WASTE REFINERY
Document 2
Customer Requirements Document

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2.00.00 CUSTOMER REQUIREMENTS DOCUMENT

2.00.01 Configuration Management

Version	Date	Name
v8	091002	nwk & pc
v9	091018	nwk & pc
v10	101018	nwk
v11	101101	nwk
v12	110308	nwk

2.02.00 DEFICIENCY

2.02.01 The need to for a new approach

The current ways of dealing with waste are expensive, or un-sustainable or polluting. The most common methods of dealing with waste are land fills and incineration. These are un-sustainable and polluting processes. In addition, current methods of recycling are expensive and incomplete. What is required is a sustainable and non-polluting method that deals with the complete waste stream.

2.03.00 INPUTS

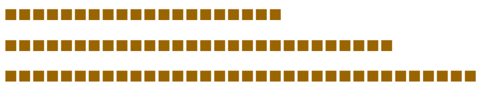
2.03.01 Waste input, average and peak amounts

Note that all amounts shown in this document are estimates, and are subject to verification. Also waste is an inherently variable material, therefore precise numbers are inappropriate.

The inputs of a waste refinery for a given population will produce about 2kg of waste per person each day. (US EPA 4.5 lb per day). Note that much of the waste created is not created at home, and therefore the amount of waste should not be confused with the residential component only.

For the calculations of this document the plant will sized to receive 100,000kg of waste per day average. However as waste is usually moved on weekdays the plant will receive about 140,000kg waste per week day. Assuming a variability of 20% then the peak input will be about 170,000kg per day.

Diagram showing waste inputs -
100t waste daily average
140t per weekday
170t peak
t = 1,000kg



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2.03.02 Water component of waste

Assuming a water content of 20% of the waste then for the daily average waste will contain 80,000kg of dry waste and 20,000kg of water .

Diagram showing waste components -
100t waste daily average ■■■■■■■■■■■■■■■■■■■■
60t digestible ■■■■■■■■■■■■
20t non digestible ■■■■
20t H_2O content ■■■■
t = 1,000kg

2.03.03 Detailed components of waste

Waste can be divided up into digestible and non-digestible components. Most waste is digestible. Note that while we group plastics as non-digestible there are many plastics that are, or may become, digestible with advances in digestion technology.

The digestible components are -
11.4 % Food scraps
5.7 % Wood
35.7 % Paper and cardboard
12.2 % Yard trimmings
7.1 % Rubber leather textiles

72.1 % Digestible sub total

The non-digestible components are -
7.9 % Metals
5.5 % Glass
11.1 % Plastics
3.4 % Other

29.9 % Non-digestible sub total

Diagram showing waste components -
60t digestible ■■■■■■■■■■■■
20t non-digestible ■■■■

10t food ■■
5t wood ■
30t paper ■■■■■■
10t yard ■■
5t rubber ■

5t metals, ■
5t glass ■
10t plastics ■■
t = 1,000kg

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2.03.04 Household hazardous waste and tyres

During a recent program to promote the collection of household hazardous waste, the amount of waste collected was about 47,000 kg in 3 months from the Perth metro area (Refer 01HAZ).
We extrapolate this to 500kg per day for the metro area. And in addition to reduce this to the appropriate population size we arrive at a figure of 100kg per day for the waste refinery. About 80% of this would be paint, batteries and gas cylinders. The remaining 20% would be fuels, pesticides, acids and the like. While for incineration and landfill methods, these items are of obvious concern, however for a waste refinery this level of household hazardous waste would not be a concern.

Because the waste refinery is essentially a wet process, we do not expect any problems from acids or alkalis which will neutralise each other. Where two parts of the waste stream combine to form a flammable material, this will not be a problem because the waste is under water.

A waste refinery will also dilute any problematic waste, in particular any waste that reacts with water, to the point where we expect the effect to be negligible. Also each batch of waste will continually introduce new biological organisms, so we assume that the digestion process will automatically recover in any digester if it became incapacitated.

With regard to tyres or other tough material, provided there are not to many of them, these materials will not affect the granulation process. The proportion of hard materials in waste is very low. Metals typically make up only 7% of the waste stream, and high proportion of the metal is aluminium, in the form of very thin sheets, which is easy relatively granulate.

For our purposes group household hazardous waste into two main groups, heavy metals and complex reactive compounds. Heavy metals can accumulate in biological systems, and cause a number of problems. A number of pharmaceuticals are specially designed to inter act with the biological processes of living things, if they are returned into the environment intact they can also cause a number of problems.

Heavy metals, like lead for example, will be dealt with by being ground up in a wet process (no dust) and will be passed through the refinery and exit in pile at the end of the process.

For complex reactive compounds, like for example pharmaceuticals, these will react with the metal powders and break down into simpler less reactive compounds. (Refer 02ZHA). Each day there will be about 28,000 kg of powdered metal and this will easily be able to cope with 100 kg of hazardous waste expected.

Therefore for a waste refinery the amount of household hazardous waste and tyres that are likely to find there way into a waste refinery should not present a problem to a waste refinery. In addition, given that there is more awareness of this issue, and various regulations, programs and practices, a larger proportion of household hazardous waste and tyres is likely to be diverted to appropriate specialist treatment facilities in the future.

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2.03.05 Granulation Electrical Energy

Waste is difficult to granulate because it is variable, and has some resilient, energy absorbing components as well has hard metals in it. However waste is routinely granulated by means of shredders.

Waste mostly consists of sheets of material like paper, bags, foil, and so on. Most of the material like paper, aluminum cans, plastic bags are less than 0,1mm thick. Which means that they are more than 10 times thinner than the target particle size. Because waste is mostly made up of thin sheets is the reason why waste lends itself to communition or granulation by shearing forces.

Granulation of waste using an off the shelf waste shredder to 50mm strips uses about 8 kWh per 1000kg of waste. (Source – Solid Waste handbook by WD Robinson) Note that 8 kWh is a figure based on communition of dry waste. We intend to shear the waste in wet conditions, and therefore have considerable energy saving.

Typically waste shredders have a built in feed back system that prevents them from breaking when they bite into something hard. In this case they reverse themselves, and then take a smaller bite, and in this way nibble away at the hard object.

In addition to large coarse (above 20mm particle size) shredders, there are also shredders on the market that are designed to finely granulate wet waste. The typical application for this process is to protect pumps systems from damage caused by larger particles from un-filtered storm water, or industrial waste water.

Granulation is difficult to scale and simulate. (Source – The History of Grinding by AJ Lynch and CA Rowland) In addition, because of the variable nature of waste, granulation will be difficult to estimate. Nevertheless we estimate that reducing the size to 7mm strips (a factor of about 7) will use 12 kWh per 1000kg, and then reducing it to 1mm strips (another factor of 7) will use 18 kWh per 1000kg.

Therefore communition of the waste we estimate will consume 38 kWh per 1000kg of waste.

2.03.06 Process Electrical Energy

As the material moves thru the plant the material has to be pumped from tank to tank (say 12 times), and circulated in each tank (say 12 times), and we allow 1 kWh per 1000kg for each of these processes. Then to energy required to process the mixture will be 24 kWh.

2.03.07 Total Electrical Energy

The total energy costs will be the granulation energy (38 kwh) and the process energy (24 kwh), so therefore the electrical energy will be about 62 kWh per 1000kg.

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2.04.00 WASTE REFINERY MASS BALANCES

The waste refinery digestion system is complex because of the biomass generation phases.

2.04.01 Continuously recycled items

A biomass phase at the end of the waste refinery cycle, will mean that in addition the continuously recycled water, there will also be an amount of continuously re-cycled biomass.
In between the low and high temperature digester phases, there will be two biomass generation phases. These phases will reduce the acidity, consume CO_2, water, sunlight and create oxygen and biomass. The subsequent digestion of the biomass, will help produce more methane for power generation.

Diagram showing continuously recycled items -
20t biomass ■■■■
460t H_2O ■■
■■
t = 1,000kg

2.04.02 Low temperature digestion phase

The low temperature first digestion phase is expected to digest only 80% of the available digestible material, and the later high temperature phase will complete the digestion.

Diagram showing low temperature digestion phase -

120t INPUTS -
20t biomass ■■■■ (from previous cycle)
100t waste ■■■■■■■■■■■■■■■■■■■■

- low temperature digestion

120t OUTPUTS -
20t biomass ■■■■ (un-digested 20%)
30t CO_2 ■■■■■■
15t CH_4 ■■■
15t digestate ■■■
20t H_2O ■■■■
20t non-digestable ■■■■
t = 1,000kg

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2.04.03 First algal biomass growth phase

Prior to this phase commencing the methane generated from the previous digestion phase is removed for power generation. This means that the volume of material for processing is reduced.

Light is added and algae growth takes place. Digestate and CO_2 and water are consumed to produce biomass and oxygen. In addition this phase will reduce the acidity of the mixture as well as breakdown harder to digest materials like cellulose.

Diagram showing first algal biomass growth phase -

120t from previous phase -
20t biomass ■■■■
30t CO_2 ■■■■■■
15t CH_4 ■■■
15t digestate ■■■
20t H_2O ■■■■
20t non-digestable ■■■■

Removed from previous phase -
15t CH_4 ■■■ (taken off as fuel)

105t INPUTS -
20t biomass ■■■■
30t CO_2 ■■■■■■
15t digestate ■■■
20t H_2O ■■■■
20t non-digestable ■■■■

- first algal growth phase (plus light)

105t OUTPUTS -
45t biomass ■■■■■■■■■ (algal growth)
20t O_2 ■■■■
10t CO_2 ■■
10t H_2O ■■
20t non-digestable ■■■■
t = 1,000kg

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2.04.04 High temperature digestion phase

The high temperature digestion phase is expected to digest practically all of the available digestible material. Prior to this phase commencing the oxygen generated from the previous biomass phase is removed, which further reduces the amount of material for processing.

Diagram showing high temperature digestion phase -

105t from previous phase -
45t biomass ■■■■■■■■■
20t O_2 ■■■■
10t CO_2 ■■
10t H_2O ■■
20t non-digestable ■■■■

Removed from previous phase -
20t O_2 ■■■■ (taken off as fuel)

85t INPUTS -
45t biomass ■■■■■■■■■
10t CO_2 ■■
10t H_2O ■■
20t non-digestable ■■■■

- high temperature digestion

85t OUTPUTS -
15t biomass ■■■
15t CH_4 ■■■
25t CO_2 ■■■■■
10t H_2O ■■
20t non-digestable ■■■■
t = 1,000kg

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2.04.05 Second biomass growth phase

Prior to this phase commencing the second batch of methane generated from the previous digestion phase is removed for power generation. Also, the non-digestible material is removed for re-cycling. And in addition water surplus to the system is removed. This means that the volume of material for processing is reduced.

Diagram showing second algal biomass growth phase -

85t from previous phase -
15t biomass ■■■
15t CH_4 ■■■
25t CO_2 ■■■■■
10t H_2O ■■
20t non-digestable ■■■■

Removed from previous phase -
15t CH_4 ■■■ (taken off as fuel)
20t non-digestable ■■■■ (for re-cycling)

50t INPUTS -
15t biomass ■■■
25t CO_2 ■■■■■
10t H_2O ■■

- second algal growth phase (plus light)

50t OUTPUTS -
20t biomass ■■■■
10t CO_2 ■■
20t O_2 ■■■■

Removed from this phase -
20t O_2 ■■■■ (taken off as fuel)
t = 1,000kg

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2.05.00 WASTE REFINERY OUTPUTS

The digestion process will produce biogas which consists of methane and CO_2. The combustion of the biogas will release CO_2 into the atmosphere. Because the CO_2 released will be from the current carbon cycle, there should be reduced concern about this release. It is estimated that combustion of biogas, by converting CH_4 to CO_2 reduces the greenhouse gas effect to about 4% compared to that would otherwise be released from a landfill. Also oxygen from the atmosphere is consumed, and water vapour is created.

2.05.01 Biogas combustion

The biomass phases increase the amount of methane produced, which means that more electricity that can be generated.

Diagram showing biogas combustion -

30t CH_4 (taken off)
40t O_2 (taken off)
70t O_2 (from atmosphere)
- - - - - - - - - - - - - - - - combustion - - - - > 19,3 MW electricity
65t CO_2
75t H_2O (water vapour)
t = 1,000kg

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2.05.02 Biogas combustion energy generation

The combustion of biogas will generate electricity and heat. Electricity will be a major source of revenue for the plant. A biogas fueled engine generator will normally convert 18 - 25 percent of the biogas BTUs to electricity, depending on engine design and load factor. (Refer 04EPA)

The maximum theoretical power is not available because the waste refinery will not be 100% efficient. There will be losses during the combustion and generation phases, and in addition the refinery will consume some of the power generated. We estimate that only a small percentage, in the region of about 10%, of the total theoretical power will be available for sale as electricity.

In addition a portion of the heat generated will be used by the digesters, the rest of the heat will be used for concrete product production, or be sold.

The energy from the methane generated -

30,000 kg Methane per day
1,250 kg Methane per hour
55.5401 kJ/g specific heat of combustion (Ref 03WOL)
69,425,125 kJ per hour
19,285 kWh
19.3 MWh theoretical power

2.2 MWh estimated surplus for sale

Waste processed per day is 100,000kg this is 4,167kg per hour.
The total theoretical energy is 19,285 kWh per hour.
Therefore the energy available is 4,628kWh per 1,000kg of waste.

The total electrical energy costs for granulation energy (38 kwh/t) and the process energy (24 kwh/t), will be about 62 kWh per 1000kg.

Genset plants are usually sensitive to energy content of the biogas feed. For example, typical landfill gas tends to have a relatively low CH_4 component. However, because a waste refinery will concentrate CH_4 and minimize the CO_2, we may be able to increase the efficiency of the genset plants and could possibly have very high efficiency. CO_2 content of the biogas will be lowered because the CO_2 will be dissolved into the water, and then consumed by the biomass phases. Also the reaction of metals will generally release H_2 into the biogas, which will further increase the energy content of the biogas.

New generator sets from Jensbacher and Caterpillar advertise 60% efficiency, but if we conservatively assume 50% for our purpose, then we have 2,314 kWh of available energy per ton. If we assume that the energy cost to process the mixture is about 62 kWh/t , then we have 2,250kWh surplus for sale.

In Australia brown coal generation plants sell power at 3c per kWh. Energy from a waste refinery has a potential sale price of 12c to 15c per kWh. (So instead of $67 per ton of waste, potential revenues could be in the region of 270.00 to 335.00 per ton of waste.)

2.05.03 Heat generation

The combustion of biogas will generate a great deal of heat. Although the Waste Refinery will consume heat to raise the digester temperatures, this will only consume a small amount of the heat available. A great deal of surplus heat will be able for sale is a suitable consumer could be found. Heat does not travel far efficiently, so it may be a difficult resource to sell. Alternatively, if un-sold, the heat can be dissipated into the environment.

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2.05.04 Output components

After the digester and biogas combustion processes the waste will be transformed into it's component parts.

Diagram showing outputs after digester and biogas combustion -
20t plastics metals & glass
65t CO_2
75t H_2O (water vapour)
Note - 20t biomass not shown because it is returned.
t = 1,000kg

2.05.04 Output composition

After digestion and combustion there will be 20,000kg of solid material and the gas will be released into the atmosphere.

Diagram showing outputs after digester and biogas combustion -
20t solid
140t gas
Note - the total mass of 160t is derived from 120t of waste and 40t from the atmosphere and sunlight.
t = 1,000kg

2.05.05 Green house gas saving compared to landfill.

When 100,000 kg of waste is placed in a landfill, as it decomposes it will produce about 28,000 kg of CO_2 and 28,000 kg of CH_4. Methane is about 21 times more powerful at green house gas than carbon di-oxide. Therefore the greenhouse gas effect of normal landfill situation is the same as releasing 616,000 kg of CO_2 into the atmosphere. (28,000 + (28,000 x 21) = 616,000)
By contrast a waste refinery will produce 65,000 kg of CO_2, effectively 551,000 kg less per day.

Diagram showing landfill and waste refinery greenhouse gas production -
65t CO_2 waste refinery
616,000t CO_2* landfill
551,000t CO_2* saving
Note - CO_2* is the effective amount of greenhouse gas measured as if it were CO_2.
t = 1,000kg

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2.05.06 Volume of inputs and outputs

The average daily input volume of the plant will be about 830m3 per day. (Equivalent volume to about 18 ISO 6m containers per day.)

Table showing average daily input volume -

Mass	Type	Density	Volume
100t	Waste	480kg/m3	200m3

t = 1,000kg

After processing in the digester array the output will be about 14m3 of solids per day. (Equivalent volume to about a third of 1 ISO 6m container per day.) A portion of this is combustible, and if the output is not sold, is could be combusted to reduce the volume of the waste, extract energy, and reduce the amount of cement needed.

Table showing volume of solid output from digester array -

Mass	Type	Density	Volume
7,9t	Metals	5200kg/m3	1,5 m3
5,5t	Glass	2550kg/m3	2,2 m3
11,1t	Plastics	750kg/m3	5,8 m3
3,4t	Sand	1900kg/m3	4,5 m3
27,9t	Sub-total		14,0 m3

t = 1,000kg

2.05.07 Post processing of solid outputs

Material from a waste refinery will be in clean, powdered form. This material will not need washing, grinding and sorting before being re-used, and will therefore be able to be sold for a higher price than conventional recovered waste. Typically powdered material sells for more than 10 times the price of hand separated raw materials from the waste stream.

Powdered raw materials fetch a much higher price than normal raw materials. For example, used aluminum cans currently sell for about $1.80 per kilogram, while depending on the specification, powdered aluminum oxide sells for between $8.00 and $40.00 per kilogram. (Priced on at 3 March 2011). Aluminum oxide is commonly used in high volumes in plastics, sun-screens, catalysts, abrasives and in new energy efficient lamps. Also it has many other industrial uses.

The metal component of the waste stream should be easy to sell. However the remaining components of waste, mainly plastic and glass, are of low economic value. If a buyer for the product can not be found, these components could be used to make value added products.

Because the material would be in powdered form, the metals, glass and plastic would be suitable for sintering. High value complex shapes are commonly manufactured by sintering. Also the powdered materials could be used by a 3D printer. A 3D printer can combine several different types of material to make complex composite objects. Therefore sintering and 3D printing are opportunities to add value to the raw material stream. A lower value proposition would be to simply incorporate the material into concrete. Concrete production would require the additional input of cement, water and heat. For example, the amount of concrete sidewalk paver production would work out to about 1m2 of pavers per population served per year.

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2.06.00 FUNCTIONAL REQUIREMENTS

2.06.01 Modular devices
As far as practicable, all the devices of the plant are to be modular.

2.06.02 Container format
All the devices, if practicable, to be industry standard bulk sacks, or ISO container format, or multiples thereof.

2.06.03 Matrix material path
All material to be able to flow thru the system in a matrix path. The malfunction or maintenance of any one device can not cause a stoppage of the system. Material must be able to flow around any device that is not operational.

2.06.04 Devices to have independent controls
Each grinder, digester, filter, or other device to have an independent process controller. The controller will be aware of the status of linked components and be able to react to the status of those components.

2.06.05 Devices to broadcast their status locally and to the web
Devices to broadcast their status locally so that local linked devices can respond appropriately. Device status is also to be broadcast to the web, so that remote monitoring is possible.

2.06.06 Devices to be controlled locally and by the web
Devices to be able to be controlled locally by manual switches and via the web.

2.07.00 NON-FUNCTIONAL REQUIREMENTS

2.07.01 Pollution
The waste refinery will not produce any odors sounds or other nuisance to neighbors.

2.07.02 Cost
The cost of a waste refinery shall be kept as low as practicable.

2.07.04 COTS Usage
Usage of commercial off-the-shelf (COTS) components is encouraged but not required. Usable components that already exist with known capabilities can help cut schedule time and development costs.

2.07.05 Ease of Use
There are no specific requirements for ease of use but the plant will be developed such that normal domestic garbage can be processed as a simple routine function.

2.07.06 Trade-off Criteria
Trade studies shall be conducted to evaluate the options on the proposed solution. There are no specific requirements for how the trade studies are performed but they should be performed in a manner consistent with comparable industry standard studies.

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2.07.07 Lifetime

The waste refinery will perform operationally with programmed maintenance on an ongoing basis. The life of each part will be assessed and replaced before it's expected failure date. With continuous improvement the plant should continue indefinitely.

2.07.08 Design Verification

The design verification process will be performed using inspection, analysis, test and demonstration. The specific method for the verification of each requirement will be detailed in the Derived Requirements document.

2.07.09 Schedule

Each device of the plant should be developed concurrently.

2.08.00 FUTURE DEVELOPMENT

2.08.01 Development options

Future development options will include -
a) Improving the efficiency of the WR, including redesign of devices to improve their efficiency, durability and cost effectiveness.
b) Improving the biological processes.
c) Improving the recycling efficiency, including new products and processes to add value to the process.

2.09.00 LANGUAGE GLOSSARY

Device	A modular component part of a plant that performs a specific function.
Plant	The system as a whole.
t	1,000kg (or metric ton).
WR	Waste refinery

2.10.00 REFERENCES

01HAZ Waste & Recycle 2009 Conference, Household Hazardous Waste in WA presented by Ms Cecilia Jordan of the Western Australian Local Government Association

02ZHA Zhang, Environmental Science & Technology, vol 42, no.15, 2008, American Chemical Society .

03WOL www.wolframalfa.com

04EPA US EPA Agstar Handbook section 3-1.1 Electricity Generation System Components

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