WASTE REFINERY
Document 6
Functional Models Document

6.00.000 FUNCTIONAL MODELS DOCUMENT

6.00.010 Configuration Management

Version	Date	Name
v1	091009	nwk, ce
v2	091011	nwk, ce

6.01.000 FUNCTIONAL MODELS ANALYSIS

This document contains many reports that in the aggregate describe the required behavior of the proposed system. Initially some models may not include potential solutions. This document will be used as a basis for developing solutions, which will be included in later iterations of this document.

For the purposes of this document, the functional models have been grouped into various categories. However it should be noted, that some functions systems may straddle several different categories, and that the way they have been categorised does not limit their scope, or importance. As a practical matter, all functions have to work in tandem with one another in order for the waste refinery to operate properly.

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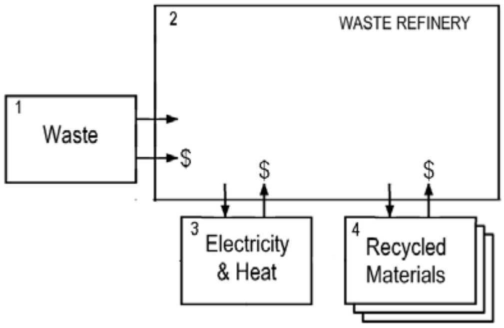
6.02.000 TOP LEVEL FUNCTIONAL MODEL ANALYSIS

The top level system is the process that encompasses all lower level systems, components, or parts thereof to achieve the designated aim of the system

6.02.010 Material and financial system model

The first function of the refinery will be to receive household waste and also to receive revenue for this function. The second function will be to process that waste, and in doing so generate revenues from the surplus heat and electricity provided. The third function will be the supply raw materials to product manufacturers and in so doing create a third revenue stream.

Diagram 2010v1 showing waste refinery material and financial functions



The waste that will be received will be un-sorted household waste. This will include small amounts of hazardous household waste, electronics and tyres, to the extent that they occur in the normal household waste stream. Revenue streams will be received from the local municipal authority who will in turn obtain a fee (directly or indirectly) from the population served. It is envisaged that the fee will be in line with first world standards for accepting waste.

The surplus electricity will be sold to a utility, or directly to a local customer. In addition in WA it is possible to transmit electricity to a remote customer via the utilities infrastructure. Surplus heat will be difficult to sell in WA because it is not a common practice, and also heat does not travel well over long distances, so depending on the location of the refinery, it is possible that the surplus heat will have to be vented to the environment for no financial gain. Other alternatives are to use the heat for post processing of materials to be sold, or to generate electricity by means of a steam turbine.

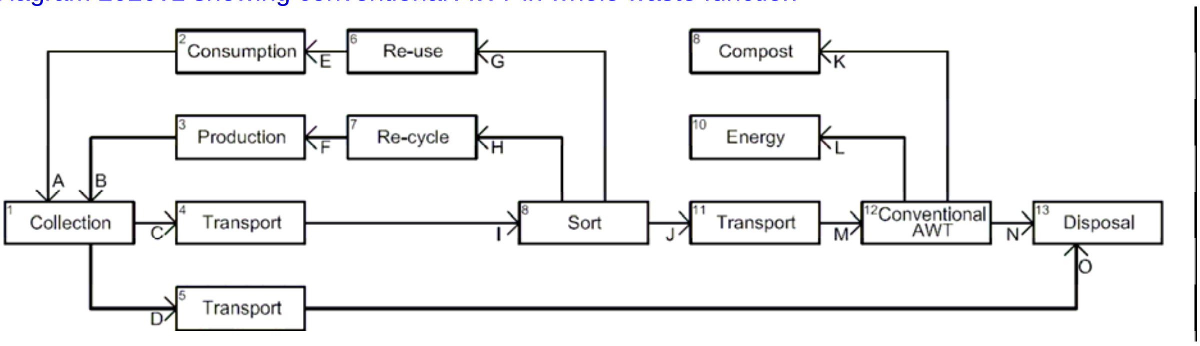
The recycled materials will be delivered for sale in 6m ISO containers. There will be four containers from each of the eight trains, making for 32 different types of solid product in all. The heaviest fraction will contain gold, lead and other heavy metals. It is likely that this group of metals will be able to be profitably reprocessed by a metal recycler off site. Lighter fractions will contain lighter metals like steel and aluminium, glass, sand, plastics and so on. It is expected that each container will contain a very consistent batch of materials over time this high quality will mean that a waste refinery will be able to command a premium, compared to other recycled materials in the market.

Inputs	**Outputs**
Household waste	Electricity
Revenue from household waste input	Recycled material
Revenue from electricity output	
Revenue from re-cycled material output.	

6.02.020 Waste Refinery functions

A waste refinery has a different function to the conventional alternative waste treatment (AWT) facilities. Our diagram 2020v1, is based on a diagram by Sarah Mullin (Ref 06MUL), and it shows that conventional AWT facilities are only a part of the whole waste process.

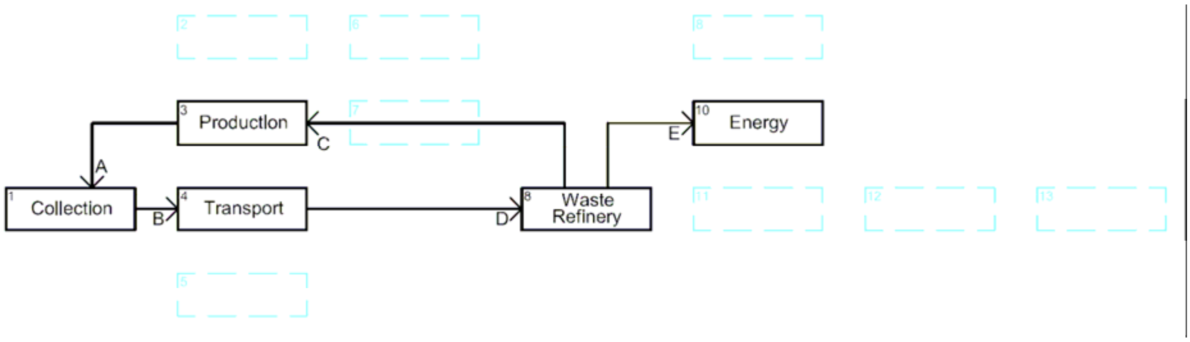
Diagram 2020v1 showing conventional AWT in whole waste function



Conventional AWT systems must still have the waste transported to a sorting facility, and then the sorting must take place. Some material can be extracted and re-used, however most waste needs considerable pre-processing before it is able to be used as basic raw material for a manufacturer. Typically after sorting waste needs to be washed and ground up before re-use.

After sorting the waste is transported to a AWT where, in Australia, it is mostly used to manufacture compost. There are currently very few waste to energy plants in Australia. After the AWT, usually there is still some material that ends up in a landfill. AWT perform a very valuable function in the waste stream by minimising the amount of material that is landfilled. However, conventional AWT's are only one part to whole waste stream function.

Diagram 2011v1 showing waste refinery in whole waste function



A waste refinery will change the waste stream function by eliminating several of the functions that currently take place. The re-use of materials will no longer occur, and this is a know deficiency of the proposed system. While transportation, compost and disposal are eliminated, it must be noted that a waste refinery will to some extent perform some of these functions within the refinery itself. There will only be 5 material transactions (A->E), instead of 15 transactions (A->0) in the conventional arrangement. Also, although not noted in the diagrams, a waste refinery will not require the waste to be sorted at source by the householder. This will result in considerable savings in the collection and transportation functions. In addition, unlike recycled materials that typically need to be washed and granulated, the raw materials from a waste refinery will be delivered in format ready for production.

Inputs	**Outputs**
Household waste	Recycled materials
	Energy

6.03.000 HIGH LEVEL SYSTEM FUNCTIONAL MODEL ANALYSIS

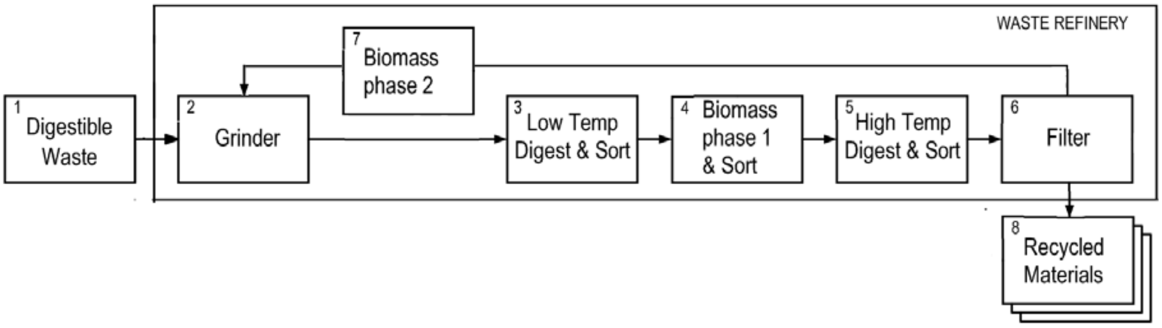
High level systems are processes that use several components, or other sub-systems, or parts thereof to achieve the designated aim of the system.

6.03.010 Non-digestible waste functional model

About a quarter of the waste that the refinery will receive will be non-digestible. The refinery will granulate this material. About 7% of the waste is metal and this portion of the waste will greatly aid the granulation process of the entire waste stream. Granulation of the waste will be relatively energy intensive, however the benefits will be to make the waste more sortable. Also smaller components are more reactive. Powdered metals will react with complex chemicals in the waste stream, and help break them down into simpler less reactive components. (Refer 05ZHA)

The waste will enter the first row of the digester array. Each digester will be shaped like a cyclone separator (also known as hydroclone) and the speed and configuration of the separator will be designed to sort heavy particles to one side of the array and lighter particles to the other.

Diagram 3010v1 showing non-digestible waste functional model



At the end of each train in the digester array, particles will be filtered out by means of a series of three cyclone separators, and then a sand filter. The solid material from each filter will enter a hopper to be de-watered. Surplus heat from the combined heat and power (CHP) system will be used to assist in drying this material. The material from the hopper when dried to specification will be deposited into a 6m ISO container. Solid containers or open top containers with a bag liner could be used, to prevent dust, odours or material loss. When each container is filled to it's volume or weight limit, it will be removed and replaced by an empty container. Removed containers will be shipped to manufacturers, who will incorporate the recycled material into their manufacturing process.

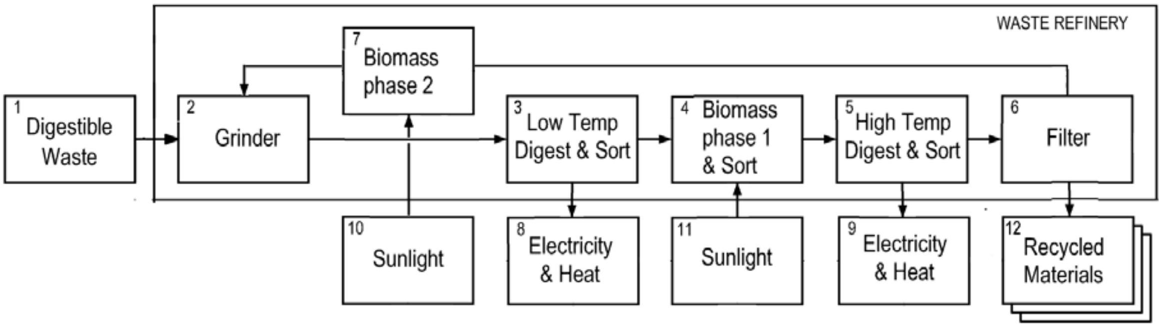
Household waste will have a water content, usually estimated to be 20% of the weight the waste, and we have used this estimate in our calculations. However, because WA is relatively dry, it is possible that waste in WA has a lower water content. A waste refinery is expected to generate water, and this surplus water will be removed after the filtration process and enter a vertical flow reed bed. After this we expect the water to be acceptable for release into the environment. Alternatively some water could be sold to an industrial consumer. In addition surplus water could be used in concrete product production.

Inputs	**Outputs**
Un-sorted household waste	Containers of powered aluminium, plastics, etc.
Water content of waste	Surplus water
Cement	Concrete products

6.03.020 Digestible waste functional model

About three quarters of the waste that the refinery will receive will be digestible. The refinery will granulate the digestible material. Granulating the waste will be energy intensive, however the benefits will be to make the waste easier to digest and easier to move. Also heating the material will speed up the digestion. In addition the cyclonic separation of the material based on it's weight will ensure that the material is well mixed, which will also speed up digestion.

Diagram 3020v1 showing digestible waste functional model



The digester array will be essentially a series of multi-stage, continuous flow digesters. The first batch of digesters in the array will be low temperature, about 35 deg C, digesters. This is the ideal temperature for mesophilic micro-organisms. Mesophilic digestion is robust and able to cope with the un-sorted waste. This phase will lower the pH of the mixture.

The second batch of digesters will be algal digesters, where light and CO_2 are added to the mixture. This will increase the biomass of the system, providing a food for the next batch of digesters. The algae will also help digest cellulose and other hard to digest material. The algal phase will consume CO_2, H_2O and raise the pH.

The third batch of digesters will raise the temperature to 55 deg C. They will also receive more sorted waste, which is ideal for thermophilic micro-organisms as they are less able to cope with change. This phase of digestion will complete the digestion of the digestible material, and also lower the pH again.

At the end of each train in the digester array, particles will be filtered out by means of a series of three cyclone separators, and then a sand filter. The solid material will be deposited into 6m ISO containers and sold.

A result of anaerobic digestion is digestate, it is envisaged that at the end of the high temperature phase, the bulk of the digestate will be liquid material that will flow through the filters to the second biomass phase. Any solid digestate that makes it's way into a container will be relatively inert, and become one of the raw material products for sale. For example, hard to digest cellulose fibres have many commercial uses, and are often used to strengthen products, like plastics.

The second biomass phase will use the liquid digestate, CO_2, H_2O and sunlight to generate biomass. Some of this biomass could be in the form of algae as well as aquatic plants. This phase will raise the pH of the mixture. The biomass is returned to the start of the process for energy extraction. Some of the biomass from aquatic plants can be removed and sold. Selecting aquatic plants for their ability to absorb heavy metals and so on, will help remove these items from the waste refinery system.

Input
Digestible waste, food, plants, etc.
Sunlight
Water

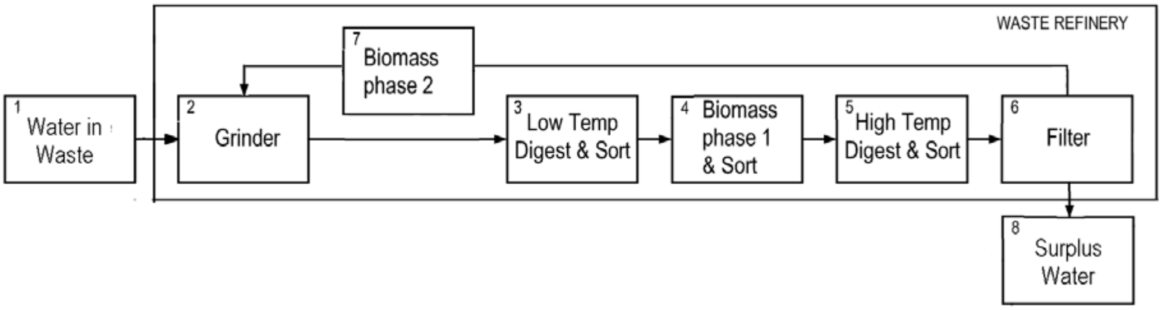
Output
Biogas comprising CH_4 and CO_2
Digestate
Water
Energy

6.03.030 Water flow functional model

When the waste refinery is operational, it will generate surplus water. The source of most of the surplus water will be from the water content of the waste received.

To fill up the refinery in the first place will require a large amount of water, and we propose to use sewerage to do this. The granulation process will be wet, which will reduce dust, and also many products like car tyres and plastics are easier to cut under water. In addition about three quarters of the waste stream consists of organic material most which looses it's structural integrity when it is saturated in water.

Diagram 3030v1 showing water flow functional model



Note that the water flow of different parts of the array, and within each digester, could be varied to allow longer retention time for digestible material, and shorter times for non-digestible material. For example, non-digestible fractions, could be pumped through the waste refinery faster than digestible fractions. This could be done without affecting the overall flow through the system.

Each digester in the array will have a cyclone separator shape. Pumps outside the digester will circulate the mixture, and also transfer the mixture from one digester to another. Nozzles will be placed to prevent settlement. At the base of the hydroclone will be a flexible screw conveyor to transport any heavy material to the next digester.

At the end of each train, particles will be filtered out by means of cyclone separators and sand filter. After the filters the water will enter the second biomass phase and then re-start the cycle in the granulator.

Input
Water in waste

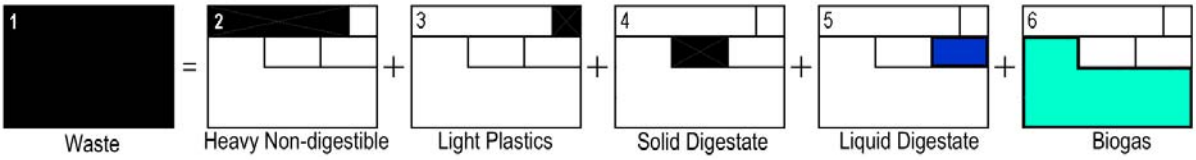
Output
Surplus water

6.03.040 Sorting functional model

As the material progresses thru the array it will be sorted in each digester, so at the end of the array the material will be grouped according to it's density. For the purposes of this model we will use very rough approximations to communicate the function, in any event waste is variable and therefore precise values are not appropriate.

The incoming waste will be composed of about 75% digestible material, and 25% non-digestible. At the end of the array, about 55% of the original digestible material will be biogas. Of the remaining digestible material about 10% will be solid digestate and 10% liquid digestate.

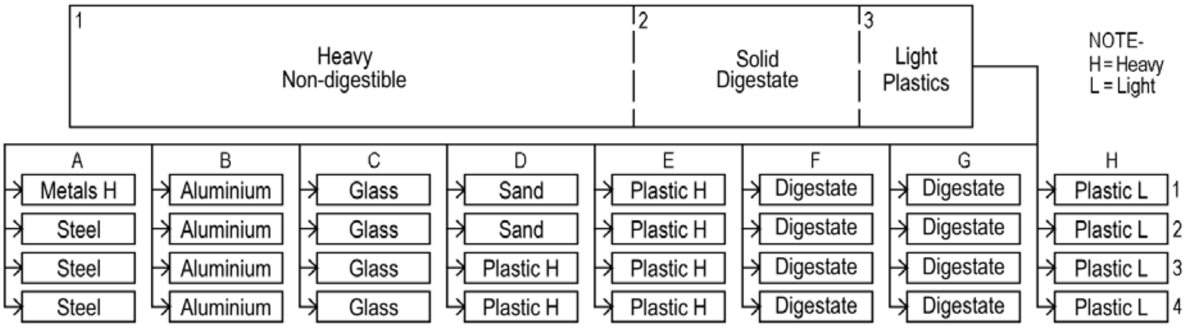
Diagram 3040v1 showing household waste composition



At the end of the digester array, the biogas will have been removed and liquid digestate will pass thru the filter system, therefore the filtered out components will be about 20% heavy non-digestible material, 10% solid digestate and 5% light plastics.

There will be 4 filters a the end of each of the 8 trains of the system, and each filter will fill up a ISO container, making 32 different containers of material.

Diagram 3041v1 showing solid component sorting functional model



Therefore about 35% of the original material will be filtered out into the containers, so each container will end up with approximately 1% of the original waste material filtered from the system. The above diagram shows the indicative arrangement of solid material in each of the ISO containers at the end of the 8 trains.

Methane digesters, that run un-heated at an ambient temperature of about 10 deg C are generally about 50% efficient. It is estimated that biological activity doubles for each 10 degree rise in temperature, and our digesters will run at 35 deg C for the first half, and 55 deg C for the second half of the process. Also the material in our digesters will be constantly stirred which also increases biological activity. In addition, perhaps most importantly, the material will be finely ground up to make it much more easily digestible. Added to that, we will have an algal phase which will also boost biological activity. Therefore we expect a higher efficiency of about 75%, so that about 55% of the original waste will be converted to biogas.

Input
Unsorted household waste

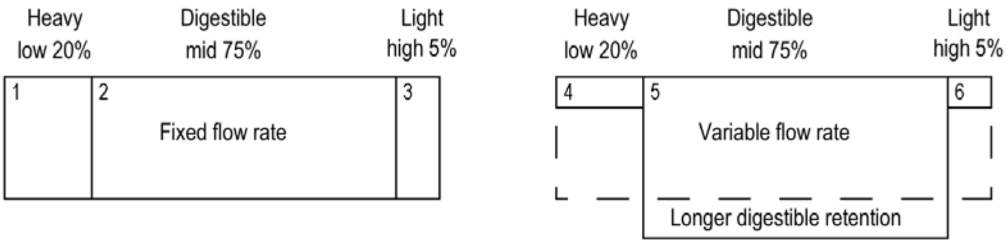
Output
Sorted granulated solid waste in ISO containers
Biogas

6.03.050 Retention time functional model

The retention time for the plant is a critical factor, which will affect the plant performance. For example, if the retention time is halved, then the capacity of the plant is doubled. The retention time of the plant will be about 14 days. This can be varied for the plant as whole, or for different parts of the plant. Because of the variable nature of waste, the ability to vary the rate of flow through the plant will enhance the efficiency of the plant.

It will be possible to vary the retention time depending on the type of material being processed. From a density stand point the waste material in a refinery can be categorised into a light group of plastics, a middle group of digestible material, and a heavy group of metals, glass and so on.

Diagram 3050v1 showing retention time functional model



As the material progresses thru the array, it will be sorted and some parts of it will contain very little digestible material, while other parts will consist of mainly digestible material.

Once the content of digestible material is known, or can be measured, then the speed of that material can be adjusted accordingly. For example, the heavy material which will have a low digestible content can be passed thru the array at a faster speed. While digestible material on the other hand, can be passed thru at a slower speed.

This means that longer digestion times can be achieved for organic material, without increasing the retention time for the plant as a whole.

Input
Waste with variable content

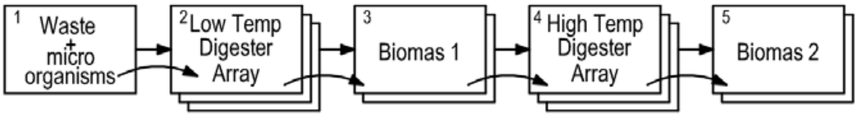
Output
Shorter retention times for non-digestible material
Longer retention times for digestible material
Efficient plant

6.03.060 Biological functional model

Waste as it enters the refinery will contain many different types of micro-organisms. Because the nature of waste is also variable, it is unlikely that a mono-culture will develop, which will make the system more resilient.

As each batch of waste introduces new strains, it is more likely that over time micro-organisms will become more well suited to the conditions in the refinery. As each new type micro-organism that is able to digest, grow and reproduce at a more successful rate, it will displace previous types of micro-organisms. As conditions change in the digesters due the variable nature of waste, those micro-organisms that are better able to cope with change will prevail. This process will be repeated in each digester of the array, and so the biological system will be under constant pressure to improve. This stress is an integral part of establishing a vibrant and resilient biological system.

Diagram 3060v1 showing biological functional model



In addition, the life cycles of micro-organisms are very short, so any adaptations that may occur in the refinery will also add to the competitive pressure. Therefore the biological systems in the refinery will be constantly improved.

Input	**Output**
Waste, including micro-organisms	Biogas
	Digestate
	Constantly updated micro-organisms

6.03.070 Biogas generation functional model

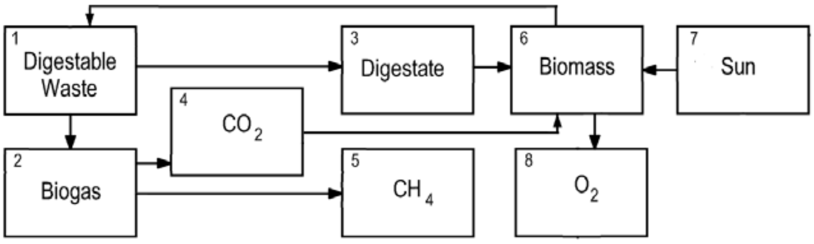
The generic formula for conversion of organic material into biogas, which is made up principally of carbon dioxide and methane, is as follows -

$C_6 H_{12} O_6 \rightarrow 3\ CO_2 + 3\ CH_4$

However, in practice digestion is never complete and results in the production of liquid and solid digestate, in addition to biogas. Typically the biogas from a methane digester is made up as follows -

%	Symbol	Compound
50-75	CH_4	Methane
25-50	CO_2	Carbon dioxide
0-10	N_2	Nitrogen
0- 1	H_2	Hydrogen
0- 3	H_2S	Hydrogen sulphide
0- 2	O_2	Oxygen

Diagram 3070v1 showing biogas generation functional model



Because of the significant aluminium, steel and copper content of the mixture, we expect the H_2S content to be very low and the H_2 content to be higher than in typical biogas, as the S atom will tend to combine with a metal in preference, and so release the hydrogen atom. The small amount of electronic waste that will enter the refinery will also contain a number of reactive metals, which will be beneficial for the waste refinery system.

Also we intend to separate the CH_4 from the CO_2 and use the CO_2 to enhance organic growth in the biomass phase. This will result in a lower CO_2 level than is typical.

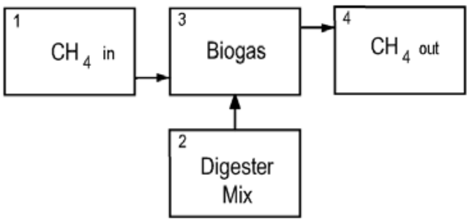
After the CO_2 has been separated it will be consumed in the biomass phases, and O_2 released. This O_2 rich gas will be ducted to the CHP gensets, to enhance the combustion of the CH_4 rich biogas.

Input	**Output**
Digestible Waste	CH_4 rich gas
Sunlight	O_2 rich gas

6.03.080 Methane separation functional model

Biogas is composed mainly of CO_2 and CH_4, theoretically in equal amounts. However in practice this can vary. CH_4 is lighter than CO_2, and we intend to use that characteristic to separate the gases.

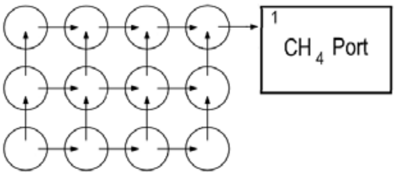
Diagram 3080v1 showing digester CH_4 separation functional model



Because CH_4 is about 3 times lighter than CO_2 it will tend to concentrate at the crown of the dome that encloses the digester. The CH_4 take off from the top of the crown will enter the next adjacent digester about half way up the digester.

As the biogas is drawn from the top of one digester into the side of the next one, this will concentrate the CH_4 into a corner of the digester array. The concentrated CH_4 gas outlet, which we call the CH_4 port will feed the gas to the CHP generators.

Diagram 3081v1 showing digester array CH_4 separation functional model-



The concept is to use the digester array to provide a CH_4 rich source of gas to the CHP gensets, because of the higher CH_4 content, the more efficient the CHP process will be.

Using the configuration of the digesters to concentrate the CH_4 will mean that the waste refinery CHP process will be more efficient than conventional biogas installations.

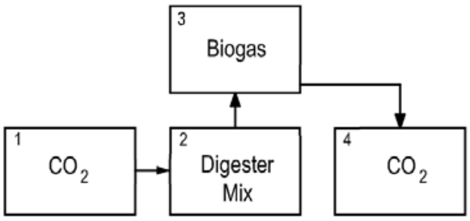
Inputs	**Outputs**
Biogas	CH_4 rich gas

6.03.090 Carbon dioxide separation functional model

Biogas is composed mainly of CO_2 and CH_4, theoretically in equal amounts. However in practice this can vary. CO_2 is different from CH_4 because it about 3 times heavier, and also it is easily soluble in water. We intend to use these two characteristics to separate the gases.

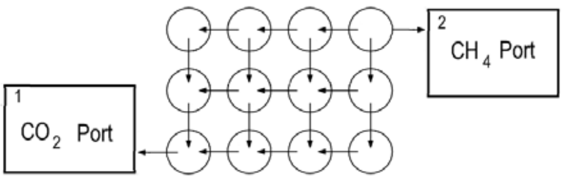
As the CO_2 is drawn from one digester to another the gas will be drawn off from the base of the digester gas enclosure. Also when the gas enters the next digester in the array it will be bubbled thru the liquid mixture. This will be so that the CO_2 can be dissolved into the water. In addition the bubbles will have the beneficial effect of inducing a vertical flow in the digesters. Also a fine spray on the surface of the tank will help dissolve CO_2, and also break up surface crusts.

Diagram 3090v1 showing digester biogas separation functional model



CO_2 that is not dissolved in the water will tend to settle at the base of the enclosure, where it will be drawn off to the next digester.

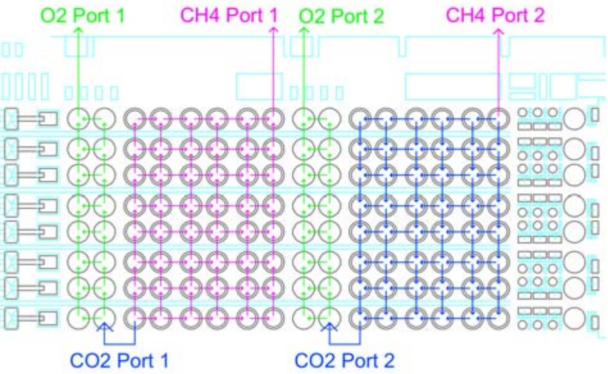
Diagram 3091v1 showing digester array CO_2 and CH_4 separation functional model



As the CO_2 is drawn from one digester to another thru the array, the CO_2 gas will become concentrated in one corner of the array, while the CH_4 will be concentrated at the opposite corner. The gas from the CO_2 port will be fed into the adjacent biomass tank array. In addition the CO_2 rich fluid mixture will also make its way to the next biomass tank array.

The CO_2 will be consumed in the biomass tanks by the photosynthetic growth of the algae. During the biomass phase the CO_2 will become displaced by O_2, and the concentrated O_2 will be ducted to the CHP gensets. Having a higher than normal O_2 intake will make the CHP process more efficient.

Diagram 3092v1 showing CO_2, O_2 and CH_4 ports from digester array



Therefore the biogas separation concept is to use a two step process. At first the array will concentrate the methane in one corner and the CO_2 in the opposite corner, and also CO_2 will be dissolved in the mixture. The second step is to feed the CO_2 rich portion of the gas, and liquid, thru the biomass digesters. The biomass digesters will absorb CO_2 and release O_2. In this way the refinery will produce CH_4 and O_2 for the CHP gensets. Note that the O_2 port will not provide sufficient O_2 for combustion of the CH_4 and additional air will be required.

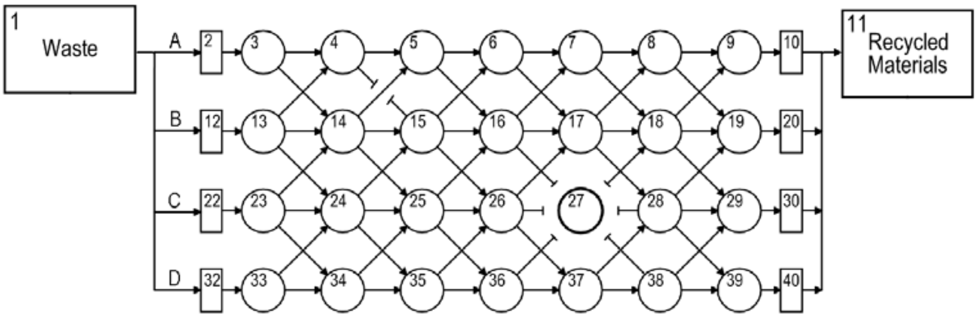
The combustion process of the gas delivered to the CHP gensets will be more efficient than usual, this will mean that more heat and electricity will be able to be generated than is usually the case from methane digesters.

Inputs	**Outputs**
Biogas	CO_2 rich gas
	CO_2 rich liquid mixture
	O_2 rich gas

6.03.100 Resilience functional model

The design of the waste refinery consists of a number of trains, which are interconnected at each stage to form essentially what is a matrix.

Diagram 3100v1 showing matrix flow for resilience functional model



Material can flow thru the matrix via alternative paths, so if a connection (as shown between module 4 and 15 between the A and B trains) or a module (as shown by module 27 in the C train) is out of commission, then the material can flow around the obstruction to keep the system functioning.

The practical effect of this arrangement is that there are no bottlenecks which can shut down the system as a whole. Another feature of this arrangement is that modules can be shut down for maintenance or upgrades without shutting down the whole system.

Another feature of the system will be it's chemical resilience. Should a hazardous material like a pharmaceutical or pesticide enter the waste stream, the first method of dealing with this will be by dilution. In addition, by not separating out the metals, it is likely that the pharmaceutical will breakdown during the granulation process when it comes into contact with fine metal particles which are highly reactive.

Because the refinery will be constantly be refreshed with new micro-organisms, should anything happen to make the biological process fail in part of the system, then as soon as conditions are favourable, the biological process will automatically restart.

The control system of each module will be independent, and different modules will have different software systems, and various methods of communicating with each other. This will make the system resistant to interference from a hacker, or a software failure.

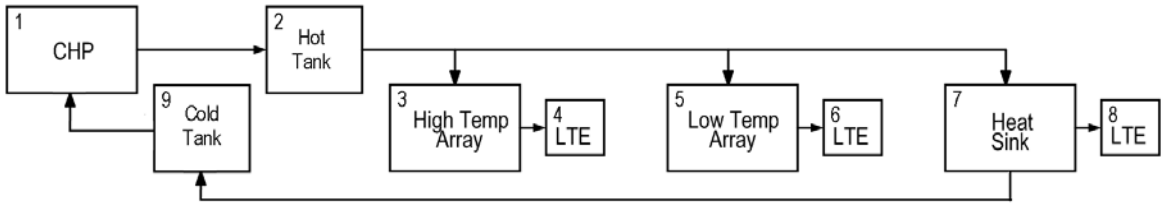
Input	**Output**
Design time	Resilient system

6.03.110 Heat distribution functional model

Heat from the CHP gensets will be distributed to the various digesters using a standard hydronic district heating system. Hydronic heating systems are COTS devices available from manufacturers like Rehau and many others. The main lines will run from the CHP units past the high temperature digesters and then the low temperature digesters. Each digester will have it's own hydronic control system and take off any heat as it is required locally.

After this, any excess heat will be extracted via a heat sink. The heat can be lost to the environment (LTE) by being dissipated into the ground, or a water source, or to the air. After the heat has been removed the water enters a cold tank, ready to be re-cycled by the CHP system.

Diagram 3110v1 showing heat distribution functional model



In addition, a back up system of electric heating coils will be built into the digesters, these are cheap to install, but are expensive to run. However they will only be used in a back up situation.

Additional continuous flow gas heating units could be used were the temperature is raised from the low temperature digesters to the high temperature digesters, or additional hydronic heating could be applied to this area. Also when the mixture is cooled before filtration and the second biomass phase, a heat exchanger could be used to remove the heat and apply it to the granulation phase which will use it to heat up the incoming waste material.

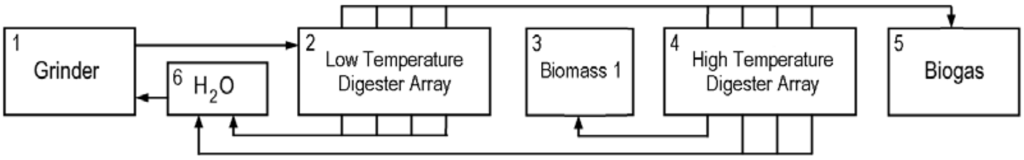
Input	**Output**
Hot water	Cold water
	LTE

6.03.120 Solid ratio functional model

For our calculations we have used a water to solids ratio of 20%. This is high compared to many other anaerobic systems. However, because some of the waste in a waste refinery is very dense metal, this means that the mixture, even with a ratio of 20%, should still be easily workable.

The actual ratio to be used by the system will be determined by the workability of the mixture and will have to be a parameter that is managed because of the variable nature of the waste inputs. Nevertheless, as waste is digested most of the mass is given off as biogas, and therefore the solid ratio would drop unless water was removed commensurate with the biogas generation.

Diagram 3120v1 showing solid ratio functional model



To manage a consistent water ratio, water will be filtered off each digester and returned to the adjacent biomass generation phase. It is proposed to use ceramic filters with a reversible flow for cleaning to remove the excess water. Water will be added to the biomass generation phase because water will be consumed by plant growth in this phase.

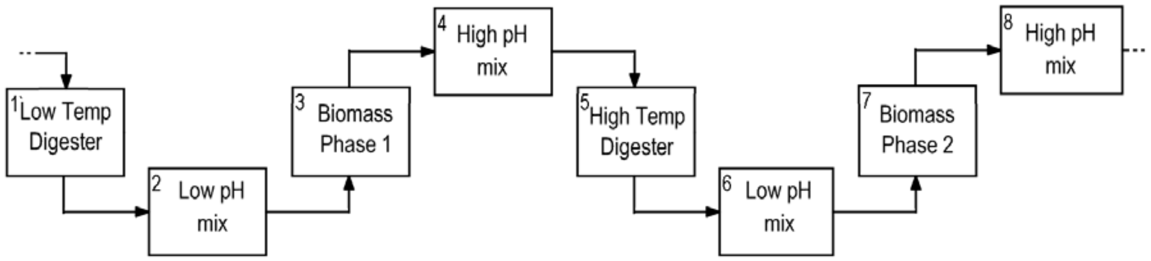
To maintain workability of the fluid in the biomass phases, growth will have to be managed by adjusting parameters like heat, light, CO_2, water and so on. Limiting any one of the above parameters will allow the algal growth to be managed.

Input	**Output**
Water	Biogas
Growth parameters heat, light, CO_2 etc.	Surplus water
	Biomass

6.03.130 pH functional model

The anaerobic digestion phases will make the mixture in the system acidic. However the biomass phases will reduce the acidity of the mixture.

Diagram 3130v1 showing pH functional model



Therefore over time the pH of the system should not run out of control, but alternate between acidic and alkali phases. Because the tanks will be concrete it will be necessary to use a concrete additive made by manufacturers like Penetron or similar. Concrete sewerage treatment plants have a long history with acidic contents and this issue is now well understood. Alternative options to concrete additives are liners and coatings, which can be retro-fitted if necessary.

Also, material will be added to the filter beds to adjust the pH at the end of all the sand filter modules. A screw conveyor will slowly remove material from the bottom and new material slowly added. The proposed filter material will consist of an engineered mixture that will include materials like pumice, limestone and charcoal.

Therefore we expect the pH of the waste refinery to be self-balancing. However, because of the variable nature of waste inputs it is possible that action to address the pH balance may have to be taken from time to time. Material to balance the pH like for example acid or finely ground limestone could be added via the inoculation system to any tank that needed adjustment. Or the material like concrete scrap could be added to the initial granulation phase.

Inputs	**Outputs**
Waste	Spent pH balance correction material
pH balance correction acid	
pH balance correction alkalis, limestone etc.	

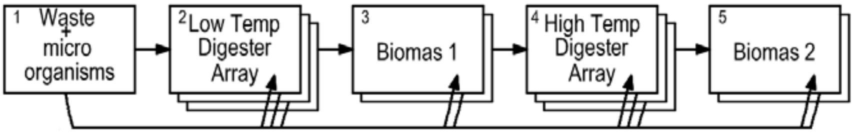
6.04.000 LOW LEVEL SYSTEM FUNCTIONAL MODEL ANALYSIS

Low level systems are processes that use several components, or other sub-components, or parts thereof to achieve the designated aim of the system

6.04.010 Inoculation functional model

Waste that is introduced will be a rich source of micro-organisms. Some micro-organisms may be beneficial in the high temperature digesters, but may not be able to survive going thru the low temperature phase and biomass phase. So an alternative route is supplied, every day a small amount of fluid, about 5 kg from the granulation phase will be piped into each tank in the train. In this way potentially valuable micro-organisms will have a direct path to many different environments.

Diagram 4010v1 showing inoculation functional model



By constantly allowing the introduction of many different micro-organisms, it means that if a population of micro-organisms failed in one tank, they would be replaced by other micro-organisms.

It is possible that a population of algae for example in one digester could produce a ‘bloom’ and a toxic by-product, that could affect downstream digesters. The inoculation system would constantly be introducing micro-organisms into the downstream digesters, so that as soon as conditions were favorable, the digesters would recover.

Also, beneficial micro-organisms could be introduced using this system. For example, there are micro-organisms that are found in termite guts that are adapted to digest difficult to digest material like cellulose. All the micro-organisms that are introduced via the inoculation system, will be subject to competitive pressures in the environments into which they are introduced. If they are not able to survive, they will be eliminated.

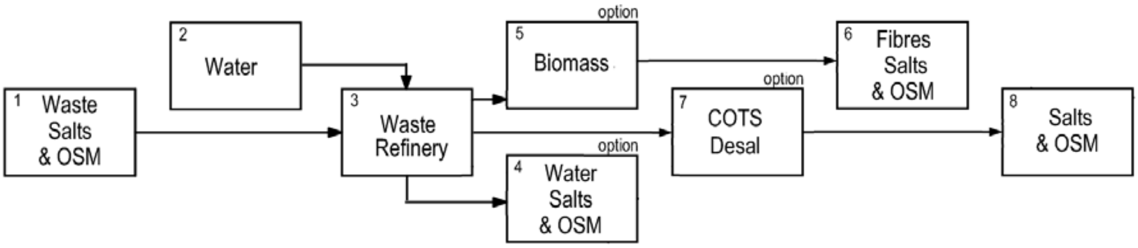
Input	**Output**
Waste, including micro-organisms	Biogas
	Digestate

6.04.020 Soluble material functional model

A small amount of salt and other soluble material (OSM) will be present in the waste that is delivered to the refinery.

It is possible that, over time, the salt or other soluble material could build up in the water that is re-circulated in the refinery. The concern is this could negatively affect the biological performance of the system as a whole. Should this problem materialise, there are a number of possible solutions that could be applied.

Diagram 4020v1 showing soluble material functional model



Desalination
There are a host of commercial of the shelf solutions (COTS) for desalination that use pumps, membranes, filters, absorption, surface tension, electrolysis, electrodialysis, heat, pressure, flash evaporation, evaporation ponds and catalysts to remove impurities. Because the waste refinery would have a large amount of surplus heat, methods which use heat to remove soluble materials will most likely be the most suitable.

Flushing
Another option would be to flush the waste refinery. A controlled amount of sewerage could be added to the system, and an equal amount of water returned to the sewer system. In this way the water in the system could be maintained without using any other desalination technique.

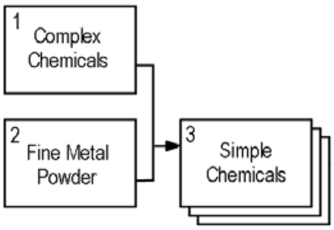
Biological
Aquatic plants like water hyacinth, deployed in the second biomass phase, will absorb soluble material (Refer 01UPA, 02ABO, 03MAI, 04SKI) and this plant material can be removed from the waste refinery and the fibres used for industrial purposes. While not widely used in WA, water hyacinth is commonly used to make wicker style woven frames for furniture. Note that there are a number of plants which will perform this function, and it is not necessary to specifically use water hyacinth, which is a restricted plant in some locations. The features that make water hyacinth a excellent plant in water treatment like fast growth rates, and hardy nature have also made it problem invasive species in some areas.

To deal with soluble materials, it is likely that a combination of the above solutions could be employed, as this would be the most resilient solution.

Input	**Output**
Salts and OSM in the waste	Salt and OSM Aquatic plant fibres including salt and OSM.

6.04.030 Metal chemical decomposition functional model
The waste delivered to the refinery will include complex long chain chemicals, like some medicines or pesticides. Also the waste will include a number of metals, like iron, aluminium, copper and so on. When material is ground up, it makes it much more chemically reactive. And we expect that complex chemicals to be quickly broken down into more stable simple chemical configurations by means of chemical interactions with the ground up metal. (Refer 05ZHA)

Diagram 4021v1 showing metal chemical decomposition functional model



The generic chemical formula for the break down of the complex chemicals is expressed as follows-

COMPLEX + M -> M(SIMPLE) + M(SIMPLE) + M(SIMPLE) +...

The most common metals in the waste will be Fe, Cu, Al, Zn. However household waste will contain many other metals, and those from electronic waste are even more reactive than the common metals.

High concentrations of metals, while useful for dealing with complex chemicals, can negatively effect the biological systems. To prevent metals from degrading the biological performance of the system, the level of metal concentration will have to be managed. Generally metals will react with oxygen or sulfur and in so doing release hydrogen gas.

Aluminium, especially in powdered form, will react with water. The reaction produces hydrogen which will be released into, and enhance the energy potential of, the biogas.

$2Al + 3H_2O \rightarrow Al_2O_3 + 3H_2$

Another common by product to digestion is H_2S which is responsible for the classic rotten egg smell. H_2S can also cause problems with the biogas combustion process. In a waste refinery we expect the following generic reaction -

$H_2S + M \rightarrow H_2 + M(S)$

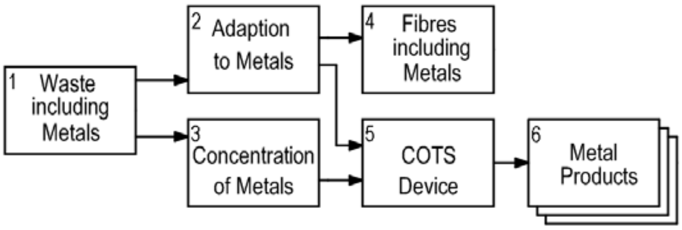
In addition to eliminating the H_2S smell, the additional H_2 gas will enhance the CHP combustion process.

Input	**Output**
Complex chemicals	Simple chemicals
H_2S	H_2
Metal powders Fe, Al, Cu, Zn etc.	

6.04.040 High metal content functional model

The waste will have a metal content of about 7% and when diluted to a solid ratio of 20% the metal content will be further reduced. However, it is possible that soluble metals will accumulate in the mixture.

Diagram 4040v1 showing high metal content functional model



The WR will use 4 strategies to address metal concentration

Adaptation
High metal contents are known to degrade biological digestion. However in this case we estimate that the micro-organisms will become adapted to the situation in the waste refinery. Over time, micro-organisms that perform better will prevail, and as their life cycles are short this should not take long.

Concentration
Also, the heavy metals will become concentrated in one part of the array, and digestible lighter material at other parts.

Biological removal
Removal of aquatic plant material from the second biomass phase will remove heavy metals.

COTS removal.
There are a number of commercial water purification technologies that could be applied to remove heavy metals. The installation of COTS to remove metals would be an option.

Because the WR will use adaptation, concentration and biological removal as part of it's normal function it is envisaged that a COTS for removal will not be required. However if metal build up is a problem then a COTS device that can use the surplus heat from the CHP system will be an attractive option.

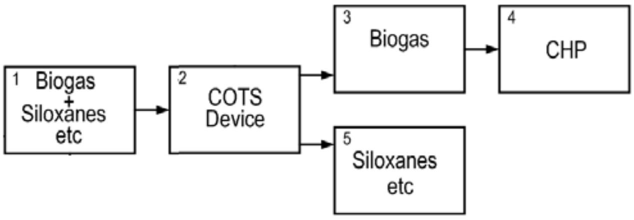
Input
Waste containing metals

Output
Metal powder in sorted groups
Biological fibres containing metals
Metal removed by COTS device

6.04.050 Gas de-contamination functional model

Biogas made from waste can contain siloxanes and other potentially problematic chemicals. Siloxanes are not usually a problem for CHP gensets that use reciprocating engines. However should the siloxanes or any other chemical become a problem then there are may COTS devices that can deal with this situation.

Diagram 4050v1 showing gas de-contamination functional model-



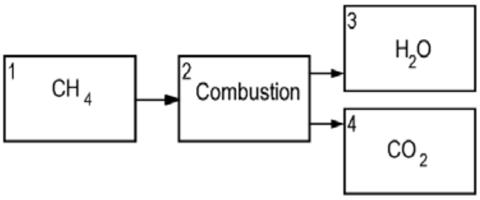
To deal with micro-organisms like legionnaires, the biogas will be exposed to UV light. The UV treatment will also deal with any CFC's that may exist. We do not expect to find too much CFC gas in the current waste stream as the manufacture of CFC's has been discontinued, and the only source is likely to be very old products that are only now finding their way into the waste stream.

Inputs	**Outputs**
Biogas plus siloxanes and contaminants	Biogas without contaminants
	Siloxanes and other contaminants

6.04.060 Greenhouse reduction functional model

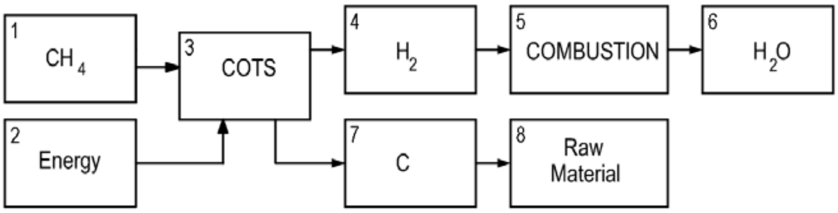
The waste refinery will generate methane for combustion. Conventional combustion of CH_4 results in H_2O and CO_2.

Diagram 4060v1 showing CH_4 to H_2O and CO_2 functional model



Because CO_2 is a greenhouse gas, it is widely accepted that efforts should be made to reduce the amount of it in the atmosphere. There are now COTS devices that can be used to remove the carbon atom from the methane, leaving only hydrogen for combustion. This would mean that no CO_2 was generated from the combustion of only hydrogen.

Diagram 4061v1 showing CH_4 to H_2 and C functional model



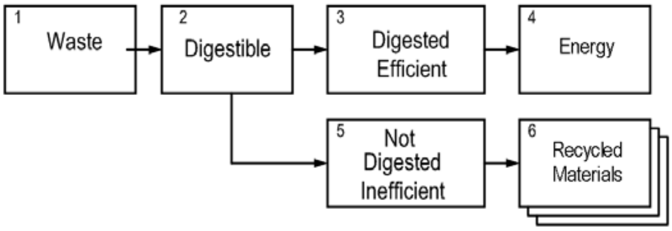
The strength of the carbon-hydrogen chemical bond in methane is among the strongest of all hydrocarbons, however despite the high activation barrier for breaking the C and H bond, CH_4 is still the principal starting material for manufacture of hydrogen in many processes. The catalysts and other efficient methods of generating H_2 from CH_4 is an area of research with considerable significance. Several COTS devices are available that can remove the C from CH_4 and leave the $2H_2$ for clean combustion. Currently the energy cost of a COTS device for this purpose is relatively high. In addition the capital cost will also be high. Also, the CO_2 from a waste refinery will be mostly sourced from the current carbon cycle, and not from fossil fuels. The reduction of CO_2 from fossil fuels should be a priority for a society, rather than CO_2 from the current sources. A commercial and environmental decision will have to be made regarding the implementation of such a device.

Input	**Output**
Methane	Hydrogen
Energy	Carbon
	Greenhouse gas reduction

6.04.070 Efficiency functional model

The waste refinery, or any other industrial device, is never completely efficient. There will always be some loss. It is envisaged that the waste refinery will be very efficient because of its low and high temperature arrangement. However this will be offset because of the high metal content and also because the digestible material feed stock is variable.

Diagram 4070v1 showing efficiency functional model



Some potentially digestible material will remain un-digested at the end of the high temperature phase. It is envisaged that difficult to digest particles of cellulose will make up the majority of the un-digested product. This solid product will be filtered out and become one of the re-cycled materials for sale. Cellulose fibres have many industrial uses as fillers in plastic, or part of concrete or paper products.

Over time, we think that it is likely that the biological systems will develop to the point where they will be able to digest most of the cellulose fibre, and thereby increase the biogas output. Also an alternative would be to pass the cellulose fibres on to the second biomass phase and thereby digest them by effectively doubling the retention time of this fraction of the mixture.

Other efficiency criteria to watch will be the sorting efficiency. The consistency of the product groups when they are filtered off will be critical to the success of charging a premium for high quality raw materials.

Another area of concern will be energy efficiency of the granulation operation, and the energy efficiency of the pumping and other materials handling procedures.

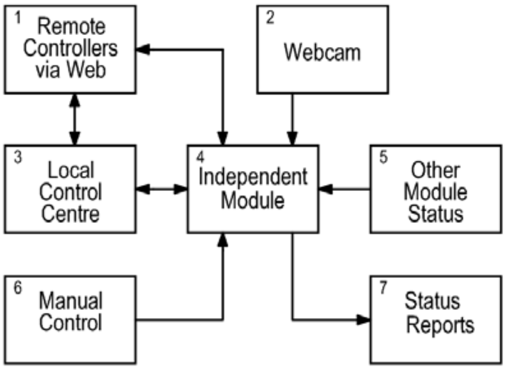
Input	**Output**
Waste	Energy
	Raw materials

6.04.080 Operational functional model

Each independent module of the waste refinery should be able to be operationally controlled by remote control via the web, or from a local control centre on site, or from manual controls directly on the module.

The normal everyday functions of the system should not require controller input. If the module detects items that are outside the normal parameters it should request information from local or remote controllers about what action to take. If no response is received then, depending on the situation the module should take appropriate action, like venting excess gas to a flare, or shutting down pumps, and so on.

Diagram 4080v1 showing operational functional model



Public access webcams should view the operations of each module. Each module should be able to report it's result of other modules status, so that any anomalies can be easily detected. In addition each module will be able to issue status reports to local, site and web controllers.

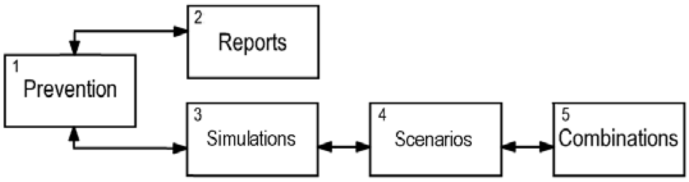
Input	**Output**
Design time	Higher efficiency
	Resilient system

6.04.090 Safety functional model

A waste refinery will in addition to the normal industrial work place issues involve risks from flammable materials, toxic materials and biological organisms. Therefore the safe operation of a waste refinery will require a safety system.

The system will focus on prevention, and reports of any problems, or potential problems, will be made. Feedback from the reports will enhance the level of safety.

Diagram 4090v1 showing safety functional model



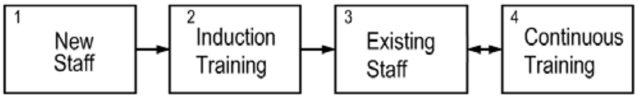
Safety prevention will also involve simulation. Various scenarios will be simulated to try to ensure that safe practices can be established for likely situations. In addition, random combinations of scenarios can be simulated, so that safety prevention procedures are experienced at dealing with unusual combinations of events.

Input	**Output**
Management procedures	Safe working environment
	Higher efficiency

6.04.100 Training sub-system functional model

New staff will receive induction training, to make them aware of how the plant works and how they should conduct themselves. For all staff there will be continuos training to help ensure that the staff have a good understanding of the plant.

Diagram 4100v1 showing training functional model



It is proposed to use a wide range of training methods from computer based questions, to personal interviews and group seminars.

Input	**Output**
New staff	Safe system
Existing staff	Productive system

6.04.110 Software functional model

The software of each module will be independent, and it is possible that different modules could have completely different operating systems. The main issue will be to have a modules that can interact with each other, to achieve the desired outcome.

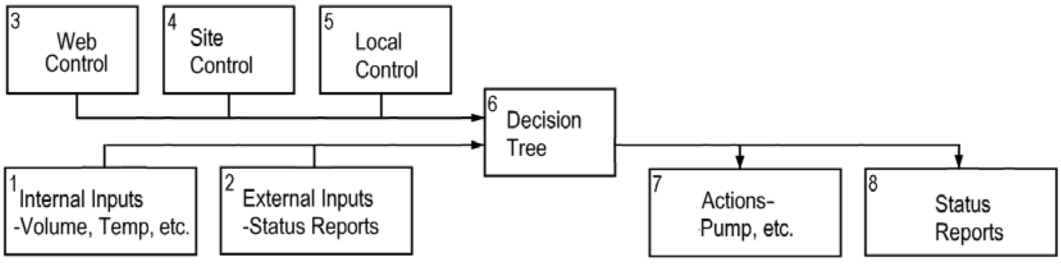
Each module would have a set of internal inputs from sensors and other devices which would inform the device of the state of it's condition. Inputs would include the volume of material in the tank, it's temperature, density, pH and so on. Also the module would be aware of the inputs regarding the status reports of surrounding devices.

Based on the internal and external inputs, the module would follow a decision tree to make decisions about what action to take. Therefore, for example, if the material was spinning in the tank too slowly it could increase the pump speed or duration to modify this.

In addition, the module would issue status reports about it's condition to a database. This data would include pictures and other information.

The module's decision tree could be changed by local controls, or from a site control area, or via web controls.

Diagram 4110v1 showing software functional model



There should be multiple ways in which modules can communicate with each other, these should include via the web, local hard wires, or using a wireless protocol. The method of communication should be robust, and be resistant to tampering from hackers.

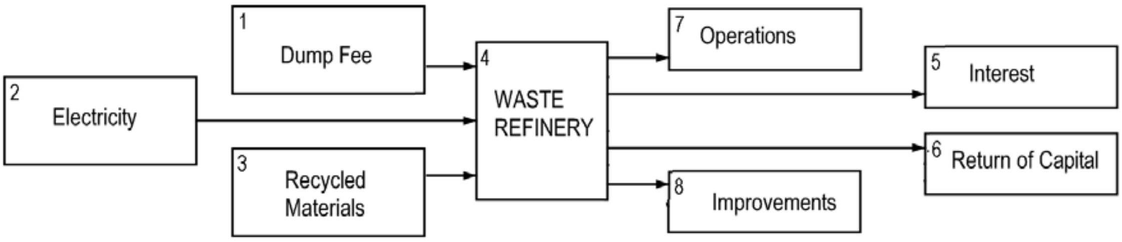
The software status reports should be stored in a searchable database, with free form report capability so that past performance can be studied.

Input	**Output**
Design time	Higher efficiency
	Resilient system

6.04.120 Financial functional model

The waste refinery will receive revenues from dump fees, electricity sales, and the sale of re-cycled material. It is envisaged that these revenue streams will be of roughly similar value.

Diagram 4120v1 showing financial functional model



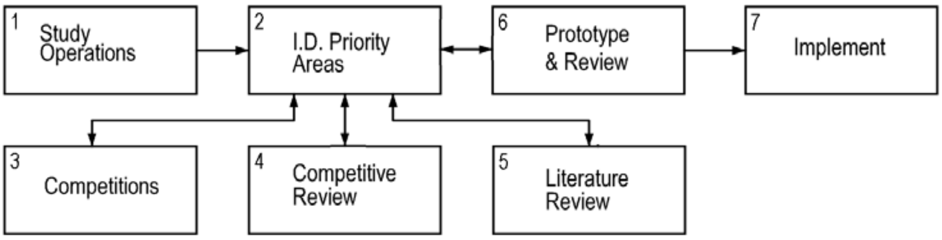
Revenues received will be used to fund interest payments, return of capital, operational costs and improvement costs.

Input	**Output**
Dump fee revenue	Interest
Electricity revenue	Return of capital
Re-cycled material revenue	Operations
	Improvements

6.04.130 Improvement functional model

The waste refinery will be in a state of constant improvement. To achieve this, a study will be made of the efficiency of the operations. The intention is to identify areas where there is the most scope for improvement.

Diagram 4130v1 showing improvement functional model



Once the priority areas have been identified, then a review of the technical literature of this area can be undertaken. Also a review of how other organisations are dealing with comparable situations. In addition, for a specific defined problem a competition could be established to provide an alternative solution.

Once potential solutions have been identified, a process of prototype and review can begin. And potentially successful solutions can be implemented. The matrix flow arrangement of a waste refinery will be able to accommodate upgrades of any module, without degrading the overall performance of the system as a whole.

We expect constant efficiency improvements to be made in materials handling, pumps and biological systems. Another potential priority area will be to maximise the value of the re-cycled material by finding better uses for each group of material.

Input	**Output**
Study of system	Improved system
Competitions	
Competitive review	
Literature review	

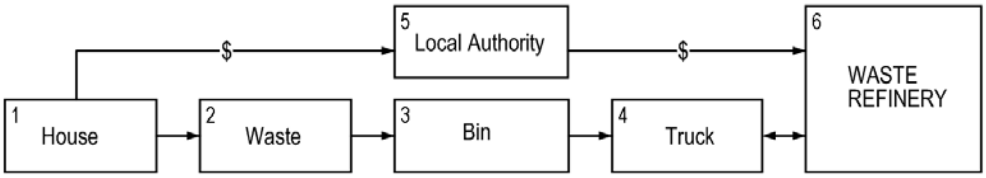
6.05.000 HIGH LEVEL COMPONENT FUNCTIONAL MODEL ANALYSIS

High level components are discrete devices that can perform several functions and so provide the basis on which functional systems can be constructed.

6.05.010 Delivery component functional model

The delivery component will be very similar to the conventional WA system, without the requirement for household sorting of waste. Basically each household would place their waste in a wheelie bin and a waste truck would collect the waste once a week.

Diagram 5010v1 showing delivery component functional model



Collecting un-sorted waste has a lower capital cost, and lower ongoing running costs. The waste collection process would therefore be more efficient than the current 2 or 3 bin system. We do however note that there is a view that the act of requiring people to sort waste, makes them waste conscious, and the proposal to have only one bin would undermine this consciousness.

The waste would ideally enter the refinery at the hottest time of day, so that the amount of heat needed to raise the waste to initial operating temperature of 35 deg C was minimised.

Typically a local government authority collects the waste, or arranges for the collection, and charges the householder directly, or indirectly, for this service. In WA we would expect that the local authority would pay the refinery to accept the waste.

Input	**Output**
Waste	Waste acceptance
Dump fees	

6.05.020 Granulation component functional model

The waste refinery will granulate the waste so that it is easy to digest, and easy to sort. This will also make the waste more chemically reactive, which will have the effect of breaking down complex chemicals that are found in waste like discarded pharmaceuticals, pesticides and so on.

Waste typically consists of very thin sheets of material, and most of these sheets are a factor of more than ten times thinner than the desired particle size of a waste refinery. Many of the materials in waste are resilient and energy absorbing, and are inherently variable this means that waste does not lend itself to communition in a conventional roller mill.

Waste is normally reduced in size by shredding. Conventional dry waste shredders are available off the shelf, from many different manufacturers, that reduce waste to 20mm strips. In addition, companies like Franklin Miller and others, make wet waste shredding machines that process waste to very fine particles.

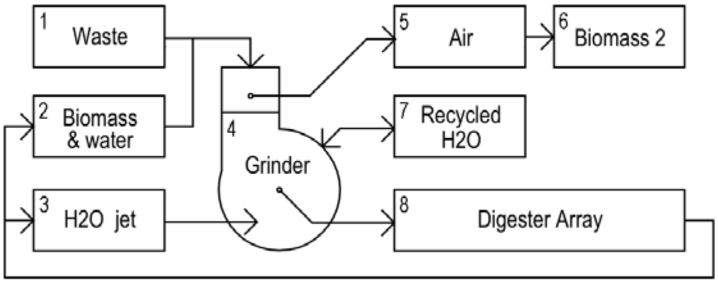
Most of the waste stream, over 90%, will be easy to shred. The remaining amount will consist of metals, stone and so on, are more difficult to shred, but are routinely dealt with in commercially available machines. Most machines have some intelligence built into them, which prevents the machine from breaking. Usually if the machine encounters a hard material, it reverses itself and takes a “smaller bite”, and so in this way nibbles away at the hard material.

Should the harder materials build up in the granulator, then very high pressure water jet cutters, or pneumatic ram can be deployed to cut or shatter the material. Alternatively a ‘hydraulic claw’ can be deployed to remove the difficult item from the waste stream for disposal by other means. It is envisage that the granulation system will relatively high maintenance, and expensive, device to operate.

The granulation system is likely to consist of a series of devices that deal with progressively smaller sizes such as a 49mm, 7mm, 1mm (factor of 7 reduction) or 64mm, 16mm, 4mm, 1mm (factor of 4 reduction)

Because of the modular nature of the plant, the opportunity exists for testing out new waste granulation modules without compromising the waste refinery operation as a whole. In this way it is likely that, on an iterative basis, a very reliable, and efficient, granulation system can be developed.

Diagram 5020v1 showing granulation component functional model



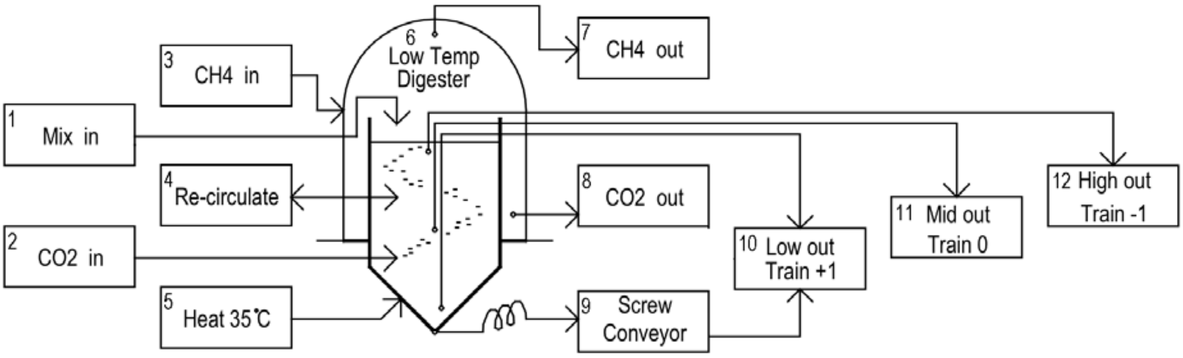
Input
Waste
Biomass and water
Re-circulated water
Water jet cutter, shear

Output
Waste ground up to digester array
Air containing odours to biomass array

6.05.030 Low temperature digestion component functional model

The low temperature digestion phase will be an anaerobic digestion phase, with the temperature at about 35 dec C. This temperature will provide an ideal environment for anaerobic digestion by mesophilic micro-organisms. There are thousands of different micro-organisms that are involved in the process of anaerobic digestion. Acetic acid-forming bacteria (acetogens) and methane-forming archaea (methanogens) will consume the initial feed stock in the waste stream. A number of different processes conversions and intermediate molecules are formed including sugars, hydrogen and acetic acid before finally being converted to biogas. This is a very robust process and the waste will contain many of these micro-organisms which will constantly add to the variety and resilience of the system.

Diagram 5030v1 showing low temperature digestion component functional model



The mixture will enter from the granulators or other digesters in the array at the top of the digester, in such a way to provide rotational force to the contents of the digester, and also to break up any crusts that may form on the liquid surface. External pumps, will provide additional rotational force and will also have nozzles to prevent settlement of solids at the base of the tank.

The tank will be shaped like a cyclone separator or hydroclone, essentially a cylinder on top of an inverted cone. The shape will be designed to draw the heavy fraction to the base of the tank. At the base of the tank will be a screw conveyor which will remove any settled particles to the next appropriate tank in the array. Above the screw conveyor will be an intake pipe to pump the heavy liquid fraction out of the tank. In the centre of the tank will be an intake for the middle fraction. And floating just below the surface will be an intake for the high fraction to be removed. The rotational flow in the tank will enhance the digestion of any organic matter as micro-organisms and their food are likely to come in contact with each other and waste products from digestion will not accumulate in one place.

As digestion takes place CH_4 and CO_2 are given off. CH_4 is lighter than CO_2 and will accumulate at the crown of the dome above the tank, while the CO_2 will tend to accumulate at the base of the insulation layer around the tank. At this low point CO_2 rich gas will be taken off and will be piped off to the next digester in the array. The CO_2 that enters this digester will be piped in at the base of the cylinder to provide upward vertical flow, and also CO_2 will be dissolved in the water because it is highly water soluble. In addition there will be a fine spray onto the surface of the liquid, which will prevent surface crusts, and at the same time also absorb CO_2 gas. The CH_4 rich gas that enters this digester will enter at the base of the dome and the CH_4 component will rise to the crown of the dome.

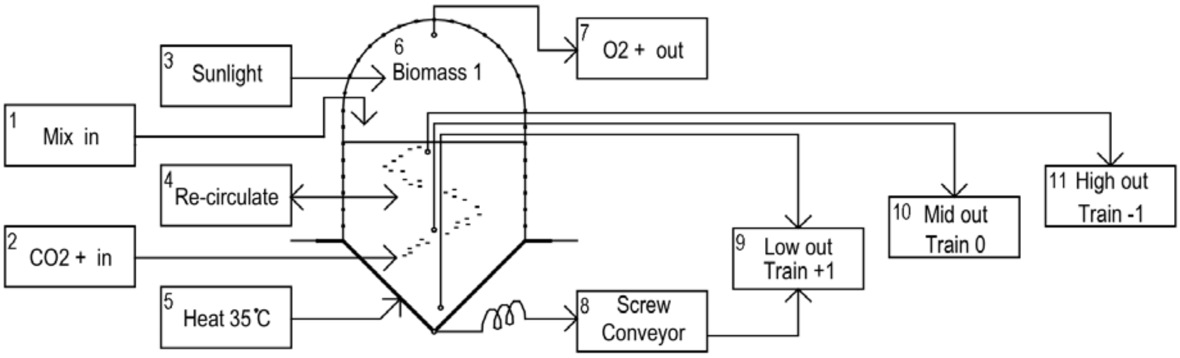
In this way the digesters in the array will sort the liquid mixture, and also the biogas, into its component parts.

Inputs	**Outputs**
Mix	CH_4
Heat	CO_2
CO_2	High fraction of mix
CH_4	Middle fraction of mix
	Low fraction of mix

6.05.040 Biomass first phase component functional model

After the low temperature digester array, the mixture enters the biomass first phase array. This biomass phase will generate biomass in the form of algae. This phase will also raise the pH and generate biomass which will boost the next digestion phase. At the same time algae will help break down relatively hard to digest items like cellulose.

Diagram 5040v1 showing biomass first phase component functional model



The mix, which will contain a high amount of CO_2 and digestate enters the top of the tank, this will help break up any crusts on the surface. This will create an ideal environment for algae growth. A screw conveyor with a macerating device on the end will harvest any sediment at the bottom of the tank.

CO_2 will be pumped through the mixture and be consumed by the algal photosynthetic growth process, which will give off O_2. The top of the tank will be enclosed in a translucent poly tunnel material and the O_2 will be directed towards the CHP units.

The sides of the tank will be translucent to promote algal growth, and the mixture will be stirred by means of external pumps. Also the gas bubbling thru will induce a vertical flow, also the gas will prevent crusting and congealing of any algal mats that may form. In addition there will be a fine spray onto the surface of the liquid, which will prevent surface crusts, and at the same time also absorb CO_2 gas.

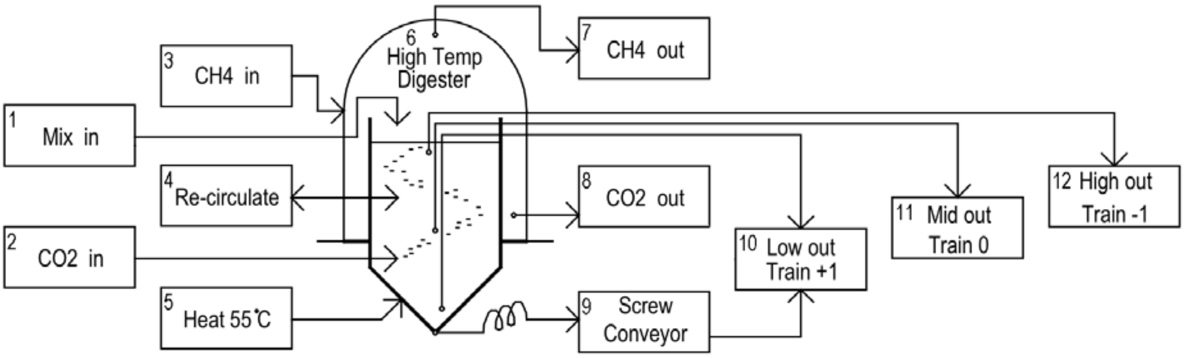
There will be a macerating device that will be passed down each intake pipe to prevent blockages, and also break down any algal mats that may be difficult to digest in the next phase. The macerators will be able to be removed for maintenance from external cleaning ports built into the pipe system.

Inputs	**Outputs**
Mix	O_2
Heat	Biomass
CO_2	Biomass sediment
Sunlight	Data
Water	Water

6.05.050 High temperature digestion component functional model

The high temperature digestion phase will be essentially the same as low temperature digestion phase, except that the temperature will be raised to about 55 dec C. This elevated temperature provides an ideal environment for anaerobic digestion by thermophilic micro-organisms.

Diagram 5050v1 showing high temperature digestion component functional model



The mixture will enter from other digesters in the array at the top of the digester, in such a way to provide rotational force to the contents of the digester, and also to break up any crusts that may form on the liquid surface. External pumps will provide additional rotational force and will also have nozzles to prevent settlement of solids at the base of the tank.

The tank will be shaped like a cyclone separator or hydroclone, essentially a cylinder on top of an inverted cone. The shape will be designed to draw the heavy fractions to the base of the tank. At the base of the tank will be a screw conveyor which will remove any settled particles to the next appropriate tank in the array. Above the screw conveyor will be a intake pipe to pump the heavy liquid fraction out of the tank. In the centre of the tank will be an intake for the middle fraction. And floating just below the surface will be an intake for the high fraction to be removed. The rotational flow in the tank will enhance the digestion of any organic matter as micro-organisms and their food are likely to come in contact with each other and waste products from digestion will not accumulate in one place.

As digestion takes place CH_4 and CO_2 are given off. CH_4 is lighter than CO_2 and will accumulate at the crown of the dome above the tank, while the CO_2 will tend to accumulate at the base of the insulation layer around the tank. At this low point CO_2 rich gas will be taken off and will be piped off to the next digester in the array. The CO_2 that enters this digester will be piped in at the base of the cylinder to provide upward vertical flow, and also CO_2 will be dissolved in the water because it is highly water soluble. In addition there will be a fine spray onto the surface of the liquid, which will prevent surface crusts, and at the same time also absorb CO_2 gas. The CH_4 rich gas that enters this digester will enter at the base of the dome and the CH_4 component will rise to the crown of the dome.

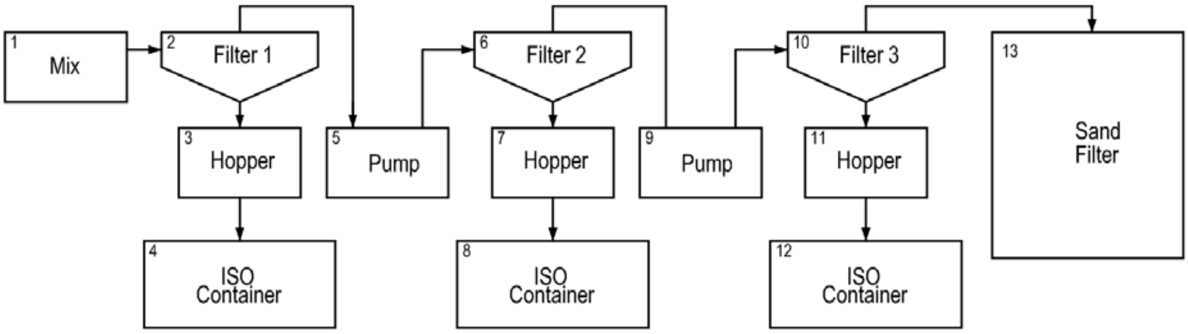
In this way the digesters in the array will sort the liquid mixture, and also the biogas, into its component parts.

Inputs	Outputs
Mix	CH_4
Heat	CO_2
CO_2	High fraction of mix
CH_4	Middle fraction of mix
	Low fraction of mix

6.05.060 Hydroclone filter component functional model

After the high temperature digestion phase, solid material is filtered off from the mixture. The intention is to construct a robust method of removing the solids from the mixture and depositing them into ISO containers.

Diagram 5060v1 showing hydrocyclones filter component functional model



The first phase of the filter process will consist of cyclone separators in series. Each one designed to progressively remove the heaviest fraction of solids left in the mixture. The mechanics of cyclone separators is well understood and the shape of the cyclone can be constructed accordingly. Also the speed of the mixture in the cyclone can be adjusted to provide operational control.

The product from the base of each filter will be removed by means of a screw conveyor into a hopper. The hopper will apply heat and lower the pressure to dewater the product. When dewatered, the hopper will deposit the product into an ISO container. The container will be an open top container, and the product will be in a number of sealed industry standard FIBC bags. It is envisaged that the bag filling and sealing procedure will be an automatic process.

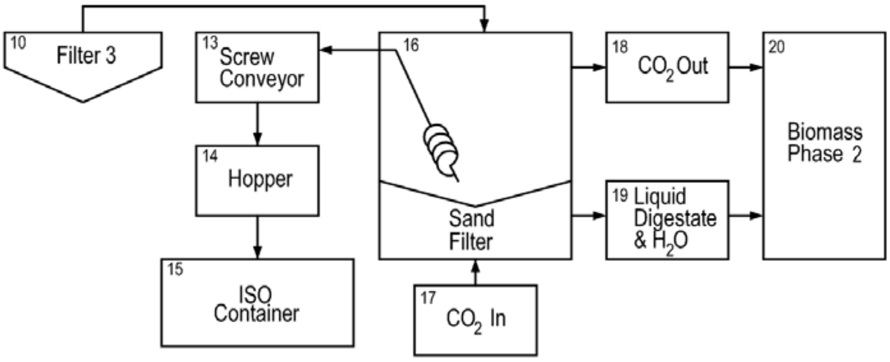
Inputs
Mix
Energy from pumps
Heat

Outputs
Liquid digestate
Solids grouped according to weight
Water
Data

6.05.070 Sand filter component functional model

After the cyclone filters have removed the bottom fractions of the solid components the mixture will enter a large sand filter.

Diagram 5070v1 showing sand filter component functional model



A screw conveyor will remove the product as it forms a sediment at the bottom of a cone shape slip surface. The slip surface will have holes in it to allow the water to percolate downwards. The holes will also allow CO_2 to percolate upwards. The gas will be introduced to prevent crusting and congealing of the sand system below the slip surface. In addition there will be a fine spray onto the surface of the liquid, which will prevent surface crusts, and at the same time also absorb CO_2 gas.

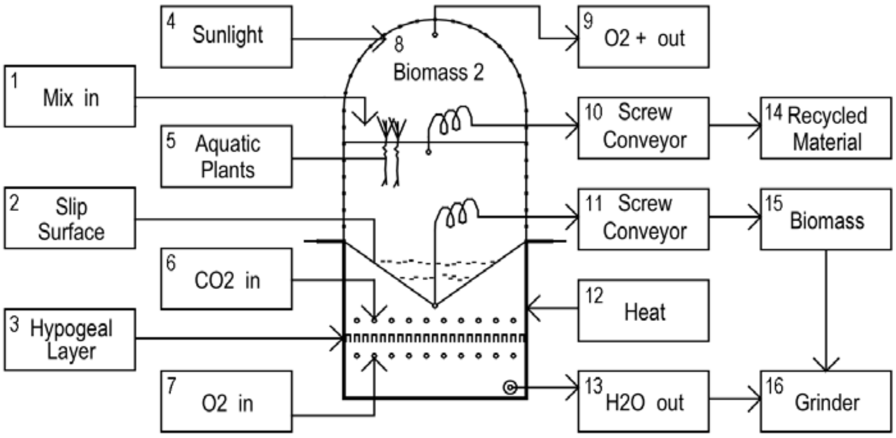
Below the slip surface will be an engineered sand filter, designed to chemically interact with the water to reduce the acidity, and also mechanically prevent large particles passing thru the filter. The sand will be slowly and constantly replaced by means of flexible screw conveyors.

Inputs	**Outputs**
Mix	Product sorted various groups.
CO_2	Liquid digestate
	Water
	CO_2

6.05.080 Biomass second phase component functional model

After the filtration process, the mixture enters the second biomass phase. This biomass phase will generate biomass in the form of plant fibres that can be removed and sold. This phase will also raise the pH and generate biomass which, after granulation, will assist in the next digestion phase.

Diagram 5080v1 showing biomass second phase component functional model



The mix, which will contain a high amount of CO_2 and digestate enters the top of the tank. This will create an ideal environment for aquatic plants and algae. The plants selected will be selected for their fast growth, their ability to absorb metals, and ability to cope with this type of environment. A screw conveyor with a macerating device on the end will harvest the plants on the surface, and these plant fibres will be one of the product groups generated by the refinery.

CO_2 will be pumped through the mixture and be consumed by the plant and algal photosynthetic growth process, which will give off O_2. The top of the tank will be enclosed in a translucent poly tunnel material and the O_2 will be directed towards the CHP units. In addition there will be a fine spray onto the surface of the liquid, which will prevent surface crusts, and at the same time also absorb CO_2 gas.

The sides of the tank will be translucent to promote algal growth below the aquatic plants on the water surface.

A screw conveyor will remove algae from the bottom of a cone shape slip surface. The slip surface will have holes in it to allow the water to percolate downwards. The holes will also allow CO_2 and O_2 to percolate upwards. The gasses are introduced to prevent crusting and congealing of the sand system below the slip surface. Also they will increase biological activity. Below the slip surface, CO_2 gas will be released.

The next layer will be an engineered hypogeal layer (also known as a biofilm or Schmutzdecke) designed to promote the growth of fungus. The fungus will be introduced when the tank is constructed. There will be a layer of upside down glass jars to provide an air space. The sand substrate will contain timber at this level, and below this layer, air will be introduced. The air will contain oxygen which will help sustain the fungus, and it will help break up any crusts that may develop. Essentially this will be a ideal environment for fungus growth.

The sand filter material will be slowly and constantly replaced by means of flexible screw conveyors.

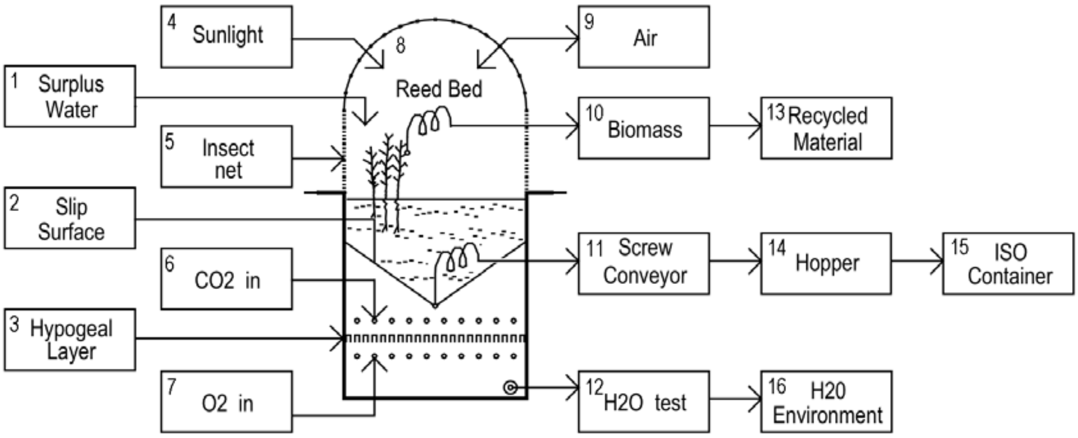
Inputs
Mix
Heat
CO_2
Sunlight

Outputs
O_2
Water
Biomass
Biomass sediment
Liquid digestate
Data

6.05.090 Reed bed component functional model

After the filtration process, and before the water enters the second biomass phase, surplus water will be drained off to a vertical flow reed bed device. After the reed bed process the water should be tested, and then it should be of a standard where it can be released back into the environment.

Diagram 5090v1 showing reed bed component functional model



Surplus water is pumped onto the reed bed. The plants selected will consist of a wide range of plants to make a resilient system. Some of this biomass can be harvested, and the fibres sold.

The reed bed will be enclosed in a poly tunnel and insect net structure. The poly tunnel will help enhance plant growth and prevent rainwater overloading the system. The insect net will prevent mosquitos.

The plants will live in an engineered sand substrate. The sand substrate will consist of limestone, charcoal, pumice and other elements. The sand will be designed to chemically treat the water, and also provide a large surface area for biological systems that will inhabit the sand.

Because the sand above the slip surface will build up over time, a screw conveyor will slowly remove sand from the bottom of a cone shape slip surface, to maintain a consistent level for the plants. The slip surface will have holes in it to allow the water to percolate downwards. The holes will also allow CO_2 and O_2 to percolate upwards. The gasses are introduced to prevent crusting and congealing of the sand system. Also they will increase biological activity. Below the slip surface, CO_2 gas will be released.

The next layer will be a second engineered hypogeal layer designed to promote the growth of fungus. (The top layer of the reed bed will be the first hypogeal layer.) The fungus will be introduced when the reed bed is constructed. There will be a layer of upside down glass jars to provide an air space. The sand substrate will contain timber at this level, and below this layer, air will be introduced. The air will contain oxygen which will help sustain the fungus, and it will help break up any crusts that may develop. Essentially this will be a ideal environment for fungus growth, and this should help clean the water even further.

The sand filter material will be slowly and constantly replaced by means of flexible screw conveyors.

Inputs	**Outputs**
Surplus water	Water
CO_2	Biomass
O_2	Sand
Sunlight	Data
Air	

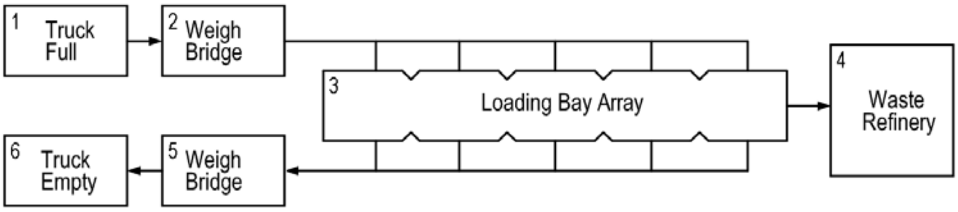
6.06.000 LOW LEVEL COMPONENT FUNCTIONAL MODEL ANALYSIS

Low level components are discrete devices or sub-components that can perform several functions and so provide the basis on which higher level functional systems can be constructed.

6.06.010 Loading bay functional model

The loading bay will receive full garbage trucks via a weigh bridge. As the truck enters it will be automatically assigned a loading bay to use, this will ensure an even flow of material through the system. The trucks will be able to access many paths through the loading bay area, to prevent a system blockage. After discharging the waste in the loading bay the trucks will leave via a second weigh bridge. The amount of waste entering the system can be calculated from the different weigh bridge readings. The trucks will be identified electronically and weighed without coming to a halt, this will ensure a fast discharge operation.

Diagram 6010v1 showing loading bay functional model



Alternative traffic management plans must exist so that the system can be operational if any one weigh bridge is out of commission. The loading bay will be under constant video surveillance so that no illegal dumping can take place. Also only trucks and drivers who are authorised to enter the loading bay will be granted access.

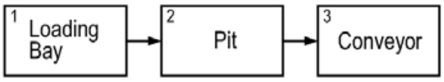
Should public dumping be required this could be accommodated at a waste transfer station where their dumping would be under the visual supervision of an authorised person.

Input	**Output**
Full truck containing waste	Waste Empty truck

6.06.020 Pit functional model

The pits will be located adjacent to the loading bay, and will be cone shaped to use gravity to accumulate the waste on to a conveyor belt.

Diagram 6020v1 showing pit functional model



The pits should be able to accommodate several truck loads of waste. To prevent the wind from disturbing the waste, the pit should be enclosed on all sides except for the loading bay side.

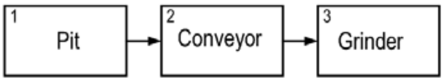
The pit should be able to be mechanically emptied with a back hoe it there is a breakdown or if unsuitable material is detected in the waste stream. The pits should have a self hosing cleaning system which will keep the pit clean and odour free. Water from the wash down will be discharged into the granulation system.

Input	**Output**
Waste from trucks	Waste via the conveyor

6.06.030 Conveyor functional model

The conveyor belt will lift waste from the base of the pit into the top of the granulater.

Diagram 6030v1 showing conveyor functional model



The conveyor will be a mechanical component that will need regular maintenance. It is envisaged that the conveyor will be a modular device that can be picked up and replaced by a JCB type vehicle with a boom on the back hoe. This way a replacement conveyor can be put in place in a short time, and the removed conveyor can be maintained in a workshop.

The conveyor should have a self hosing cleaning system which will keep it clean and odour free. Water from the wash down will be discharged into the granulation system.

At the top of the conveyor a duct will remove air to the biomass array. This will create a negative pressure area above the granulator and conveyor which will prevent odours from the waste escaping.

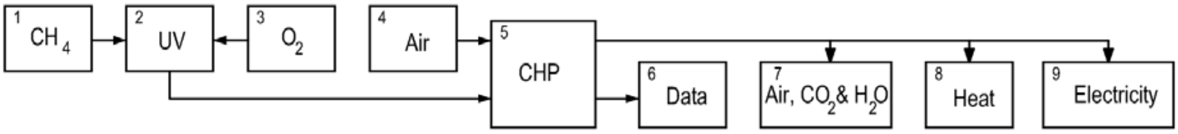
Input
Waste from the pit

Output
Waste into the granulator
Air ducted to the biomass array.

6.06.040 CHP functional model

The CHP devices would consist of modular units in a ISO container format, or combinations thereof.

Diagram 6040v1 showing CHP functional model



The waste refinery will have a two CH_4 ports and two O_2 ports. This would allow for two CHP compounds. The compound which is connected to the low temperature digester array and the second biomass phase would receive a lower volume of gas.

Ideally each unit would have its own control system, motor and generator in one ISO container. That way as CH_4 production was increased over time by higher plant efficiency, then additional modules could be added. Also as the capacity of the CHP modules increased over time perhaps fewer units would be required.

Having a modular system would allow for some units to be taken out of service for programmed maintenance without affecting the performance of other units. Also units could be progressively upgraded as new technology with higher performances becomes available. This would also make the CHP component of the plant inherently more reliable and resilient.

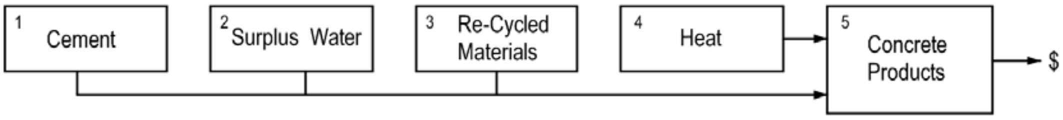
Inputs
CH_4
O_2
Air

Outputs
Data
H_2O
CO_2
Air
Particulates.
Electricity
Heat comprising hot water

6.06.050 Concrete product functional model

A number of the product groups from the waste refinery will be low value components, like sand for example. It is envisaged that because it will be difficult to sell some of the low value products it would be best to use these products to make non-structural concrete products like side walk paving.

Diagram 6050v1 showing concrete product functional model



The low value products will be relatively inert, and suitable for incorporation into concrete. To manufacture concrete, cement and water must be added to the re-cycled material. In addition heat is useful to speed up the process. Surplus water from the refinery will be able to be used in the production, with minimal pre-treatment. The only additional item required to be brought in from outside will be the cement.

Because the amount of concrete pavers will be relatively small compared to the population served it should not be to difficult too sell the pavers. The manufacture of concrete components will only take place if it is found that the low value products are not able to be sold.

Inputs
Cement
Surplus water
Low value product groups
Heat

Outputs
Non-structural concrete products

6.07.000 LANGUAGE GLOSSARY

AWT	Alternative Waste Treatment, usually a system to treat sorted organic waste.
CHP	Combined heat and power generator set
CH_4	Methane
COTS	Commercial off the shelf solution
CO_2	Carbon dioxide
Device	A modular component part of a plant that performs a specific function.
Digestate	Liquid or solid remaining after anaerobic digestion of a biodegradable feed stock
FIBC bag	Flexible intermediate bulk container bag
Fluidised bed	Bed with a matrix of nozzles thru which a fluid is pumped to prevent congealing.
Genset	Generator set
JCB	Small combination backhoe and endloader earthmover (originally ex JC Bamford Co)
LTE	Loss to environment
H_2S	Hydrogen sulphide
Hydronic	Heating and cooling system using water as the heat-transfer medium
Hydroclone	A cyclone separator to filter solids out of water, rather than air.
Hypogeal	A layer of biological activity, also called a 'biofilm' or 'Schmutzdecke'
Mix	The combination of waste and water
Mixture	The combination of waste and water
OSM	Other soluble material.
Plant	The system as a whole.
WR	Waste refinery

6.08.000 REFERENCES

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