BC Hydro
Vancouver, British Columbia

Bioenergy Projects Technology Review

Amec Foster Wheeler Americas Limited Project No. 173758

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1.0 INTRODUCTION

BC Hydro have requested Amec Foster Wheeler to conduct a high-level review of the characteristics of Bioenergy Project Technologies. These characteristics included capital costs, Operations, Maintenance and Administration (OMA) costs and biomass consumptions.

The technologies include steam-based power plants, gasification and Organic Rankine Cycle (ORC) plants. For power generation, it appears that gasification is not yet fully developed.

The review will include a discussion on the different types of conventional steam boilers.

2.0 STEAM-BASED PLANTS

2.1 General

Steam-based plants can be either stand-alone or cogeneration.

A stand-alone plant typically would include the following major equipment:

- Biomass conveying system
- Biomass boiler
- Electrostatic precipitator
- Condensing steam turbine generator
- Steam condenser
- Cooling tower
- Deaerator

A cogeneration plant would include:

- Biomass conveying system
- Biomass boiler
- Back pressure steam turbine generator*
- Deaerator

*The steam turbine configuration can also be extraction/back pressure or extraction/condensing

For a given amount of biomass fuel, the stand-alone power plant will produce more electrical power than a cogeneration plant. However, it will have a significantly lower cycle efficiency than a cogeneration plant. For a stand-alone plant, the biomass fuel is used to generate only power.

A cogeneration plant requires a “steam host”. Kraft pulp mills are well suited for cogeneration since they have significant process steam demands in addition to electrical loads. The biomass fuel is used to generate both power and process steam.

For new projects, it is usually difficult to find “steam hosts”. Consequently, it is likely that future projects in British Columbia would be stand-alone.

2.2 Conventional Steam Boiler Types

Conventional steam boilers can be categorized as:

- Fixed grate
- Travelling grate
- Bubbling fluidized bed (BFB)
- Circulating fluidized bed (CFB)

All these types can burn biomass fuel, although CFB boilers are more commonly used for coal. BFB and CFB boilers have the highest thermal efficiencies since they have low unburnt carbon (UBC) losses. The BFB/CFB boiler efficiencies are about 3% higher than those of grate boilers. However, they are offset to some extent by higher auxiliary power consumptions.

A popular travelling grate is the air-cooled vibrating grate. Fixed grates are an older design that have to be manually de-ashed. The other technologies have automatic ash removal.

In British Columbia pulp mills, most of the older boilers have travelling grates. The newer boilers at the Powell River and Port Alberni mills are BFB boilers.

2.3 Conventional Steam Boiler Performance

Biomass fuel typically contains a significant amount of water. For coastal areas, the water content of biomass can be 60% and higher, on a wet basis. In interior areas, it can be 50% and lower. This moisture content has a significant adverse impact on thermal efficiency. The more the moisture content, the lower the efficiency. A biomass boiler has a somewhat lower efficiency than a boiler firing natural gas.

2.4 Steam Turbine Generator Performance

Steam turbine generator performance depends on:

- Inlet steam pressure and temperature
- Exhaust pressure (cogeneration)
- Condenser pressure (stand-alone)

The condenser pressure depends on the type of the cooling system. The cooling system can be:

- Once through water
- Wet cooling tower
- Air cooled

A wet cooling tower is commonly used in British Columbia.

2.5 Biomass Consumption

The biomass consumption in oven dry tonnes (ODt) per MWh depends on the following:

- Thermal power cycle (stand-alone or cogeneration)
- Steam boiler performance
- Steam turbine generator performance

The following biomass consumptions are considered typical by Amec Foster Wheeler:

- Stand-alone: 0.80 ODt/MWh (grate boiler)
- Stand-alone: 0.78 ODt/MWh (BFB boiler)
- Cogeneration: 0.24 ODt/MWh (power only)

2.6 Operating, Maintenance and Administration (OMA) Costs

Operating, Maintenance and Administration (OMA) costs typically are separated as follows:

- Fixed
- Variable

The total cost is the sum of fixed and variable costs, on an annual basis.

OMA includes all labour costs for operation, maintenance, administration and support. There is regional variation within BC in labour costs. OMA also includes equipment costs such as those for preventative maintenance, annual overhauls as well as consumables.

Fixed costs are based on the installed plant gross capacity and are expressed in $/kW. Gross capacity is the installed capacity. Net capacity is the output after internal consumption.

Variable costs are based on actual power production and are expressed in $/MWh.

For a stand-alone plant, Amec Foster Wheeler would suggest the following values:

- Fixed: $120/kW - yr
- Variable: $11/MWh

The variable amount does NOT include fuel costs.

These values are indicative only and should be used with caution.

2.7 Capital Cost

Amec Foster Wheeler were requested to provide order-of-magnitude capital costs. Amec Foster Wheeler have assumed that the required accuracy is +/-50%. Any order-of-magnitude cost estimate has to be used with caution, as site specific factors can adversely affect it. There is also regional variability in construction labour costs. The capital cost estimate is presented on a $\$/MW_{gross}$ basis. It should be noted that this parameter varies with plant capacity. A large plant will have a lower value than that of a small plant.

It should be noted that biomass power plants can be built to different “standards”. A plant built for a pulp mill may be more “sophisticated” than that built for a sawmill. This difference would have an impact on capital cost. A BFB or CFB boiler will be more expensive than a travelling grate boiler although the impact on overall project cost will be small (~5%).

For a stand-alone plant, Amec Foster Wheeler would suggest the following value:

- $5,400/kW

The associated plant size is 40 MW. Land costs are not included.

It is difficult to assign a similar value to cogeneration plants since their scope varies widely. For example, a pulp mill may add an extraction/back pressure steam turbine generator to their steam plant that already has a biomass steam boiler.

3.0 ORGANIC RANKINE CYCLE (ORC) BASED PLANTS

3.1 General

A stand-alone steam-based power plant operates on the Rankine cycle. An Organic Rankine Cycle (ORC) plant uses an organic fluid such as propane instead of water. The steam Rankine cycle generally operates at high temperatures whereas the ORC operates at low temperatures. One application for an ORC plant is to use the exhaust gas of a gas turbine driving a natural gas pipeline compressor, to generate electricity.

A recent application is to add them to sawmills where biomass-fired thermal oil heating plants are used to dry lumber. ORC power plants tend to be smaller than steam plants. Turboden's (ORC equipment manufacturer) maximum unit size is 15 MW whereas steam plants can be greater than 50 MW. ORC power plants can be fully automated.

An ORC plant typically has the following major equipment:

- Biomass-fired thermal oil heater
- Electrostatic precipitator
- Organic fluid turbine generator
- Regenerator
- Condenser

3.2 Organic Rankine Cycle (ORC) Performance

For a stand-alone biomass steam power plant, the cycle efficiency is low, about 24%, on a fuel higher heating value (HHV) basis.

European equipment suppliers typically use the fuel lower heating value (LHV). This appears to give a better efficiency. If the fuel HHV/LHV ratio is 1.05, a stand-alone steam plant efficiency would be 25.2% (LHV).

For ORC plants, Turboden claim LHV efficiencies of 18-25%. Converting these to a HHV basis would give 17.1-23.8%.

Therefore, stand-alone ORC power plants are less efficient than stand-alone steam plants.

3.3 Biomass Consumption

For ORC power plants, the following consumption is considered typical by Amec Foster Wheeler:

- Stand-alone: 1.10 ODt/MWh

3.4 Operating, Maintenance and Administration (OMA) Costs

For a stand-alone ORC plant, Amec Foster Wheeler would suggest the following OMA value:

- Total: $12/MWh

This value is indicative only.

3.5 Capital Cost

For a stand-alone ORC plant, Amec Foster Wheeler would suggest the following value:

- $5,000/kW

The associated plant size is 5 MW. The capital cost per KW would be expected to decrease with increasing plant size.

This value is indicative only. Land costs are not included.

4.0 GASIFICATION

4.1 General

Solid biomass can be converted to a synthetic gas (syngas) which contains hydrogen, carbon monoxide and methane. This syngas can be used in a steam boiler as a fuel instead of natural gas. After conditioning the syngas can be supplied to a spark-ignition engine driving a generator.

4.2 Thermal Generation

A gasifier system to provide a syngas for burning in a boiler could include the following major equipment:

- Biomass handling system
- Gasifier
- Oxidizer
- Boiler
- Electrostatic precipitor

4.3 Power Generation

A gasifier system to generate electricity could include the following major equipment:

- Biomass handling system
- Gasifier
- Tar cracker
- Syngas conditioning equipment
- Engine generator

4.4 Discussion

Nexterra has supplied a Combined Heating and Power (CHP) biomass gasification plant to the University of British Columbia (UBC), at a reported cost of $34,000,000. The design outputs are 2 MW_E and 9,600 lb/h of steam. Amec Foster Wheeler understand that the plant has had problems and is currently shutdown. It is thought that there are both process and mechanical issues. One of the challenges with biomass gasification is to achieve sufficient removal of tars and particulates to satisfy the fuel requirements of internal combustion engines.

It appears that gasification for power generation is not yet fully developed.

5.0 SUMMARY

A summary table is listed below.

Technology	Typical gross output (MW)	Typical net output (MW)	Typical Capacity factor	Annual output (MWh)	Nominal biomass consumption (ODt/MWh)	Nominal annual biomass consumption (ODt/a)	Typical Plant life (years)	Typical Project period (months)	Nominal capital cost ($/kW gross)
Stand-alone steam plant – grate boiler	40	36.8	0.85	297,840	0.80	238,270	20-25	36	5,400
Stand-alone steam plant – BFB boiler	40	36.8	0.85	297,840	0.78	232,315	20-25	36	5,670
Cogeneration steam plant	20	17.8	0.85	148,920	0.24	35,740	20-25	36	N/A
Stand-alone ORC plant	5	4.6	0.85	37,230	1.10	46,955	20-25	36	5,000

An allowance for internal power consumption has been made to estimate the net outputs. Only the net output is of interest to BC Hydro.

The capacity factor is based on the gross output, as per IEEE Standard Definitions for Use in Reporting Electric Generating Unit Reliability, Availability and Productivity (IEEE Std 762).