

## Small Scale Technologies and Options for Waste to Energy Production

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### 1. Introduction

The wood to energy industry is based largely upon combustion technologies to provide steam and electricity for process use and occasionally for export. Such plants are typically quite large.

Wood gasification offers the opportunity to produce useful electricity and heat at a smaller scale, however small scale projects need to be examined and developed carefully if they are to provide long term financial rewards.

Wood pyrolysis also offers small to medium scale power generation, but with quite different costs and benefits when compared with gasification.

In the longer term, liquid fuels from wood can be expected to become commercial. This will not be at the small scale, but such plants could be a major influence on waste to energy in decades to come.

Each of these issues is explored further in the paper below.

### 2. Gasification

Gasification is the process of heating wood with a supply of air (or oxygen) that is insufficient for proper combustion. A fuel gas or "wood gas" is produced that may then be used in a variety of ways.

#### 2.1 Direct Combustion

Wood gas may be combusted directly to provide a hot gas stream for industrial or building heating. A well-known local example of gasification and direct combustion is found in the Waterwide units made for many years in New Zealand. These units provided close coupling between gasification and gas combustion, and were originally designed to provide clean, hot gas for direct drying and heating applications. A large number of these units have been installed around the Pacific for drying of agricultural produce, and some have also been installed in saw mills. In North America, Chiptec sells small gasifiers that are focused on providing heating.

#### 2.2 Steam Cycle

The combustion of wood gas can produce temperatures quite suitable for raising steam, and this steam may be used to generate power via a turbine. Boiler design must be suited to the particular heat transfer from the combusted gas.

#### 2.3 Gas-fired Engines

If wood gas from a gasifier is cooled and cleaned it may be used as fuel for modified engines coupled to generators. The gas cleaning process is critical if the engine is to operate efficiently, and with good availability, over an extended period. A number of gasification companies

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overseas have developed prototypes or commercial units that power engines with wood gas, usually in the range up to 70 - 500 kWe. We estimate that there are probably thirty or more such commercial units operating worldwide, from half a dozen manufacturers. The world's largest gasifier/engine project is in Italy and uses gasifier technology from PRME of the USA and Guascor engines to generate approximately 4 MWe. In Australia, the BEST group has undertaken work with gasifiers and engines, and the Fluidyne company that was once operating in New Zealand is working in Canada at present on a gasifier and engine project.

#### **2.4 Gas-fired Turbines**

It is possible to fire a gas turbine with wood gas. The fuel gas must be cooled and carefully cleaned prior to use. Air-fired gasifiers can be used, however the resulting wood gas is of lower energy content than if the gasifier is oxygen fed. The latter approach comes at a higher capital cost.

A number of groups worldwide have looked at large scale gasification and gas turbines. Only Foster Wheeler has run a unit for extended periods and that plant in Europe is now shut down. The well publicised ARBRE project was built in the UK several years ago to show operation of a 5 MWe Alstom turbine on wood gas, but was never fully commissioned.

Smaller scale gasification-turbine systems are also possible. JC Smale Pty Ltd in Melbourne has combined CSIRO gasification technology and a micro turbine from US company Capstone in a prototype unit that has recently been commissioned and is capable of generating 22 kWe plus waste heat. The next step for the company is a beta unit, possibly with a larger turbine from Capstone (a 200 kWe turbine is expected to be available within a year).

### **3. Project Sensitivities**

Diesel engines and generators are characterised by a relatively low capital cost but a high operating cost, which will go higher if the price of crude oil continues to increase.

In contrast to diesel gensets, small biomass generators have higher capital cost and lower operating cost. A decision to proceed with such a system must therefore be based on a complete understanding of the pros and cons of this approach, and where responsibilities for performance and risks lie. Some of the issues to consider are introduced below.

#### **3.1 Fuel characteristics**

*Moisture content* – some gasifiers are specifically designed to cope with high moisture content fuels and variable moisture contents over time. In contrast, other gasifiers are unable to operate on fuels with a moisture content above 15% WB.

*Particle size* – As with moisture content, different gasifiers have quite different requirements for both average particle size and range of particle size for the wood feed. This is partly due to different design to allow for interstitial spaces for the gas to contact with the wood feed. Thus some gasifier suppliers require fuel to be 10 mm or less, while other gasifiers are designed to operate only on fuel the size of large briquettes or billets.

*Ash fusion temperatures* – The design temperature for the gasifier and the variability of this temperature within the chamber will determine the extent to which that gasifier can cope with fuels that have low ash fusion temperatures. Some suppliers make a feature of their ability to deal with fuels such as annual crop residues and the low ash fusion temperatures that this implies.

For these reasons and others, changing the fuel for a gasifier will potentially change the operating characteristics and even cause major damage. If fuel variability is likely it should be

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designed into the project from the outset. If fuel needs to be prepared for use (for example via drying, grinding or pelletising) then the costs of doing this must be included in the project financial analysis.

### 3.2 Equipment cost versus project cost

It is easy to reach a falsely optimistic assessment of a small power project by considering only the cost of the main equipment and not the complete project cost. For example, the cost of a gasifier and generator module FOB overseas port may be \$1 million. Then add:

*For the module:* purchase, expediting and inspection, compliance with local standards, shipping, insurance, duties, site foundations, installation, commissioning, spares, consumables for initial operation.

*Other equipment:* feed conveyors and bins, short term and long term feed storage, emission controls, ash handling, water supply and waste management, power takeoff and reticulation, power supply to the grid, site civil works, labour and maintenance facilities, fire protection etc

*Other costs:* financing, permits and approvals, design and layout work, purchasing, project management.

The final project using a \$1 million gasification module may cost as much as \$2 million before it is ready to generate electricity. It can be seen that there are two problems with small power projects:

- The unit cost of equipment for generation is high relative to larger projects
- The additional costs are also significant and do not capture any benefits from economy of scale.

As a result, the installed cost of a 1 MW plant may be \$5 million, whereas the installed cost of a 30 MW plant may be \$45 million, or just \$1.5 M per MW. The unit cost of the small plant is more than three times that of the large plant.

### 3.3 Availability

Availability is the amount of time that a power plant will reliably generate power. For example, large coal-fired and gas-fired plants offer availabilities in excess of 90%, meaning that they can be operational (or “available”) for at least 7,884 of the 8,760 hours each year. The balance of the hours each year are used for routine maintenance etc.

Very few gasifier suppliers offer such high levels of availability. The availability of gasifiers may be higher than the availability of the engines that they fuel. Moreover, if actual availability falls below expectations it will quickly have an adverse effect on project returns.

### 3.4 Operating Costs

Technologies such as gasification and pyrolysis offer power generation via suitably modified engines and gas turbines. In all cases one of the keys to success is the pre-treatment of the gas or liquid fuel to allow it to run cleanly in the engine or turbine. Also in most cases the engine or turbine still requires more maintenance and consumables than if it was operating on a fuel such as diesel or natural gas. Initial project analysis must include full allowance for such costs. Suppliers should be able to provide such detail, and warrant that it is accurate.

Labour costs can also have a major impact on project viability. Consider a project of approximately 1 MW electrical output that operates for 8,000 hours per year on an unattended basis. Electricity sales will be 8,000 MWh per year. Now assume that full-time attendance is needed, comprising 1 operator for each of 4 shifts at an average salary of \$60,000 per year. The impact on electricity selling price is \$240,000/8,000 or \$30 per MWh.

### 3.5 Running time

It was noted above that the unit capital cost for a small bioenergy project may be three or more times the unit cost for a large project. As such, capital recovery becomes a significant fixed cost each year on small projects. Viability for a small power project is enhanced when the plant operates and sells electricity for as many hours per year as it can. If a power plant can operate 8,000 hours per year but the host site only needs power for 2,000 hours per year, the impact of the entire cost of capital will be felt on those 2,000 hours of sales. Hopefully such a plant can remain in operation when the host site is shut down and sell electricity into the grid (albeit at a lower cost).

### 3.6 Cogeneration

A small gasification module may generate three units of heat for each unit of electricity produced. Much of this heat may be recovered and used productively, provided the temperatures for use correspond to the temperatures at which the heat is available. Put differently, it is not easy to use waste heat that is available at 100 deg C in a kiln that needs to operate at 120 deg C. The use of cogeneration (or combined heat and power ) in European countries is partly supported by the use of such low temperature thermal energy for domestic heating.

### 3.7 Reliability

Gasification modules are available at sizes as low as 70 KW electrical output. Using multiple modules can add to the reliability of a project by ensuring that partial generation is possible at times that one module is taken out of service for maintenance. This can be expected to add to the capital cost of a project, but may avoid additional costs from the grid-based electricity retailer that may need to provide power at any time a single gasifier plant is inoperative.

## 4. **Pyrolysis**

### 4.1 Wood Pyrolysis

When wood is “pyrolysed” (heated in the absence of oxygen), it breaks down into solid, liquid and gaseous fractions. The liquid fraction is known as pyrolysis oil or bio-oil. It comprises as much as 70% of the pyrolysis products, and has multiple uses:

- a) as a fuel for the generation of renewable electricity and heat in:
  - boilers
  - gas turbines
  - potentially in diesel gensets.
- b) as a feed stock for manufacture of food flavourings and potentially as a starting point for industrial resins and other natural chemicals.

With chemical production occurring in parallel with renewable energy production, the long-term economics of a wood pyrolysis industry are significantly improved.

Wood pyrolysis was used commercially a century ago when charcoal, methanol and other chemicals were derived from wood. The modern wood pyrolysis industry is relatively new and there are presently only a handful of plants operating commercially, all in North America. Feed requirements start at around 15,000 dry tonnes of wood per year. Pyrolysis plants can be located inside factory buildings on relatively small sites, and are not significant emitters of physical wastes or noise. Pyrolysis has been tested successfully on many different types of wood and other forms of biomass, making it potentially a useful and flexible way to recover energy from relatively small quantities of wood, bark and green wastes.

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## 4.2 Production of Renewable Energy

Pyrolysis oil offers a particular advantage for renewable biomass energy – it may be stored and it may also be transported. So the oil can provide flexible, base load power generation at a site that is close to, or quite remote from, the source of biomass. The heat produced during power generation may also be harnessed to produce steam. Cogeneration in this way can allow overall efficiencies of 70% or more. Generation options include:

### (a) **Gas turbines**

The Canadian turbine company Orenda has tested pyrolysis oil in its industrial gas turbines, with the oil first being conditioned in a treatment module also designed by Orenda. The first commercial Orenda unit to operate on pyrolysis oil is presently undergoing commissioning in a pyrolysis plant near Toronto.

The Orenda GT2500 turbine can provide flexible base load power, generating up to 2.5 MWe continuously from a pyrolysis oil supply of up to 2 tonnes per hour. It also produces 5 MW heat, which may be recovered as steam and used for heating or additional power generation.

### (b) **Combustion plant**

Pyrolysis oil may also be used as a fuel in combustion-boiler systems, including large power stations and industrial applications such as food processing plants and saw mills. It can replace or augment coal or natural gas and provide renewable electricity and heat. Systems should be sized and designed for ease of integration into existing industrial sites.

## 4.3 Chemical Production

At present a pyrolysis plant is expected to be more expensive than a gasification or combustion plant for equivalent electrical output. While this cost differential may reduce as more plants are constructed, it may also be justified by the ability of pyrolysis plants to produce multiple products for sale. Some can already be made, while others require further technical development and marketing.

### (a) **Charcoal**

The pyrolysis process also produces charcoal, which can be used directly as a fuel or as raw material for charcoal products such as cooking briquettes.

### (b) **Resins**

Pyrolysis oil contains chemicals that can be incorporated into industrial resins, particularly as a replacement for phenol in phenol formaldehyde (PF) resins. PF resins are widely used in engineered wood products, foundry operations, brake pads and other applications.

## 5. **Liquid Fuels**

### 5.1 Introduction

Ethanol is routinely used as a liquid transport fuel in a number of countries, via blends of ethanol and petrol, and as a fuel in its own right. It is generally perceived to offer a range of benefits over fossil fuels, including:

- Lower greenhouse gas emissions
  - Lower levels of certain exhaust emissions
  - Provides octane enhancement to petrol/alcohol blends
  - Domestic production of ethanol allows reduced imports of fossil fuels
  - Can utilise sugar or starch by-products and be part of integrated processing industries
  - Favours rural industry and employment.
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Against the significant benefits above, it is recognised that alcohols are not the only way to address fuel security and balance of trade issues. Alternative non-renewable options in Australia and New Zealand include liquid fuels from shale oil, natural gas and coal. Also, as the oil industry notes, there are alternative mechanisms for reducing vehicle exhaust emissions that do not require the use of alcohol fuels. If alcohol fuels are to find a significant and secure place in our economies they must offer demonstrable benefits to the triple bottom line of environment, economics and community. They must then receive sustained market recognition for these benefits.

At present ethanol (and methanol) from renewable sources are generally more expensive than fuels derived from crude oil, a fact hidden sometimes by ignoring the impact of different levels of excise. At some time in the future crude oil will suffer a sustained rise in cost. If renewable alcohol fuels are to be a viable alternative it is important to develop an understanding of these fuels and the form and needs of a wood to alcohol industry.

## 5.2 Ethanol from wood

Ethanol in Australia is currently produced via the fermentation of materials available as by-products of the sugar and starch processing industries. Such production is limited by the availability of low value feed materials. Any new plants that use dedicated sugar and starch feeds will presumably need to allow for simultaneous production of ethanol and other products, or the opportunity cost of such feeds will be for human or animal consumption and make the ethanol too expensive to compete as fuel. Large scale use of renewable alcohol fuels in Australia could also involve wood as feed material.

Technologies for the manufacture of ethanol from wood focus on two areas:

- Hydrolysis of the wood to recover the sugars that make up the cellulose and hemicellulose in the wood feed. Most current technologies use acid hydrolysis to soften the wood and then break the sugar polymers down into individual sugar molecules. There is also considerable work underway overseas to develop enzymatic hydrolysis to the stage where it can be used instead of acid hydrolysis. Recent work by Genencor<sup>1</sup> in the USA has shown major advances in the use of enzymes for wood hydrolysis.
- Fermentation of the sugar solution produced. The sugars released from biomass by hydrolysis are a mixture of six carbon and five carbon sugars. This makes the fermentation step more complex than for cane sugar or sugars from starch, which are solely six carbon sugars. Several different micro-organisms are being used and improved around the world for this fermentation step, including modified yeasts, bacteria such as *E. coli* and *Zymomonas mobilis*, and thermophilic organisms.

There are no full scale biomass to ethanol plants currently operating anywhere in the world. However, there is considerable expertise already available in the relevant technologies. More than half a dozen groups in the USA, Canada and Europe have developed, built and operated multi-million dollar pilot plants to investigate different cellulosic feed materials (wood, MSW, agricultural residues), hydrolysis routes (acid and enzyme) and fermentation pathways. The US National Renewable Energy Laboratory (NREL) and its associates in the USA have identified a range of opportunities for improvements. If these are all achieved they could reduce the cost of ethanol from wood by up to 50% over the next 15 years.

Resolving these issues and finding a competitive position against petroleum fuels may take two decades. However when wood to ethanol technology is commercialised it will have a major impact on biomass use. A full scale ethanol plant will typically require 1 million tonnes per year

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<sup>1</sup> [http://www.genencor.com/wt/gcor/pr\\_1089826646](http://www.genencor.com/wt/gcor/pr_1089826646)

of wood feed and as such could have the same impact on a region as a large pulp mill, both in terms of the forestry to support it and the economic benefits that it provides.

*Summary of major wood to ethanol technologies under development in North America:*

Organisation	Feed priorities	Hydrolysis	Fermentation	Pilot Plant Development
Arkenol	Flexible, driven by low cost	Concentrated acid	Modified NREL Z. <i>mobilis</i>	Two pilot plants; USA and Japan
BCI	Bagasse, rice straw (tested hardwoods)	Two stage dilute sulfuric acid. Some work with enzymes	Uni of Florida engineered organism for C5 and C6	Two pilot plants at Jennings, Louisiana, USA
Iogen	Cereal straw	Enzymatic	Yeast modified for C5 and C6	Two plants built and operated in-house
Masada	Municipal Solid Waste (have also tested hardwoods)	Concentrated sulfuric acid	Waste plant to use C6 only	Used the TVA plant
NREL	Corn stover, also tested hardwoods	C5 – dilute sulfuric C6 – enzymes	Various	Pilot plant in place, used on assignment
TVA	Variety of feeds, no preferences	Concentrated and dilute sulfuric	Various	Range of pilot plant facilities

### 5.3 Methanol from Wood

Wood can also be converted to methanol, via a quite different processing route to that used for ethanol. The wood is initially gasified to make a synthesis gas, followed by catalytic conversion of the gas and recovery of methanol. Biomass gasification is well understood already via its role in heat and power generation, although there is still much to learn about managing the gasification to produce synthesis gas optimised for subsequent catalysis. Similarly the catalysis of natural gas to methanol is practised world-wide and provides useful experience for potential wood-based systems. However, considerable work is needed to integrate the various elements of a wood-to methanol plant using this technology, even at the pilot scale. The German company Choren<sup>2</sup> is undertaking such work, with support from interested parties that include Daimler Benz.

<sup>2</sup> <http://www.daimlerchrysler.com/dccom/0,,0-5-73591-1-75180-1-0-0-74520-0-0-135-7166-0-0-0-0-0-0,00.html>