Project number: 5915
Funding source: Teagasc
Date: October, 2013
Project dates: Jan 2009 - Dec 2012

Combined heat and power from biomass

Key external stakeholders:

Commercial and industrial users with high energy costs, biomass suppliers, local and national government/ government agencies, scientific community.

Practical implications for stakeholders:

Small scale combined heat and power production from biomass is now possible. This project has shown that this concept is feasible but that some of the technologies entering the market place require further development. Such technologies are likely to work best where there is a constant demand for heat.

Main results:

- A small biomass CHP plant (200 kw) based on stirling engine and gasifer technology was operated over three heating seasons and produced 36.3 MWh of electricity and 268.5 MWh of heat over 2,157 hours of plant operation.
- Electrical efficiency (12%) was low due to the fact that the plant was not operated continuously and was only operated at part load.
- The Stirling engine did not give any problems until its seals failed and needed to be replaced after 2,108 hours of operation.
- Gasification proved difficult to control and most of the problems of the plant were associated with the gasifier.
- Energy efficiency increased when the plant was operated continuously.

Opportunity/Benefit:

Technologies for small scale (<500 kw) co-generation of heat and electricity from biomass are now becoming available for commercial users. This project has shown that such technologies can work, although, in the case of this technology, further development is needed.

Collaborating Institutions:

Stirling, Denmark

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1. Project background:

Co-generation of heat and power in rural areas using biomass as a feedstock offers the attraction of a high overall plant efficiency, reduced transmission losses, closer proximity to feedstock materials and the use of an indigenous energy source in addition to mitigation of the effects of climate change. It would also assist in achieving the renewable electricity targets set out in the 2007 White Paper on Sustainable Energy. Development of the sector has been constrained to date by the lack of suitable plant, especially for applications less than 200 kW.

A wide range of technologies may be considered for the co-generation of heat and electricity from biomass. For example, the biomass may be burned in grates or fluidised beds, or gasified using up- or down-draft systems. Power may be generated by an internal- or external-combustion engine, or by a turbine. A number of new technologies for small scale biomass CHP have recently become available:

- Organic Rankine-cycle (ORC) plant where steam is replaced by an organic working medium with a lower boiling point.
- Grate boiler with air-to-air and air-to-water heat exchangers which transfer heat first to recirculating air driving a micro-turbine and then to water for heating (e.g. Talbott CHP system).
- Grate boiler or gasifier operating an external-combustion Stirling engine (e.g. Stirling Denmark).

A review of the state of development of small-scale technologies concluded that ORC plants were most suited to demands between 400 and 1500 kWe, with Stirling engines offering most promise between 10 and 150 kW. The Stirling engine unit, though having a low electrical efficiency, was felt to be most suitable for small installations with a suitable heat-power profile. Small scale (< 500 kW) biomass CHP plants are now becoming available and the objective of this study was to evaluate a small (200 kW) biomass CHP plant based on gasification and Stirling engine technology.

2. Questions addressed by the project:

To evaluate a small (200 kW) biomass CHP based on gasifier and Stirling engine technology to determine if this technology is suitable for small scale combined heat and power production from biomass.

3. The experimental studies:

The biomass CHP plant at Oak Park has an electrical output of 35 KWe (Kilowatts electrical) and 140 KWth (Kilowatts thermal). The overall process of the plant is shown in the Figure below. The plant uses wood chips at 40% moisture as a fuel, the chips are augered into the gasifier where gasification occurs in an atmosphere containing a partial measure of oxygen. The gasifier in the plant at Oak Park had a total capacity of 800 kW to allow for further expansion of the system. The gas from the gasifier is taken from the top of the gasifier at a temperature of between 70 and 80 degrees C before being conducted into a combustion chamber where it is burned. The heat from combustion is used to heat water in a water jacket around the combustion chamber but also to turn the Stirling engine attached to the combustion chamber. The Stirling engine is cooled by the return water circuit of the plant. Part of the flue gas stream from the combustion process is used as a gasification agent for the gasification process and is conducted to the bottom of the gasifier, after its oxygen content has been adjusted by the addition of air. The remainder of the flue gas stream is passed through a heat exchanger (economiser) before exhaustion to the atmosphere.

Electricity from the Stirling engine is fed into the sub-station at Oak Park and subsequently used around the Oak Park campus. The hot water from the plant is used to heat water in buffer tanks, this water is then used to heat buildings and glasshouses around the campus via a district heating system.

Gasification

Gasification is a form of incomplete combustion in which a fuel is burnt in an atmosphere which is deficient in oxygen. During gasification, an energy rich gas consisting principally of methane, carbon monoxide and hydrogen is formed but only a limited amount of heat is released. In contrast, carbon dioxide, water vapour and heat are released during combustion when a fuel is burnt in an atmosphere which is not deficient in oxygen.

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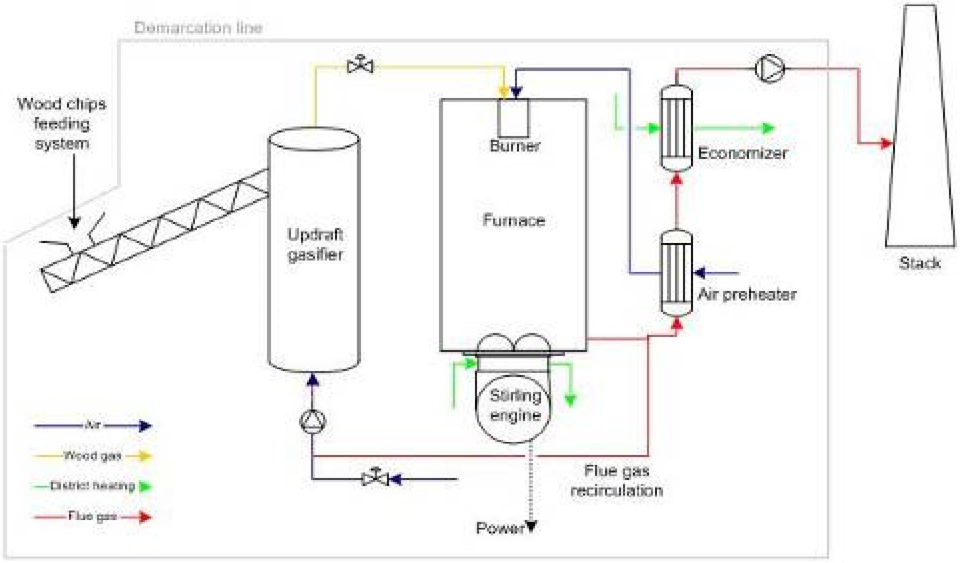
Stirling Engine
A Stirling engine is an example of a closed cycle engine in which the expansion and contraction of a working fluid is used to turn a crankshaft. In the CHP plant in Oak Park, the Stirling engine is bolted onto the combustion chamber where gas produced in the gasifier is burnt, and heat from the combustion of the gas is absorbed by the working fluid of the Stirling engine through heat exchangers. The engine starts to rotate once its' working fluid (helium) absorbs sufficient heat, and a generator on the crankshaft of the engine starts to produce electricity once the engine rotates.



The plant was installed at Oak Park during 2009 and 2010 and was first run during the 2010/2011 heating season. It was subsequently run during the 2011/2012 and 2012/2013 heating seasons.
Initially, the plant was only run for a relatively small number of hours (4-8) on working days (Monday to Friday). Heat was supplied initially via a district heating system to two buildings in the campus which required heat between 8am and 4pm from Monday to Friday. The district heating system from the plant was eventually expanded to include five large glasshouses in Oak Park which need to be supplied with heat during nighttime and at weekends, in addition to during the daytime.
The expansion of the heat load of the plant in addition to improvements in the reliability of the plant allowed the plant to be run continuously when there was sufficient heat load.

4. Main results:

- **Plant:** The plant was operated over three heating seasons and was run for a total of 2,157 hours during the study. The plant was run at full load (35 KWe) on several occasions without any problems but was generally operated on part load (15 KWe to 25 KWe) due to limitations in heat demand. Energy efficiency reached 81% when the plant was operated continuously under partial load.
- **Energy Generated:** 36.3 MWh of electricity and 268.5 MWh of heat were generated during this period.
- **Electrical Efficiency:** The average electrical efficiency of the plant was 12%. This figure is low and is attributable to the fact that the plant was not in continuous operation during this period and because the plant was only operated at part load.
- **Stirling Engine:** The Stirling engine did not give any problems during this period but its' seals failed and needed to be replaced after 2,018 engine hours and this effectively ended the study.
- **Gasifier:** Most of the problems encountered during the study period were related to the operation of the gasifier. The gasifier ran at a high temperature during the first heating season due to the fact that the concentration of oxygen supplied to the gasifier was too high (18%). This problem was eliminated once the oxygen concentration was reduced to 13%. High temperature operation caused considerable damage to the bottom of the gasifier and to the ash scrapers, although this problem was partially attributable to the fact that these components were not covered with a sufficiently deep layer of ash before plant operations commenced.

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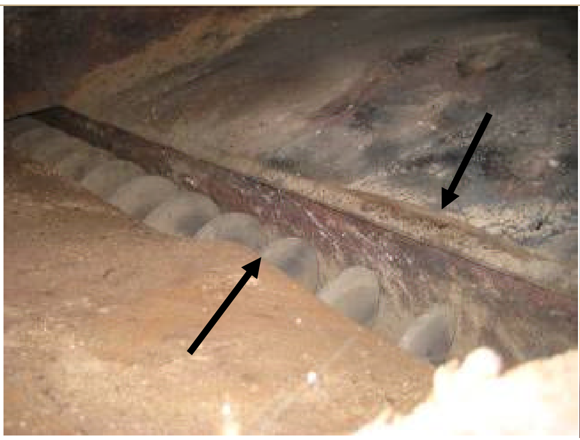


- **Tar Formation:** No problems were encountered with tar formation during the course of the study. The pipe conducting product gas from the gasifier to the combustion chamber was almost totally clean at the end of the study (shown below). This is most probably attributable to the use of moist wood chips as a fuel for the plant. The resulting high moisture content of the product gas ensured that the tar did not lodge in pipes but was conducted to the combustion chamber and burned there along with the other constituents of the product gas.

- **Wood Chip Usage:** Wood chip usage was dependant on the operating cycle of the plant and the moisture content of the wood chips. Wood chip usage varied between 55 and 70 kgs of wet chips per hour during periods when the plant was operating continuously.
- **Manpower Requirements:** The plant proved to be manpower intensive and a part-time operator would be needed to run such a plant. Manpower was needed on a regular basis to supervise chip loading, ash removal and for regular checking of plant operation. Additionally, a significant amount of time was found to be required for repair, annual maintenance and cleaning.

5. Opportunity/Benefit:

Technologies for small scale (<500 kw) co-generation of heat and electricity from biomass are now becoming available for commercial users. This project has shown that such technologies can work although, in the case of this technology, further development is needed.

6. Dissemination:

Finnan J., Brett P., Ralph T. (2012). Producing Electricity and Heat from Biomass. *TResearch*, 7(4), 18-19.

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