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H-CHP Test Installation

Technical Report

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Overview

A Microgen Micro CHP system was installed in the Blackhouse, Knock, Isle of Lewis as part of the NPA H-CHP project. A temporary extension to the building was constructed to house the unit and the associated components.

The purpose of this report is to evaluate the installation process, the operation of the unit, and further changes needed if a small CHP system is to work effectively in the Western Isles and make a significant impact at both a local level (fuel poverty, high building heating requirement) and a global level (displacing fossil fuels to mitigate climate change effects).

The system and the installation is costly, but that is not considered an issue. For any new technology, the cost is always high before it is widely adopted, but with mass production and volume production benefits, the price can drop significantly. The important thing is to make a judgement on whether the total system price can come down under these circumstances, and that probably is the case here.

It should be noted that the investigation is not complete and that further work is required. This is therefore an interim report, not a final report. It is evident the Microgen system, though treated as a commercial product is still not fully developed as a consumer product (though it has clearly moved beyond the proof of concept and prototyping stage).

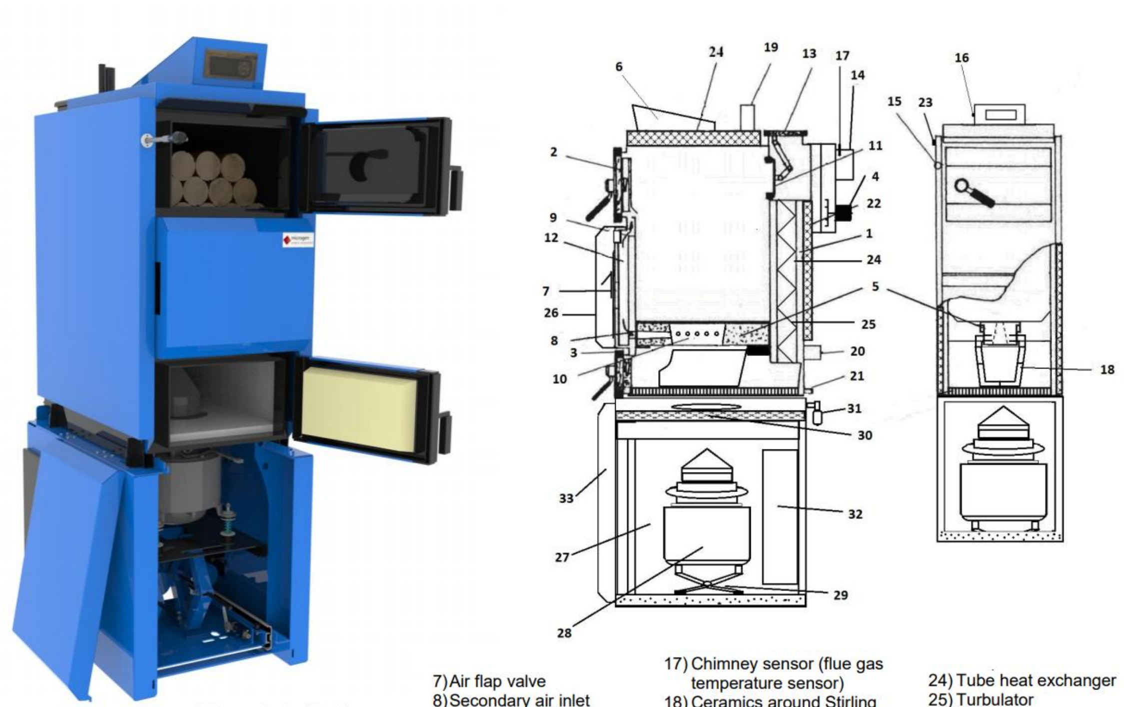
Principle of Operation

The CHP system is shown in **Fig. 1**. Wood is burnt in the upper combustion chamber, initially with surplus air supplied. Once the flue gas has reached a temperature of 230°C the air supply to the combustion chamber can be significant reduced and the flue gas redirected to a lower chamber. If this is not done, the system will produce only heat, and no electricity.

The redirect flue gas will contain a significant quantity of methane and carbon monoxide. When mixed with fan-driven air in the lower chamber the gas self-ignites achieving a very high temperature close to the Stirling engine.

The Stirling engine drives a linear generator. To work effectively, a very high temperature differential is needed. Whilst the hot gas produces the high temperature, the low temperature comes from cooling water taken from the bottom of the water storage tank. The water is heated from the top by the wood log heater, but the heat flow works against the direction of convection with the result that eventually the water at the bottom of the tank becomes too hot to maintain the temperature differential the Stirling engine requires.

To ensure this does not happen, a tank with a capacity of 3,000 litres is recommended. In this installation, a tank of 1,500 litres was used because of limited space and it was found that at times the hot water had to be run off to keep the engine running.



1) Heater body (shell)
2) Door to add fuel (upper door)
3) Door to remove ash (lower door)
4) Exhaust fan
5) Bottom of combustion space (refractory concrete)
6) Controller display box
7) Air flap valve
8) Secondary air inlet
9) Primary air inlet
10) Ceramics nozzle
11) Firing flap valve
12) Primary air inlet duct
13) Clean-out cover
14) Smoke flue outlet
15) Firing valve's draw rod
16) STB-reset button with cover
17) Chimney sensor (flue gas temperature sensor)
18) Ceramics around Stirling head
19) Hot water outlet (DN 40, G1,1/2´´)
20) Cold water inlet (DN 40, G1,1/2´´)
21) Inlet opening
22) Thermal insulation
23) Heat exchanger (water-filled)
24) Tube heat exchanger
25) Turbulator (air-brake valve)
26) Upper front cover panel
27) Stirling engine section
28) Stirling engine
29) Lift system
30) Bottom Cover
31) Bottom Cover Motor
32) Stirling electronics
33) Bottom front cover panel

Figure 1 The Biogen Wood Log Heater

The electrical output is designed for direct connection to a mains supply (it is an asynchronous generator). However, permission to connect to the local mains supply is not possible unless the boiler is certified.

The alternative is to generate a separate stand-alone supply and use the power generated to charge batteries. The stored electricity can be used afterwards in the reverse process – the battery powering an invertor which feeds consumer devices within the home (with power available for essentials during a grid interruption).

A suitable device is a Sunny Island, but a Victron Multiplus 3000 (**Fig. 2**) was recommended and installed here. For storage, 2 x 12 V Lithium Phosphate batteries were used, a total capacity of 2.4 kWh.

The batteries can be charged from mains, or the Multiplus can generate 230 VAC at the output. The Biogen system is connected to the output as well and will draw energy as required (170 W peak with the fan running). Once the generator produces more that is required by the Biogen electronics and components, the extra is directed to the batteries.

Figure 2 Victron MultiPlus Inverter Charger 12V/3000VA/120A, and installed.

Critical Issues & Functional Improvements

Whilst the system is operational and functional (it is a compact system and engine noise is not particularly loud), there are a number of problems that need to be addressed.

1. The Multiplus is essentially old technology and is designed to charge lead-acid batteries. It does not effectively charge lithium ion batteries through the simple-to-access DIP switches. The manufacturers claim it is possible, but after linking into the device with the dedicated communication interface the software was found to only allow trained users to adjust the settings (for obvious reasons). This issue needs to be resolved.

2. It is unclear how the Multiplus relay output can be set to act when the charge level is greater than, say, 90%, and how an appropriate amount of hysteresis can be included. This, along with the inclusion of an appropriate dump load, is necessary to deal with the issue of the Biogen producing electricity when the battery is full – this is potentially a serious problem situation.

3. The Biogen electronics is extremely sensitive to the very short voltage fluctuations that might occur when any load of more than 200 W connected to the common output is either switched on or off. A fault condition is triggered which stops generation and in some circumstances cause the engine to withdraw downwards from the active engaged position. This is a serious hazard as hot embers can then drop from the combustion chamber onto the floor and get amongst the wiring. It is clear that connecting the Stirling engine to the heat source in his way is a dubious design decision. Furthermore, even if the cause of the problem is corrected, there will always be a safety concern because the design makes it possible for the engine to drop out. For test purposes, the approach is to ensure all the walls to ground level are protected with cement board and all cracks closed with fire-resistant sealant. In addition, fire alarms must be installed and a fire extinguisher should be close at hand.

4. In some cases, an electrical spike simply stops generation (with an error **6. Overrun**). This is problematic because the situation does not fully clear until the head temperature drops below 210^{o}C. When the head temperature is high, a wait of more than 1 hour is often necessary.

5. The display unit on top of the Biogen module has a metal top (lid), but no foam underlay. Drops of water can condense on the top plate, falling into the electronics. We believe this was the cause of two events where the entire display appeared to lose power for an hour or more.

6. The serial link from Biogen to the computer is useful but awkward, but it should instead be wireless or Bluetooth, or a network connection. The negative power generation in the data needs explanation – is the generator in motor mode?

7. The practicalities of cleaning the device have not been sufficiently considered. It is only possible to clean it effectively with a temperature tolerant vacuum cleaner.

8. The water tank is extremely large at 1,500 litres and the correct 3,000 litre tank is unsuitable for domestic applications.

9. The manual process of switching from normal combustion to gasification is not appropriate for a regular domestic consumer. The process of switching between the two should be fully automated.

10. Consideration should be given to the design of an automatic feeder (perhaps 50 kg).

11. The piping is complex and might perhaps be simplified, perhaps by developing a standard layout plan (**Fig. 3**).

Figure 3 Some of the pipework.

The Feedstock

A number of different fuel types have been tried. This is because consumers will experiment regardless of any fuel recommendations made (or warnings).

Generally speaking, experiments involved 3 - 5 kg of test material.

The experiment with coal is shown in **Fig. 4**.

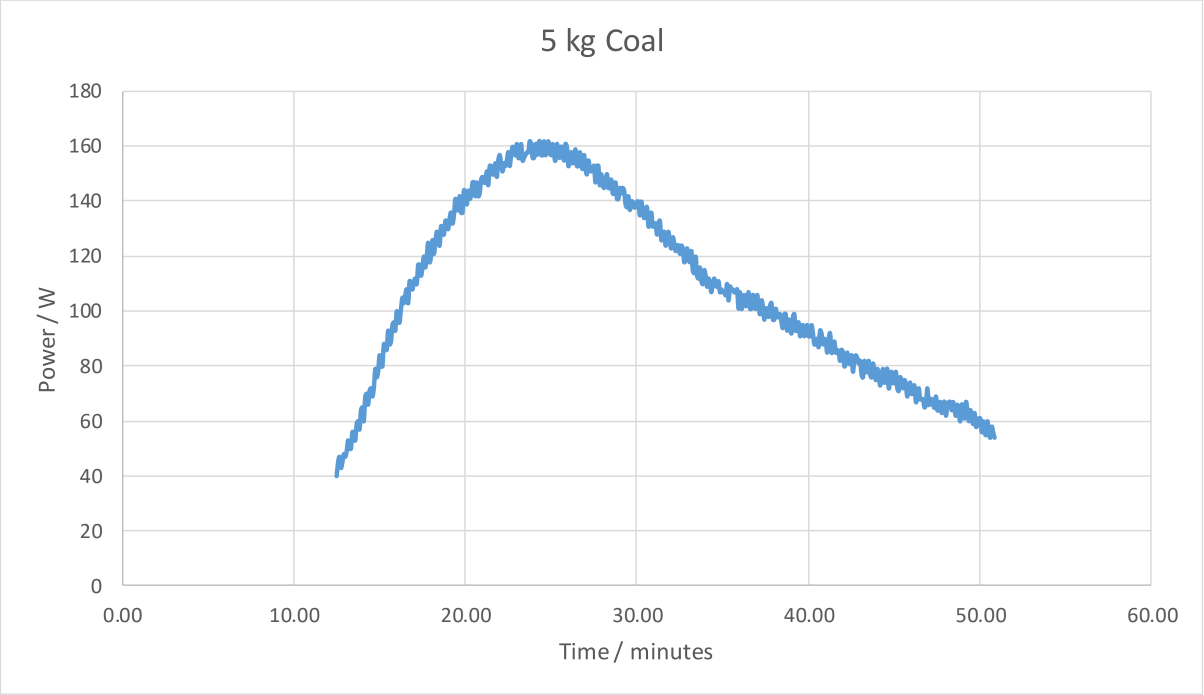


Figure 4 The experiment with coal. It was very effective at heating water.

The fuel does not make sufficient electricity even to power the Biogen. Combustion was difficult because the coal tended to block the opening at the bottom and thus limit air flow. It was surprising how little gas was produced, but impressive the way routing the flue gas for combustion cleaned it up completely.

The next experiment was with Bord na Mona compressed peat briquettes. These were very effective, but of course the extraction of peat is not completely sustainable (**Fig. 5**).

Normal uncompressed Lewis peat (20% moisture) managed about 100 W and only for a few minutes.

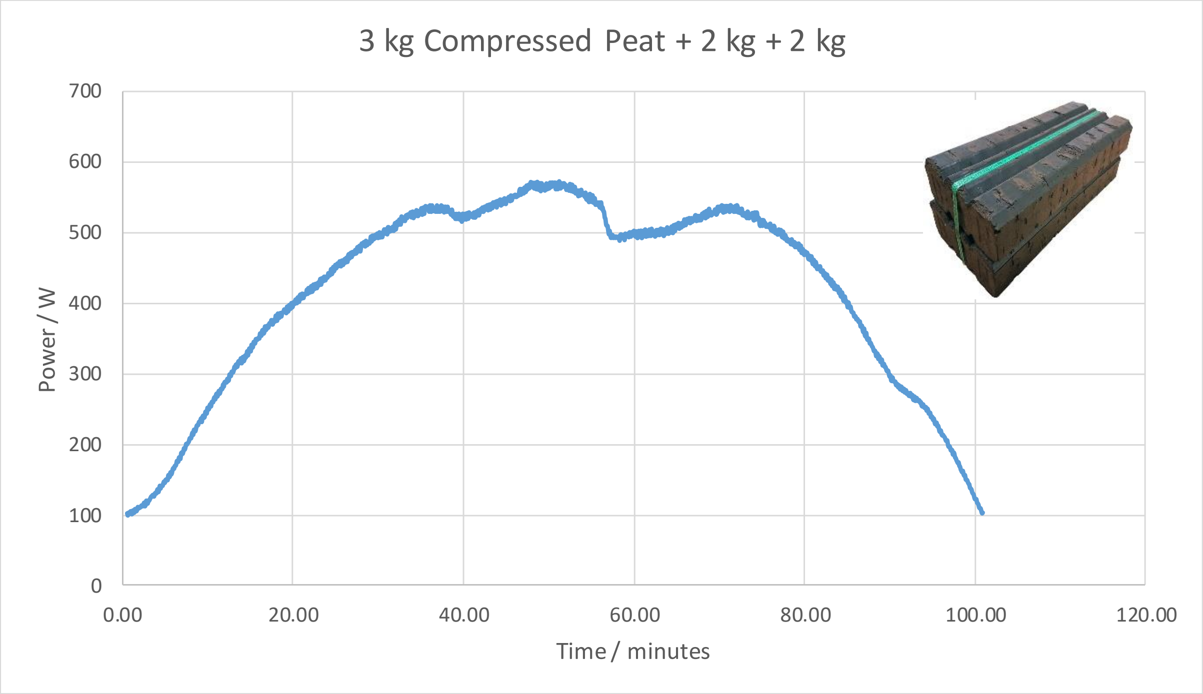


Figure 5 Compressed peat was effective and long-lasting

The best choice, of course, is wood. There are many types of 'kiln-dried logs' and it is unclear which ones are best. A large number were tried.

Look first at **Fig. 6** which shows the best type of wood –kiln dried hardwood, very, very dry and red in colour. If the combustion chamber were packed with this type of wood, we might expect 1 kW to be generated.

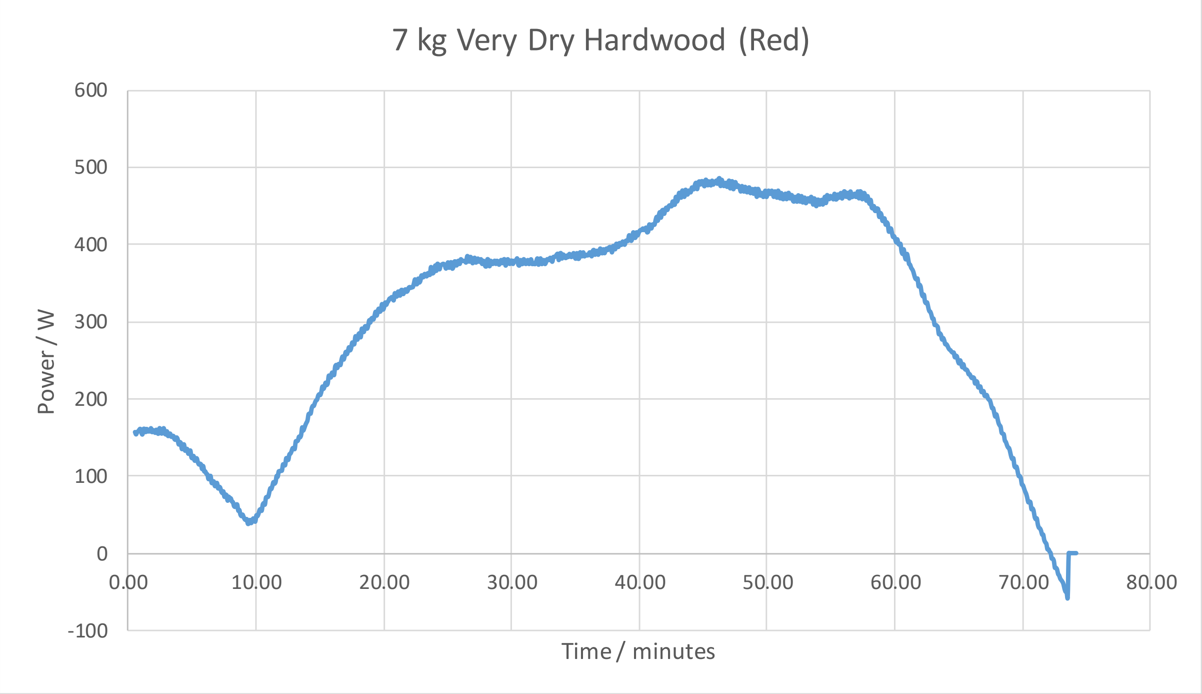


Figure 6 The best wood tested (supplied initially by TIG).

Contrast this with the variety tested in **Fig. 7**.

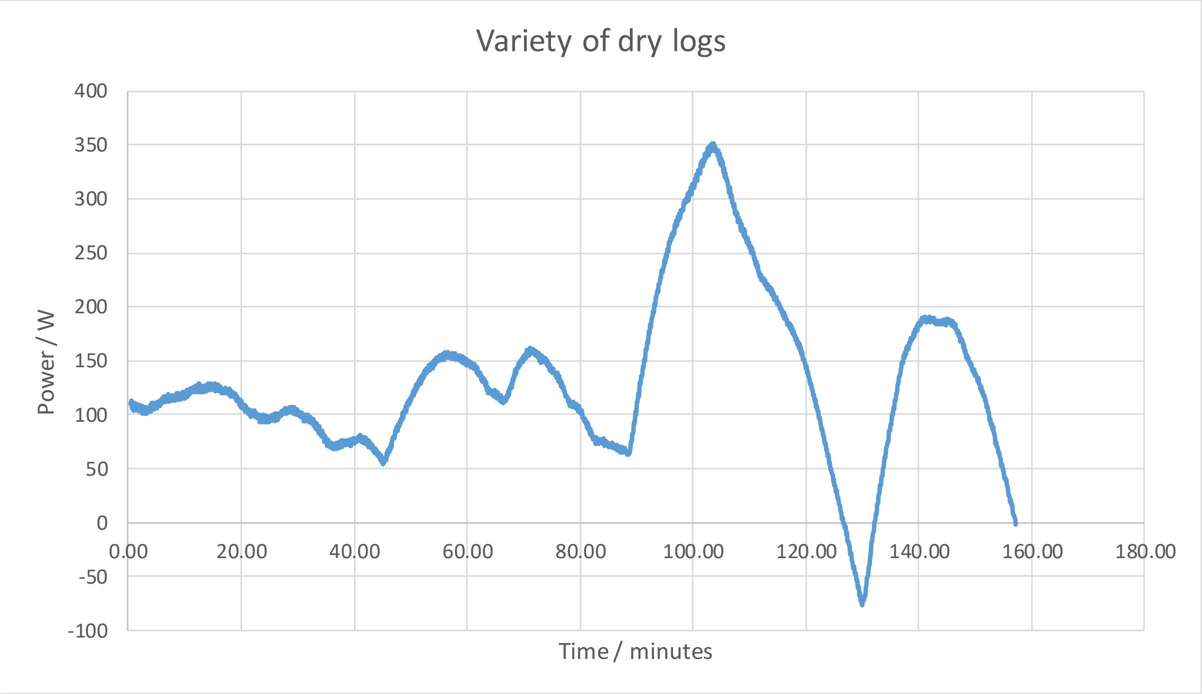


Figure 7 A variety of commercially available logs.

The first two (0 – 45 min and 45 – 90 min) are two types of log, both very white and apparently dry, but the moisture meter suggested some water present. The third one is the combustion of cylinders of compressed wood chip (very dry). The final one is a mix of all 3 types.

Over the next month, the results will be refined, evaluated and rated by fuel producer. We will also look at the effect of running with larger fuel samples (a full combustion chamber).

Recommendations and Further Work

The results so far indicate that the heating system is effective and reliable, but the production of electricity is largely a bonus. There is very little electricity produced in excess of what the unit consumes, and the mechanism used to produce it is complex and in need of improvement. The system does provide the householder with some protection against external power interruptions, but the result is very far from the ideal target of grid independence.

In all likelihood, a CHP system will be part of a mix of renewable solutions, and to his end it makes sense to combine CHP with solar PV to balance electricity generation over the year. This is something that could be investigated further with this particular installation.

Given the very limited testing so far (15th Feb – 30th Mar), it is not possible to make recommendations. Significant additional work needs to be done. Nevertheless, it is possible to say that a mass produced system with the issues identified earlier effectively addressed could have an application and impact in the Western Isles. However, it is not ideal, and an average 1:10 electricity to heat production ratio would be needed for the system to be effective. The current system operating at full power (20 kW heat) is likely to produce only 1 kWe peak and 0.5 kWe average, a ratio of 1:40.

There are a number of activities that still need to take place before the evaluation is concluded:

1. System and boiler room to be made completely fire secure
2. Accurate fuel mass, heat and electricity and heat monitoring with 1-2 tonnes of three types of highest quality wood (varying quantity in combustion chamber and determining effect on average electricity production). System efficiency in terms of extraction of primary energy from the fuel calculated. Energy monitoring to be installed in the building
3. Full assessment of fuel supply chain in terms of price, availability and environmental impact
4. Addressing electrical system reliability and increasing the battery storage capacity
5. Inclusion of 2 kW solar PV to evaluate the performance of the combined system, and a look at other possible renewable energy sources