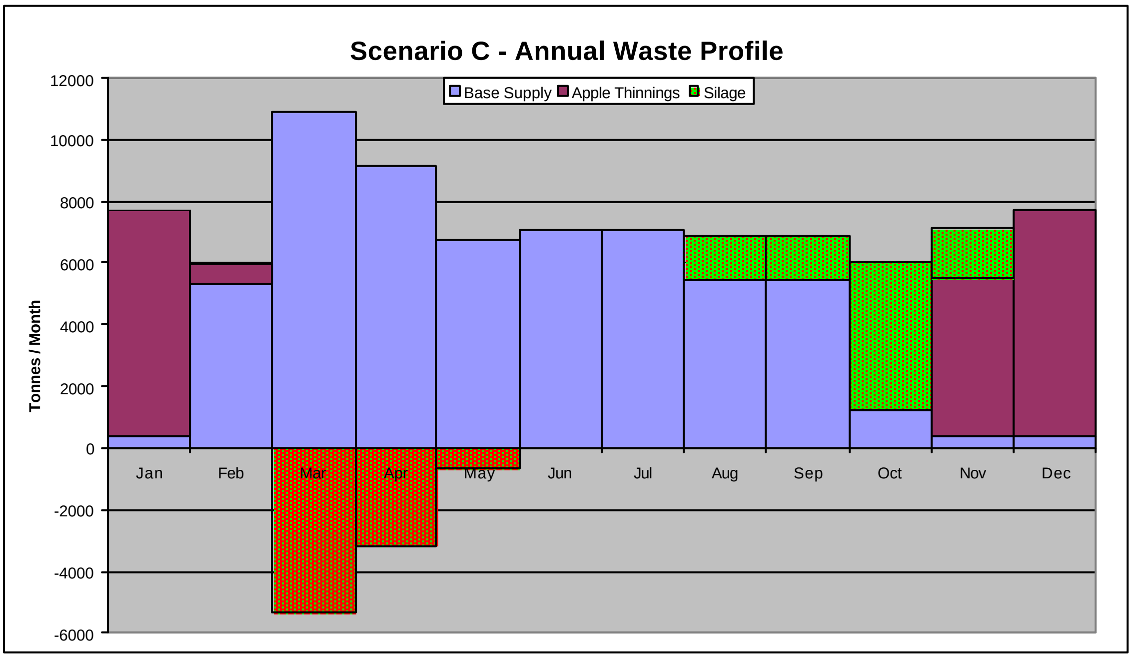

Figure 27. Estimated Annual Waste Profile for Scenario C (Wet Tonnes).

Table 20. Thinned Apple Quantities and Tonnages (Assumptions and Estimations) [RAKA-2004].

Apple orchards near Hastings (ha)	6,500
Apple trees / ha	900
Total apples per tree	500
Apples/bin*	3,000
Tonnes/bin	0.45
Tonnes/ha	34
Weeks for thinning	8
Percent of apples thinned from tree	50%
Calculated Thinned Apple Availability From Late November to February	
Thinned apples	1,462,500,000
Bins of thinned apples	487,500
Tonnes thinned /season	219,375
Tonnes thinned /week	27,422
Tonnes thinned /month	109,688

* Note: Apples are smaller at this time of year, hence 3,000 apples per 450 kg bin, whereas during picking season, normally 2,500 apples fill a bin [RAKA-2004].

Appendix D – Digester Yield

Table 21. Calculated *Net* Energy Yield and Plant Capacities for Scenarios A, B and C.

Gas Yield MJ/m^3	GWh_{th} / year			kW_{th} (@ 8 h/day)			kW_{th} (@ 16 h/day)			kW_{th} (@ 24 h/day)		
	A	B	C	A	B	C	A	B	C	A	B	C
21	1.3	457	194	152	152	152	457	1,757	2,812	152	586	937
25	1.6	544	272	181	181	181	544	2,092	3,348	181	697	1,116

Note:

1. Digester plant is assumed to utilise 15% of gas production for operation[21].
2. Average gas yield of $46m^3$ per tonne of feedstock is used.
3. Gas yield may vary between 21 and 25 MJ/m^3 depending on feedstock and operating conditions.

[21] "Own-use" of energy by digesters is quoted as being as much as 35% of total energy produced (Kompogas plant, Switzerland) [CADDET#18]. For the purposes of this report, a figure of 15% is assumed for own-use (digester heating and feedstock processing), given the comparatively temperate climate within the Hawke's Bay region.

Appendix E – Technology Costing

Table 22. Estimated Cost Breakdown of RCM Digester Technology for Scenarios A, B and C [RCM-2004, RCM-SWINE].

Description	Scenario A (10,000 T p.a.)	Scenario B (45,000 T p.a.)	Scenario C (80,000 T p.a.)
	Total Cost (NZ$000's)		
Indirect Costs			
Engineering	115	154	192
Project Management			
Site Evaluation			
Start-up support (heating)			
Subtotal	**115**	**154**	**192**
Equipment			
Valves and Specialised Equipment	42	65	100
Transformers	0	0	0
Control Equipment	29	45	70
Mixers	63	97	150
Water Heater and Pumps			
Boiler Unit	0	0	0
Tanks	126	194	300
Gas Storage and Treatment	84	129	200
Instrumentation	76	116	180
Subtotal	**419**	**645**	**1,000**
Construction			
General			
Mechanical			
Electrical			
Subtotal	**0**	**0**	**0**
Contingency	0	0	0
GRAND TOTAL	**534**	**799**	**1,192**

Table 23. Estimated Cost Breakdown of Integrated Systems Engineers Digester Technology for Scenarios A, B and C [ISE-2004, NZDE-4-2004].

Description	Scenario A (10,000 T p.a.)	Scenario B (45,000 T p.a.)	Scenario C (80,000 T p.a.)
	Total Cost (NZ$000's)		
Indirect Costs			
Engineering			
Project Management			
Site Evaluation			
Start-up support (heating)			
Subtotal	0	0	0
Equipment			
Valves and Specialised Equipment	290	1,450	2175
Transformers	0	0	0
Control Equipment			
Mixers	0	0	0
Water Heater and Pumps			
Boiler Unit	0	0	0
Tanks			
Gas Storage and Treatment			
Instrumentation			
Subtotal	290	1,450	2,175
Construction			
General	0	0	0
Mechanical	0	0	0
Electrical	0	0	0
Subtotal	0	0	0
Contingency	0	0	0
GRAND TOTAL	**290**	**1,450**	**2,175**

Appendix F – Digestion Assumptions

Table 24. Biogas Production and Energy Output Potential from 1 Tonne of Various Fresh Feedstocks [BIOGEN-W].

Feedstock	No of Animals to Produce 1 Tonne/Day	Dry Matter Content	Biogas Yield (m^3/Tonne Feedstock)	Energy Value (MJ/m^3 Biogas)
Cattle slurry	20 – 40	12%	25	23 – 25
Pig slurry	250 – 300	9%	26	21 – 25
Laying hen litter	8,000 – 9,000	30%	90 – 150	23 – 27
Broiler manure	10,000 – 15,000	60%	50 – 100	21 – 23
Food processing waste	-	15%	46	21 – 25

Note:

1. Figures should be taken as indicative values
2. Cattle slurry covers both dairy and beef cattle
3. Poultry manures are highly susceptible to ageing and should be used as fresh as possible
4. $1m^3$ of biogas (at an assumed $20MJ/m^3$) would typically give the following:
    - Electricity only: 1.7 kWh of electricity (assumed conversion efficiency 30%)
    - Heat only: 2.5 kWh of heat (assumed conversion efficiency 70%)
    - combined heat and power: 1.7 kWh of electricity and 2 kWh heat

Table 25. BTA Process Parameters [CANCOM-W].

Operation Parameter		Units	BTA Single Stage Digester	BTA Multi Stage	
				Hydrolysis	Methanisation
Retention Time		Days	14-16	2-4	3
Temperature	Mesophilic	ºC	37	37	37
	Thermophilic	ºC	55	—	—
Biogas Production (from Biowaste)		cu ft/ton	2,800-3,200	3,900 –4,600	
Methane Content		% Volume	60-65%	30-50%	65-75%
Heating Value		BTU/cu ft	600-650	600 - 650	
Energy Production		BTU/ton	1.7-2.1 million	2.3-3.0 million	
Compost Quality					
Total Solids		%	30%		
Volatile Solids		%	70-75% of Total Solids		
Heavy Metals		mg/kg	Pb:85/Cr:44/Cn:52/Cd:1.04/Hg0.25/Ni:27/Zn:135		
Nutrient Value		% TR	N: 1.71/P:0.33/K:0.40		