Department of Mechanical and Aerospace Engineering

Optimizing the use of Sustainable and Renewable Energy in the World Heritage Site of New Lanark.

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Copyright Declaration

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed: *Leonard A Gray.*

Date. 6th September 2014.

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Abstract.

The historic village of New Lanark consists of former cotton mills and housing once occupied by the workforce. It is now a thriving community and tourist attraction. It has grade A conservation status and is now run by the New Lanark Trust.

This thesis will investigate the current situation with New Lanark Trust's properties with regards to how much energy is being generated, how efficiently it is being consumed, and what other means of sustainable and renewable energy sources are available. On the conservation side, an audit of current practice examines how well the Trust controls energy waste with recommendations for the future, including the proposed redevelopment of Double Row.

The unique status of New Lanark greatly limits the potential to make any changes to the area, including additional infrastructure to provide further forms of energy.

The whole village is A listed, is within a Conservation Area, and is also now a World Heritage site. (1) This inevitably leads to issues for Planning Consent for any project undertaken.

Balanced against this is the changing attitude towards carbon reduction and sustainable energy by Scottish, British and European Governments.

It is recommended that a 100kW turbine be installed in the Mechanics Workshop to generate electricity, and that a Biomass Heating system is installed in the former Retort Building in order to heat the nearby buildings.

The Trust appears to be making a serious attempt to reduce energy losses, and have to be commended in this. This is reflected in the fact that in 1995 the Trust won a "Highly Commended" certificate in the Eurosolar UK Awards sponsored by the European Commission.

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If implemented, the Trust will be generating a surplus of energy over its requirements.

TABLE OF CONTENTS.

6 APPENDICES

7. Electronic Attachments

1. Hydro Costing Analysis
2. Biomass Sizing Tool
3. Chimney Height Calculation.

LIST OF REFERENCES.

1. Historic Scotland (2014) *World Heritage Sites in Scotland, New Lanark* [on line], Available at http://www.historic-scotland.gov.uk/index/heritage/worldheritage/world-heritage-sites-in-scotland/new-lanark.htm (Accessed June 29, 2014)

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LIST OF FIGURES.

LIST OF TABLES.

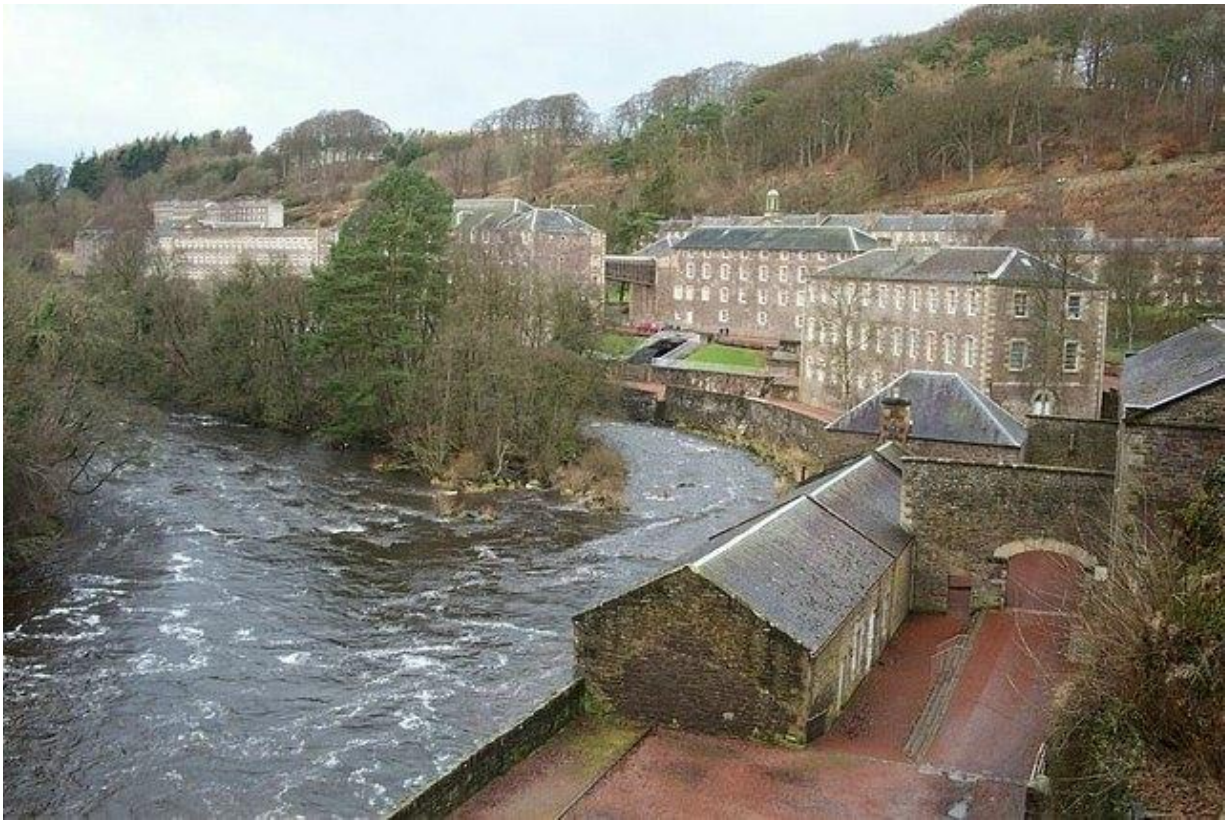


Fig 1 New Lanark Village

1. Introduction

In 1785 Robert Owen founded the village of New Lanark on the banks of the River Clyde south of the old town of Lanark. The village was to consist of a number of mills for the production of cotton, a very lucrative market at the time. In addition, housing was built to accommodate the large workforce required. Owen, and later his son in law Robert Owen, did pioneering work with their treatment of their considerable workforce.

Owen was a man with a mission. Not only was he a good philanthropist, he was a man of ideals. In 1818 he published "*A New View of Society"* where he outlined his views on " Humanity with the labourers" (2), Owen used his influence with politicians to extend his philosophy of better treatment to labour forces, and was close to having Parliament discussing the Bill when the Napoleonic War diverted its attention.

Owen educated the children, encourage high morality with their workers, and founded the first Cooperative shop in the village. Interestingly in 2014 when the self-sufficiency of Scotland is under scrutiny, it is significant that Owen provided a self -sufficient society often out with the cares of the legal system! (2)

The village gain international interest including visits from Grand Duke Nikoli (afterward Tsar Nicholas 1 of Russia), in 1816, the future President of the United States John Quincy Adams, and the famous reformer William Wilberforce.

For more information on this fascinating history see "Historic New Lanark ; Donnachie, Hewitt"

As cotton manufacturing declined, the mills were eventually taken over by the Gourock Rope Works Company in 1881 (2), eventually for the manufacturing of canvas.

In the 1960s the mills closed and the village fell into serious decline.

The New Lanark Association was formed to improve the substantial housing stock and some pioneering restoration work was carried out aided by funding from various agencies.

Following limited success with the first restoration project, and with concerns over the condition of the industrial buildings, the New Lanark Conservation Trust was created to deal with the whole village and to avoid the threat of widespread demolition.

The Conservation Trust was successful in restoring much of the total village by 1996, and in 2001 the village was A listed and was made a World Heritage Site by UNESCO.

The New Lanark Association was adsorbed by the Conservation Trust, and now is simply known as the New Lanark Trust. It is in partnership with South Lanarkshire Council and

Historic Scotland. The Trust manages the site. The Trust itself controls the activities of most of the industrial buildings, either directly, or through wholly owned companies, New Lanark Trading Limited, New Lanark Leisure Limited, and New Lanark Homes.
New Lanark Trust has a policy of using renewable and sustainable energy whenever possible, and at the moment claims to be self-sufficient thanks to its present renewable installations. They wish to investigate methods of increasing and maximizing their use of such energy.
From the Trust's point of view the village can be considered to consist of two main operational areas, one being the housing stock and the other the former industrial mills and their associated buildings.

The majority of the housing stock has been restored to modern building standards, and has either been sold or is rented by the Trust. There are plans to restore Double Row in Rosedale Street, and a Planning Application was submitted in April 2013 to South Lanarkshire Council. (3) The rented properties have an annual expenditure for maintenance, and this is covered as part of the rental charges.
The mills section relies on income generated in the rental of a small number of properties to small businesses and organizations. The majority of the income is generated by visitors. New Lanark attracts over 300,000 visitors a year who pay to see the historic industrial heritage, or who come to use the hotel, and its leisure suite. Others hire holiday self-catering accommodation or stay in the Youth Hostel. The profits generated by both the hotel and the trading section are used to pay for the upkeep of the sector, and to fund future restoration projects. External funding is available from several bodies, for example Heritage Lottery Funding, but these tend to be for project based investment. The costs of running the mills section comes from maximizing the profits from visitors.
A major overhead is the cost of energy for the mills sector. In 2010 the annual consumption was approximately 5MWhr, which is currently priced at 13p per unit, giving a potential annual cost of £650,000 per annum. Such a cost would make the Trust unviable. Over the years the Trust has been addressing this by endeavouring to generate its own electricity and heat from sustainable sources which in turn has drastically reduced their energy overheads.

1.1 Project Outline.

1.2 Aims and Objectives.

- To investigate the typical annual energy consumption of the New Lanark Trust.
- To review the current methods the Trust are employing to minimise these costs.
- To review the impact of policy constraints due the Village's A Listing, being a Conservation Area and being a World Heritage Site.
- To consider the feasibility of extending the use of renewable forms of energy. Once selected they would be analysed in a model situation using various tools.
- To recommend some initiatives for future developments in the Village.

1.3 Methodology.

- Firstly a number of meetings were arranged with Lorna Davidson who is in charge of running the affairs of the Trust. From these meetings, detailed meter readings were given of the electricity consumption of the areas of the village which was under its control. Also received were details currently employed in generating heat and electricity from their own resources. A number of methods used to minimize energy usage which had been in place for some time were also produced.
- A literature review was carried out to investigate how Scottish Planning Law placed restrictions on A listed buildings, and to find out how these restrictions limited further renewable energy development.
- A review was made on the current Governmental Policy on renewable and sustainable energy. The ambitious targets set by the European, British and Scottish Governments over the future are highly relevant to any investigations. This included financial incentives for using certain classes of renewable systems.

- Two renewable types of energy were selected (Mini-hydro and Biomass) and these were reviewed to ascertain how they would stand up to the constraints they faced, both locally due to the unique status of the area, and due to national environmental safe guards currently in place.
- Each energy type was then modelled to ascertain its performance in a typical building in the village. The feasibility of both systems were tested over a number of areas using freely available tools available from the Carbon Trust and the British Hydro Association.
- The results were analysed and a number of recommendations were made.

1.4 Preliminary Meetings with New Lanark Trust and others.

New Lanark as a village has gained a reputation for being keen to support the use of renewable and sustainable energy. It is also keen to avoid unnecessary energy waste.

Informal discussions with a number of Trustees allowed a number of meetings to be arranged with the Trust's Managing Director Lorna Davidson. The following areas were covered:

- Ms Davidson explained the policy the Trust had on energy conservation.
- Insulation to the highest possible level was incorporated in all the renovations.
- Low power lighting was used whenever possible.
- The use of double glazed window panes for the original windows was something that the Government were now considering allowing, and this could make an important improvement in reducing heat loss in the village.
- The Trust operate a communal gas heating system for 45 of the houses it owns and let to tenants. This is more efficient than individual boilers, and is also safer.
- The Trust have two water source heat pumps. One produced hot water heating for the radiators in the Institute building, the heat being sourced from the adjacent mill lade.
- The second provides underfloor heating in the Hotel Leisure Suite and the swimming pool. This extracts heat from the outflow to the River Clyde after the water has passed through the Turbine in Mill Three.
- This turbine is used to produce up to 400kW of electricity which produces the energy for the Visitor Centre and the Hotel.
- The Trust was considering reinstating another turbine in the Mechanics Workshop.
- A copy of a survey of the mill lade was made available, as was the electricity readings for all the Trust's Buildings during 2010.

- The generation of renewable energy was good for the image of New Lanark and it was vital economically.
- New Lanark was not a museum. It is a fully working and viable community.

Meetings were also held with Neil Phillips, Energy Consultant and the author's supervisor, and with James Tennant the Property Manager. Mr. Tennant gave access to all the facilities requested.

These meetings at the outset produced an opinion that the money saved by any improvement was the area of highest priority, together with the maintaining the historic and architectural integrity of the village

2. Literature Review.

2.1 Planning Restrictions to Listed Buildings.

In 1983 New Lanark's buildings were placed on the Secretary of Scotland's list of buildings which are of 'special architectural or historic interest'. The category A is the highest possible and relates to 'Buildings of National or International Importance'.

With such status come constraints. The main one is that any demolition, or any other change that could affect the architectural or historic character needs listed building consent (Planning Ref(4For listed buildings both the exterior **and** interior are protected. This can extend to replacement bathrooms or fireplaces, outside alarm boxes or even the tint of the glass on outdoor windows! Changes that can only be seen from the air need consent. (Burroughs Day v Bristol City Council 1996) (5).

Historic Scotland give guidance on dealing with these subjective decisions in their Historic Buildings Memorandum, appendix 1.(6). Planning Authorities have delegated powers to approve applications for B and C listed buildings, but not those which are A listed. These had to be notified to the Secretary of State for a decision whether or not to call in the application. This power now rests with the Scottish Government following Devolution. Designating an area as a Conservation does not add substantial extra controls, but can remove some permitted development rights (Effect of Designation 12.7 Scottish Planning Law , McAllister and McMaster 1999.)

In 1972 UNESCO held a Convention concerning the Protection of World Culture and Natural Heritage. This 'World Heritage Convention' was adopted by the United Kingdom in 1984 and New Lanark was added to an elite list as a World Heritage Site in 2001. The granting of this status produces no additional statutory controls, but such a high level of importance does have a major influence on planning permission and listed building consent, not just in the site but in the buffer zone surrounding it.

At the time of writing a Public Consultation is taking place in the Cartland Hotel Lanark, where Cemex and South Lanarkshire Council are defending the decision to allow Hyndford Quarry to encroach within the buffer zone of New Lanark World Heritage Site. The working group, set up by Save Our Landscape, argue the decision could affect the World Heritage status. The decision of the Consultation will be available in 2015. (Lanark News 19th August 2014, see www.Lanark.co.uk/Lanarknews).

South Lanarkshire Council (SLC) are responsible for Planning in the area, and appear to be happy to allow interior changes to take place. Externally both the Council and the Trust are keen to avoid any changes whatsoever. Reinstating existing facilities would appear to be reasonably acceptable, but erecting a building to house a renewable facility would not. This greatly restricts the options available, and is a major influence on the course of the project.

2.2 UK Energy Policy on Renewable and Sustainable Energy.

Current Energy Policy in Scotland is not a devolved matter. The United Kingdom Government decides on policy and strategy for the whole of Great Britain. Despite this Scotland has control over planning issues which has a significant influence in future developments in energy generation. This has resulted in the creation of a Scottish Ministerial post in Energy, currently held by Fergus Ewing MSP.

Three major factors influence current Energy policy :

1. To reduce carbon dioxide emissions, currently considered responsible for changes in climate and causing global warming.
2. To shift reliance on fossil fuels which are non-renewable, to sources of energy which are sustainable.

3. To take steps to reduce where possible the net consumption of energy by increasing efficiencies, reducing losses, and managing demand more effectively.

The Scottish Government has set a target to reduce carbon emissions by 50% by 2015 compared to the 2010 figure of 347g/kWhr. This is then to reduce by 80% by 2030. (7)

It also wants 50% of Scotland's electricity demand to be produced by renewable sources by 2015 and 100% by 2020.(8)

Another target is to produce 11% of Scotland's heat from renewable sources by 2020.

Achieving these ambitious targets is a major challenge for the Government. Their strategy was to make capital available for renewable energy investment, and to give long term financial support for such projects. The UK Government now applies generous support for those generating energy by renewable means with attractive long term payments for both producing renewable energy and selling it to suppliers. The current feed-in tariffs are to be found at the end of this paper. This shift from Grant aid to Support aid is designed to encourage private outside investment in renewable energy schemes.

In addition to using the carrot as an incentive, the stick is also brought into play. Levies are applied to energy producers based on the level of their carbon emissions. The thresholds for these levels is reviewed downwards periodically.

Guidelines are issued to Planning Authorities on how to handle applications for renewable energy generating projects, and grants are available for schemes to reduce energy losses in buildings (9)

Building standards are tightened to reduce energy emissions on new build development, and grants are made available for communal heating systems. Money is also earmarked for research and development of renewable energy systems.

2.3 Government Financial Incentives

2.3.1 Renewable Electric Energy Generation.

The generous incentives offered to those using renewable energy to generate electricity are twofold. Firstly Every kWhr of energy thus generated is paid a sum of money, depending the method of production. The table in Appendix 5 gives these different rates.

These rates are fixed over a defined period of time, but are also tracked to the Retail Price Index average over the previous year.

Over time the starting rate is degressed. This rather strange expression is used by the Government to reduce the tariff levels to take account of dropping installation costs as the volumes of a particular type of generation increases. Recently the cost of Photo Voltaic (PV) panels plunged as the take up rose. The FIT was reduced to take this into account. A hydro scheme of 100kW starting in September 2014 would receive 29.72p for every kWhr produced, indexed linked for a period of 20 years.

In October 2014 the starting rate drops to 17.75 p per kWhr.

If the energy produced is fed into the National Grid, a further payment is guaranteed. This export rate is 4.77p/ kWhr and is also index linked.

(10)

2.3.2 Renewable Energy used for heating

This receives financial support through a different scheme called the renewable heat incentive (RHI).

Schemes like biomass boilers to heat water for a heating system, or heat pumps which extract heat from the air, from the ground or from water receive money according to the heat they generate. This offsets the cost of fossil fuels, gas or electricity and can reduce fuel bills significantly.

Renewable Heat Incentive **Commercial**	Scale	RHI tariffs pence/kWh revised rates	Tariff lifetime in years
Ground source heat pumps		8.7²	20
Air to water heat pumps		2.5	20
Solar thermal	up to 200 kW	10.0	20
Solid biomass¹	up to 200 kW	7.6¹	20
Solid biomass	200-1,000 kW	5.0	20
Solid biomass	over 1,000 kW	2.0	20
Biomethane	All scales	7.5	20

RHI rates published by Ofgem for the year from 1 April 2014 – rates change with inflation each year.

RHI rates for ground source heat pumps fall to 2.6p² for use over 15% of the full annual rated capacity.

RHI rates for medium and small biomass fall to 2.0p¹ for use over 15% of the full annual rated capacity.

Revised rates published in December 2013 apply to accreditations with Ofgem after 21 January 2013.

Table 1 Renewable Heat incentive Rates from April 2014 (11)

There are a number of renewable systems that can be considered unsuitable for New Lanark Village.

Solar PV would not be allowed due to Planning policy for the village

Wing Turbines also fall into the same category.

Micro Combined Heat and Power (CHP) is limited to, 2kW and is of no use for this scheme.

Heat Pumps are already installed and there is little scope for extending this.

Mini Hydro is already available in the village and there could be capacity to extend its use.

Biomass Heating is also a possibility if an existing building could be used to house the equipment without any external modification. The Planning constraints have limited the available choices to two possible areas.

A further constraint is trying to optimize the money available from the Government by careful selection of generation size. From table a 1000kW biomass system receives 5p/kWhr. Rating at 1001kWhr would drop the payment to 2p/kWhr.

2.4 Mini -hydro Scheme in New Lanark.

2.4 1 Background

Energy from flowing water has been harnessed by man for centuries. The principle is that water at a height has potential energy. If it flows to a lower height the potential energy is converted to kinetic energy which in turn can be further converted to mechanical energy.

Early methods were using undershot or overshot water wheels, and today turbines are used.

To maintain a smooth supply of water a river can be dammed to raise its level by holding back a large volume of water. If the flow in the river varies, the supply to the lower level water wheel or turbine can be maintained.

It is considered a sustainable source of energy because the Sun's energy causes water at sea level to evaporate to a higher level and produce rain. In Scotland there is no shortage of rain.

In 1769 Richard Arkwright patented the Water Frame which was a breakthrough in the mechanical production of cotton thread. Before the advent of steam as a source of power, fast flowing rivers were harnessed to drive such machinery. Arkwright was friendly with an industrialist called David Dale, and in 1784 Dale introduced Arkwright to the Clyde at the site of New Lanark. (11) This was an area where two spectacular waterfalls or linns were located, Corra Linn, and further upstream Bonnington Linn. There was also the much smaller Dundaff Linn which they decided to use as the water power source for the proposed new mill site. A weir was built across the Clyde and the water held back directed into a hand built tunnel and mill lade, some 305m long. The mill lade propelled water wheels on each if the mill buildings, and these relayed mechanical power via a system of pulleys, Bevel gears shafts and rods!

This waterpower and the latest mechanical machines allowed New Lanark to quickly grow to be the largest cotton producer in Scotland and take on its English rivals. Arkwright predicted he had found a razor in Scotland to shave Manchester!

Over the years water wheels were replaced by water turbines, and steam power was introduced in 1873. Eventually the water driven turbine was used to generate hydro-electricity.

This first took place in the 1898 when a turbine was used to drive a dynamo. This produced a DC supply to the houses for lighting and was supplied free. Famously the Company did not supply switches to turn the lights on and off. If, through the night lighting was required, say for an emergency, the whole village was illuminated! (12) In 1955 the village was connected to mains electricity, mainly as a result of blown fuses caused by residents connecting ever bigger loads to the free supply.

The last surviving Boving turbine in the village was restored in 1992/3 and was used to provide electricity. (12)It can produce up to 400kW of electricity per hour. This is housed in the basement of Mill 3 fed by the mill lade that was refurbished in the 1990's. (12)

It was originally installed in Mill 3 in 1931 as a replacement for the Laval turbine which was installed 24 years earlier. (12) (New Lanark Power Trail, New Lanark Conservation Trust, 2006 ISBN 0 9522531 4 3).

2.4.2 Mini –hydro Development Schemes Restrictions.

If an extension to the present mini-hydro scheme is to be considered, planning consent will have to be granted as in the previous section.

Environmental Issues for water courses are controlled by the Scottish Environmental Protection Agency (SEPA), who are responsible for issuing a Controlled Activities Regulations (CAR) licence.(13)

Schemes over 500kW normally require an Environmental Impact Assessment (EIA).

It is recommended that Scottish National Heritage and local Angling Clubs are included in discussion at an early stage. This would be part of the Planning Consent process.(14)

2.5 An overview of mini-hydro site types.

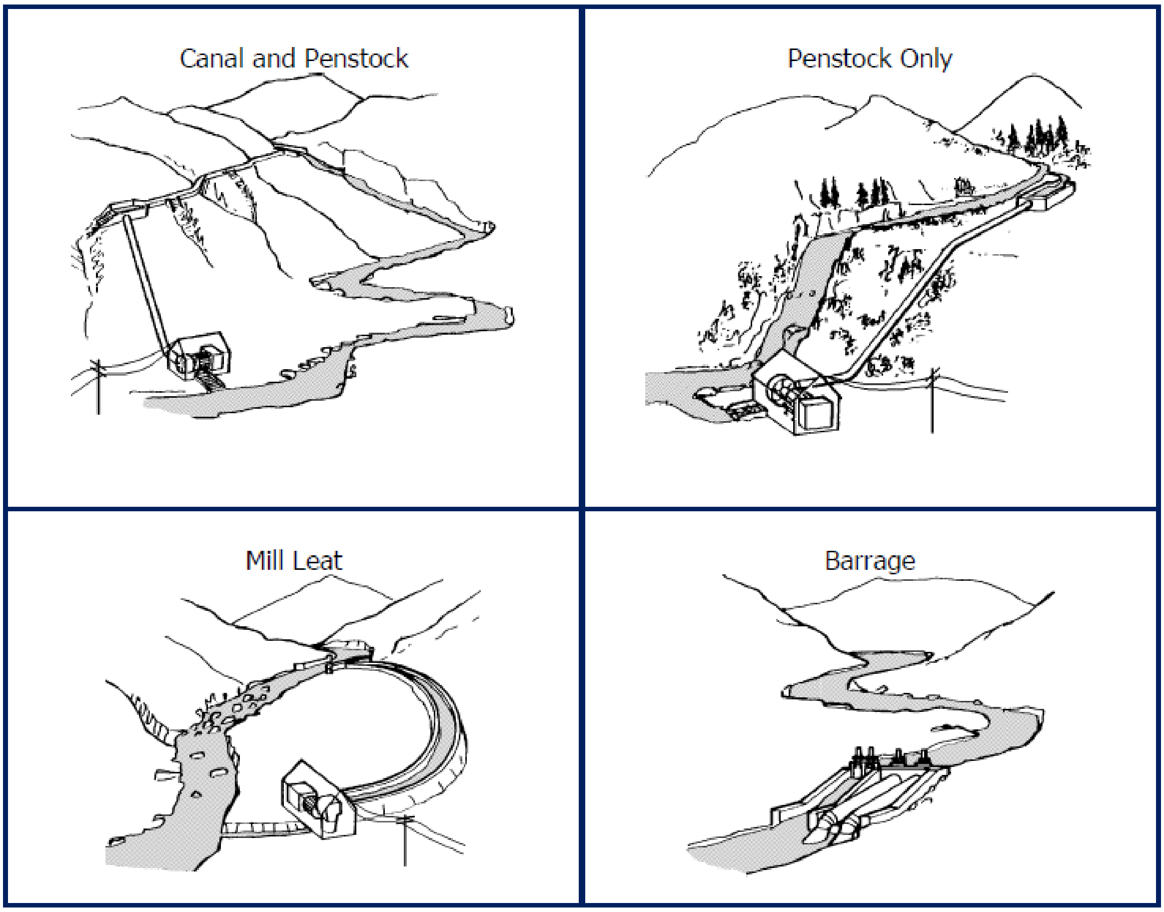


Fig 2 Mini Hydro Site Layout

The above figure gives the four common site layouts for small hydro schemes. The existing system is the Canal and Penstock type. The river is held back by a small weir which stores water to stabilize the flow in the canal or mill lade. The flow is controlled by automatically raising and lowering a sluice gate.

2.6. Calculation of the Power Availability from a head of water.

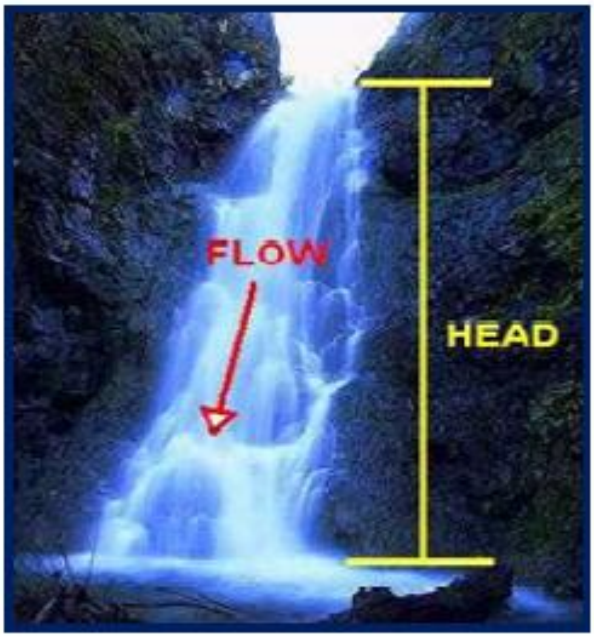


Fig 3 The two important values when estimating the power available from a head of flowing water.

(British Hydro Power Guide to mini-hydro)

Consider a head of water at a height h above the site where energy has to be extracted. A cubic meter of water can be considered to have Potential Energy PE measured in Joules. This can be calculated from the equation:

PE = mass (in kg) x g (acceleration due to gravity in m/s^2) x h (the head of water in m).

So **PE = m.g.h Joules**. (1)

Dividing both sides will give the power in watts since Power is the rate of use of Energy

Power P = (m g h) /t = Mass flow rate (kg/s) . g h Watts

The volume flow rate Q for the water is normally measured and expresses in m^3 / s.

Since a cubic metre of water is equivalent to 1000 litre which weighs 1000kg, the mass flow rate is simply 1000 the volumetric flow rate in m^3/s.

This gives **P = Qgh.1000. Watts** **(2)**

For the case of the Boving Turbine, the head of water was surveyed on Dec 12th 1939 by Babtie, Shaw and Morton for the Gourock Ropework Company. They gave the head of water at Mill 3 as 35 feet or 10.73m.

The flow rate for Mill 3 is set at 6m^3/sec

Using (2) gives **P = 631.6 kW**

The actual output from the system is reduced by the efficiencies of the turbine, the drive mechanism and the induction generator. An efficiency of 65% would be reasonable considering the age of the equipment, giving an output of around 400kW.

This is the quoted figure from The New Lanark Power Trail (12)

A survey carried out by Squrr Energy in Glasgow gave the lade flow as 10.1m^3 /s. (Appendix ?)

This leaves available up to 4m^3/s for further use.

Just as cars and horses vary dramatically depending on what is demanded from them, so does the type of turbine to match the job it is expected to do.

As has been shown, the Site restrictions are :

- The head at 10m
- The flow is 10.1m^3/s less the 6 m^3/s for the present turbine leaving around 4 m^3/s
- The power output should not exceed 500kW for the total scheme leaving a possible new development of only 100kW. This keeps the generation tariff for the whole scheme at a higher level, and an EIA is avoided.

2.7 Turbine Types.

Turbines fall into two main categories, the **Impulse Turbine** and the **Reaction Turbine.**

The Impulse Turbine operates above the water and its blades are subjected to a force when a jet of water is sprayed on to them.

A Reaction Turbine is fully submerged in the water flow. The pressure difference on the turbine blades produce a lifting force on the blades which cause them to turn.

Over the years many different designs have been produced to cater for differing head conditions, flow rates and power output requirements.

The tables below categorises these different types.

Head Classification	Turbine Type		
	Impulse	*Reaction*	*Gravity*
High (>50m)	• Pelton • Turgo		
Medium (10-50m)	• Crossflow • Turgo • Multi-jet Pelton	• Francis (spiral case)	
Low (<10m)	• Crossflow • Undershot waterwheel	• Propeller • Kaplan • Francis (open-flume)	• Overshot waterwheel • Archimedes Screw

Table 2 Turbine Types related to Head of Water

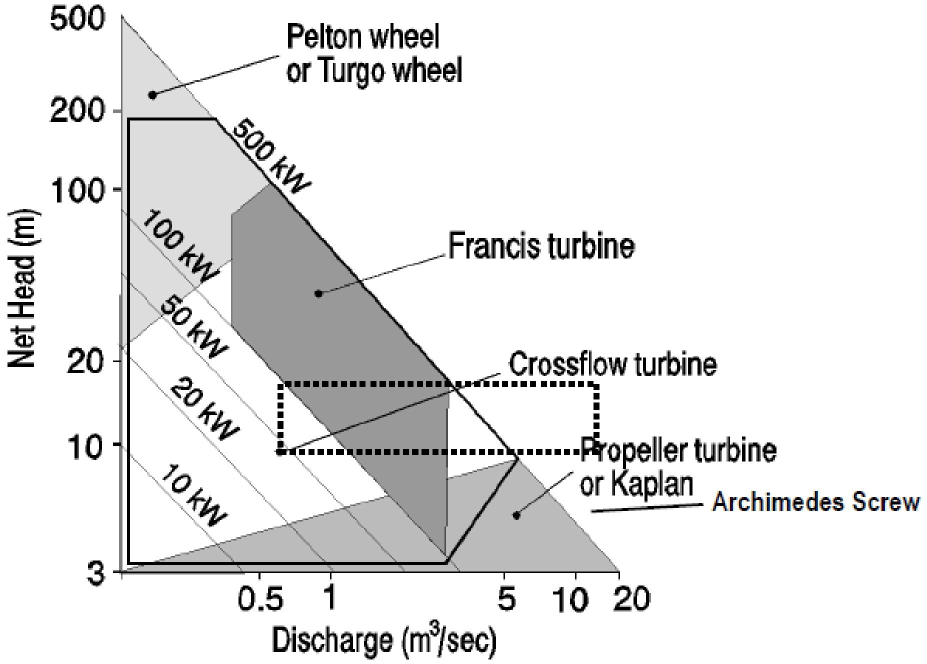


Table 3 Turbine types related to Power, Head and Discharge flow.

The required power output , flow and head of water reduces these choices dramatically, and offers a choice of a Cross flow Turbine or a Francis Turbine. These two are now compared and contrasted.

2.7.1 Cross flow turbines

A cross flow turbine is an example of an impulse turbine. In this class of turbine the momentum of water entering the turbine is directed on to the blades of the turbine, transferring the momentum to the blades and causing the blades to rotate.

Some impulse turbines do so by arranging the water to be forced through jets which produces very high speeds indeed.

A diagram of a Cross flow turbine is shown on Fig ? below.

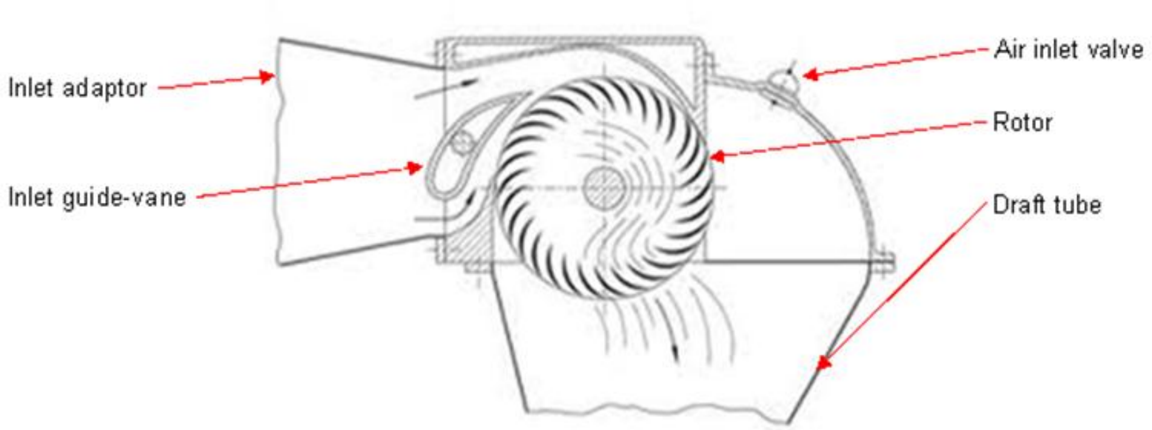
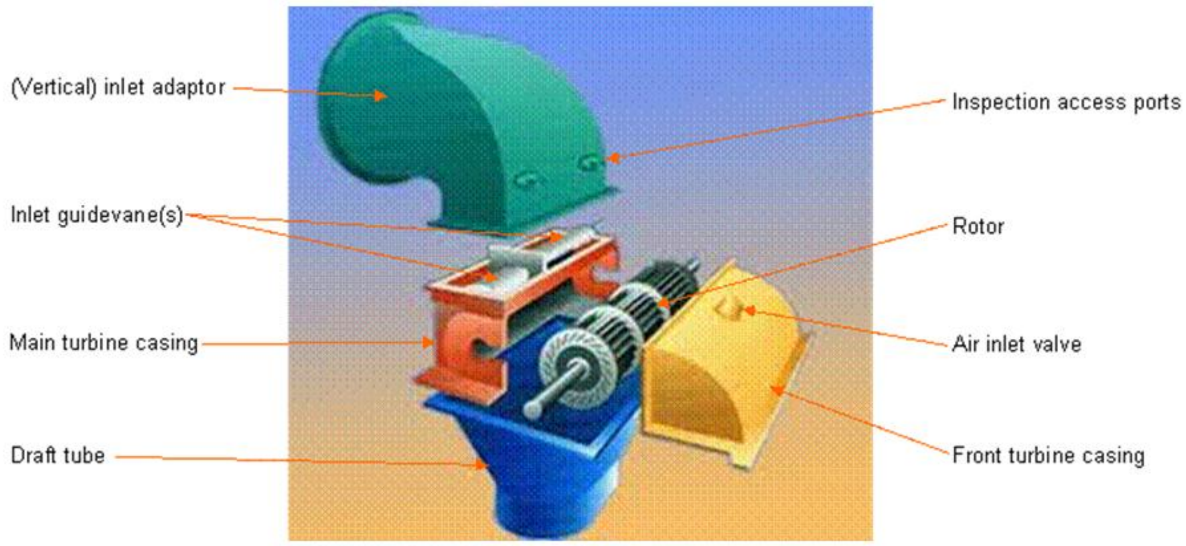


Fig 4 Cross Flow Turbine Schematic

Water is directed onto the curved blades of the turbine using an inlet guide – vane. The water flows around the vane, transferring momentum to the cylinder. It then travels across the turbine where it again flows around a further curved blade before passing into the draft tube and back to the river. (**European Small Hydro Association.** *Guide on How to Develop Small Hydropower Plant.* 2004.)



The air inlet on the front casing is adjusted to let the water in the draft tube drain away from the turbine. Not enough air will cause the turbine to flood. Too much air will alter the suction within the turbine chamber and reduce the efficiency.

Most cross flow turbines have two water feeds, on supplying 1/3 of the width of the turbine, the other the remaining 2/3. This gives control over energy output if the flow rate is reduced or there is an alteration to supply demand.

The Advantages of Cross Flow turbines are:

• Mostly used in Mini and Micro Hydropower production
• Ideal for low head conditions as low as 20 feet of vertical drop
• The flat efficiency curve yields better annual performance than other turbine systems
• Excellent behavior with partial load or low stream flow
• Well suited for unattended electricity production.
• Its construction makes it easier to maintain than other turbine types
• There are only three rotating components
• Almost no turbine noise
• Self-cleaning. No runner cleaning is necessary

• No dam required, simple diversion up stream or any water source meeting the requirements

Fig 5,6 An example of a 100kW cross flow turbine system in a remote school in Papua, New Guinea.

2.7.2 The Francis Turbine.

The Francis turbine is a reaction turbine and operates at higher rotational speeds than the Cross flow turbine. Figure 7 shows the flow of water through the turbine.

(source: adapted from http://lingolex.com/bilc/engine.html & http://starfire.ne.uiuc.edu/~ne201/1996/schoenau/wheel~1.html

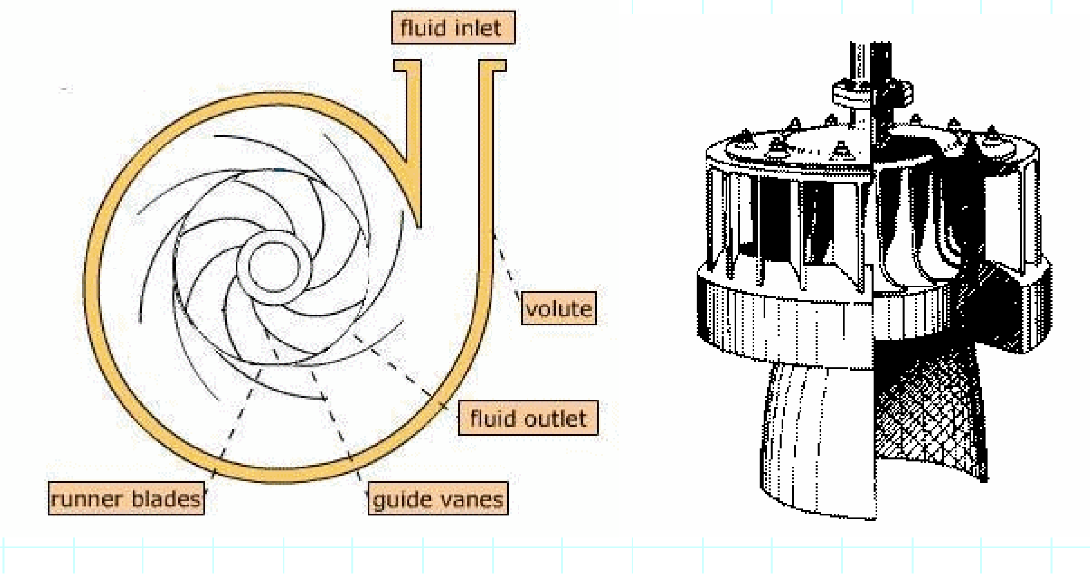


Fig 7. The Francis Turbine Schematic

Water flows radially inward fed from a spiralling inlet. It passes over the blades producing lift in a similar fashion to the wing of an aircraft. The water then leaves the runner and flows axially to the discharge pipe.

One advantage is the Francis turbine's higher speed can allow it to be directly connected to a generator without any speed varying mechanism. Their costs are greater than the Cross flow, due to the expense of making the intricate blades of the runner. The head of 10m available is border line for the Francis. (16)

In 2007 David JT McKenzie wrote "A Layman's Guide to Hydro Electricity in Scotland" and said of the Francis Turbine; " *Since the cross-flow turbine is now a less costly (though less efficient) alternative to the spiral-case Francis, it is rare for these turbines to be used on sites of less than 100 kW output."* (17)

It would appear that the Cross flow turbine would be best suited to address the requirements to extending the use of hydro generation in New Lanark.

2.8 Proposed Turbine Location.

From discussions with Ms Davidson and some Trust Members it seemed an obvious choice to consider the feasibility of locating a Cross flow turbine in the basement of the Mechanics Workshop. There were a number of factors to support this:

- This is one of the few Trust Buildings where the electricity is purchased by the lessee direct from a supplier. There is insufficient electricity being produced by the hydro scheme to supply the load for the electric storage heating.
- Current costs for heating are high.
- The building is typical in style and size of others in the village.
- Some years ago the hydro extension was professionally surveyed and costed.
- At that time there were reservations on cost and gaining access to the basement.

Using the Mechanics Workshop as a model to be analysed would allow a Biomass system to be considered and a feasibility study carried out for this second form of heating. This would enable a direct comparison between the two method.

2.8.1 The Mechanics Workshop.

Images of the Mechanics Workshop, New Lanark.

Left. Looking North.

Below. Looking West.

Fig 8, 9. The Mechanics Workshops

The Mechanics Workshop is a two story building and a basement. The basement is empty, and the upper two stories have a combined floor area of about $1000m^2$. They are presently rented to I&A Stewart Ltd, a firm of Chartered Accountants. The building has medium insulation, single glazed windows, and has an average occupancy of around 26 people.
It is used 5 days a week between the hours of 8am till 6pm.
Currently the heating employed is electric. They operate 11 x6kW heaters and 7x 4kW heaters, a peak load for heating of 94kW.

The electricity is supplied direct from Scottish Power, since the present hydro generated village supply was considered unable to cater for such an extra load. The annual bill varies from between £20,000 and 25,000 depending on the severity of the winter.

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Fig 10. The Mechanics Workshop

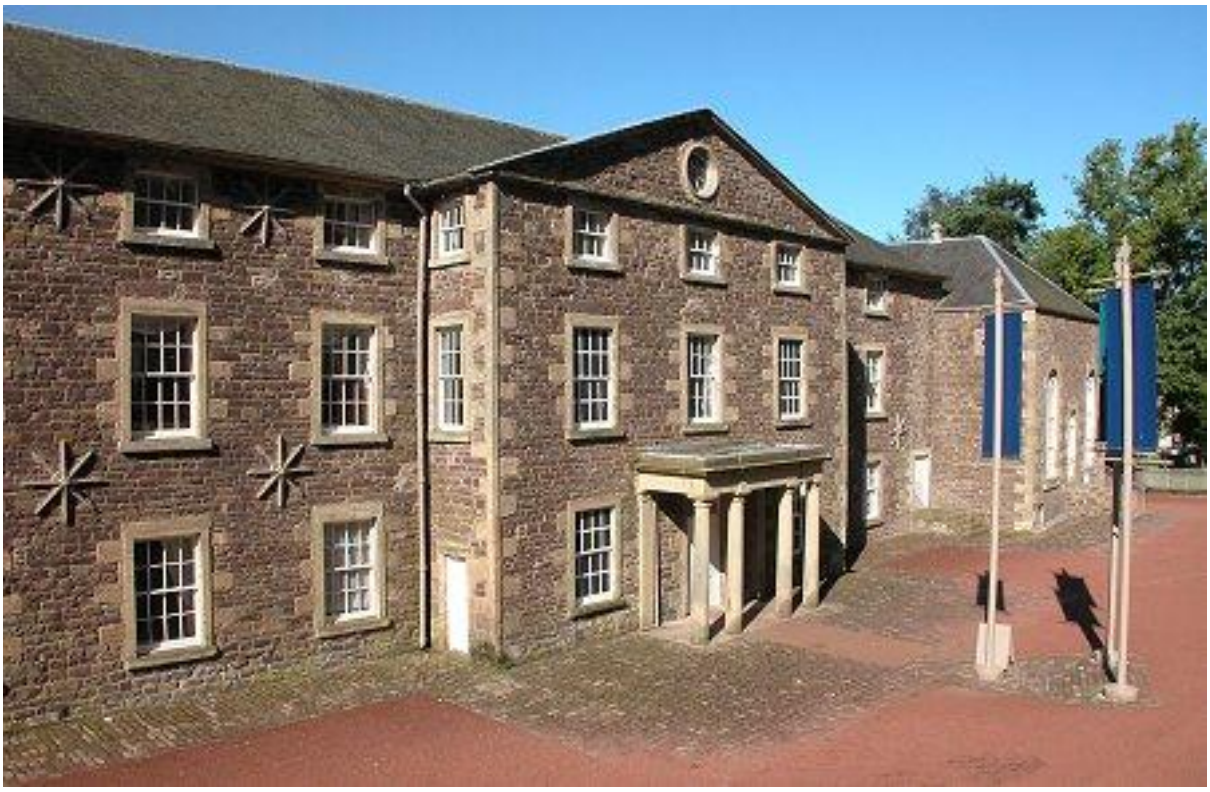


Fig 11.The Visitor Centre (Note the similarity with the Mechanics Workshop)

2.9 Biomass Heating.

2.9.1 Background.

All living matter stores solar energy as it grows. Plants do this by a process of photosynthesis. Animals will eat certain plants and obtain the energy contained in them. This in turn allows the animals to grow.

The energy stored in animals can be passed to others. Humans and other animals will hunt each other and as the prey is consumed the energy is passed to the predator.

Energy can be extracted from once living matter by burning (combustion), distillation, fermentation, or biologically. It follows that recently living matter can be a useful source of energy, as long as it can be demonstrated to be sustainable, carbon neutral and cost effective.

2.9.2 Scottish Government Energy Strategy and Biomass.

The Scottish Government is keen to support Biomass Heating systems as part of their drive to reach a target of 11% of all heating demand supplied by renewables by 2020.

In a presentation on Biomass Policy in Scotland given on 2nd June 2011 by Paul Smith, Directorate for Renewable Energy and Climate Change, the Government position was reinforced.

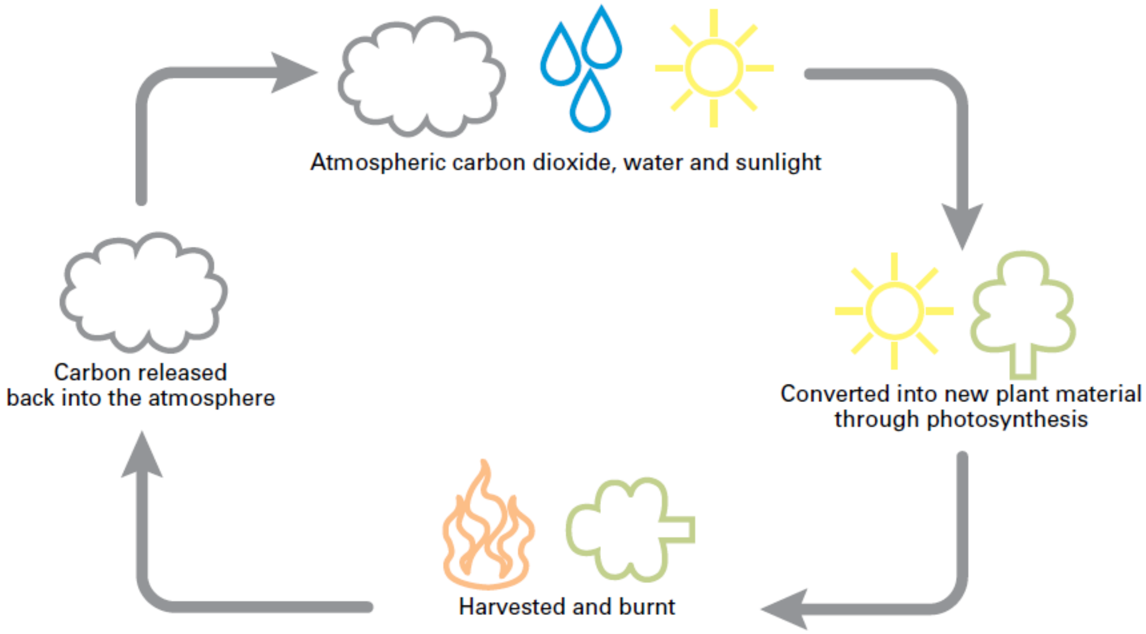
- Key to meeting renewable heat target
- –Currently provides 91% of Scotland's Renewable Heat Output
- •Deployment of biomass is increasing but significant progress is still required
- •Biomass policy and support need to encourage most efficient and beneficial use of this finite resource

- The target is sustainable economic growth
- Biomass has a large role to play and will be crucial in meeting renewable heat targets
- Commitment to supporting biomass but also to review support for large scale electricity only
- RHI Offers enormous opportunities for the biomass sector and will increase demand for wood fuel –making it a more commercially attractive product –grasp the opportunity!

2.9.3 Biomass Wood burning as a low carbon source of fuel.

When trying to recover the energy locked away in biomass material, Carbon Dioxide is released.

The following figure shows how the CO_2 released during burning is converted into new plant material as new wood grows due to sunlight, water and CO_2. Fossil fuels on the other hand release CO_2 which was captured thousands of years ago, and this has been thought by many to have contributed to climate change.



The Carbon Trust is quick to point out that such a model is not the complete story. CO_2 emissions are further generated by the transportation of the fuel, the harvesting, and the servicing of the equipment involved in the process.

None the less it is considered a low carbon source of energy, therefor supported by the Government and no doubt acceptable to New Lanark Trust.

2.9.4 Sustainability of Wood as a biomass source.

The Oxford Dictionary gives two definitions of 'Sustainable'. One is *'Able to be maintained at a certain rate or level'*

The second is '*Conserving an ecological balance by avoiding depletion of natural resources'*.

Fossil fuels are sustainable if the rate they were being used was low enough to keep the balance in check. This does not happen since fossil fuel such as oil and coal take thousands of years to form.

Wood does grow quickly and if the rate it is used as an energy source balances with the production of new wood then wood can be classed as sustainable.

In a paper produced by Phochara Bhumichitr in 2013, the sustainability of Biomass Heating in Scotland was examined in detail. The conclusion is that by 2020 Scotland's wood supply will not be sustainable if the targets for renewable energy were to be met (18) The Scottish wood fuel taskforce report to the Scottish Government looked at projected supply and demand figures for wood. They recommended not to use wood in large scale production of

electricity, and to concentrate its use in hot water heating, a stance the Government appears happy to take. (Wood Fuel Task Force 2 Report March 2011).
It would therefor appear the Biomass Heating scheme proposed would be considered sustainable. (19)

2.9.5 Restrictions and Constraints concerning Biomass Energy Production.

Creating a new Biomass Scheme faces more constraints than simply extending an existing hydro scheme. These can be summarised as follows:

- Planning Constraints as already described.
- Environmental Regulation. Combustion produces pollutants which have to be limited.
- A Chimney is required and the height must conform to guidelines.
- A place will be needed to store the boiler and the associated fuel. An existing building will have to be found capable of matching the requirements.

2.9.6 Accommodating the Technology and Financial Implications

This is crucial to the project due to the restriction in altering the building chosen to house the equipment. Luckily the Carbon Trust have a Biomass Boiler System Sizing Tool which gives access to such information. Just how this has been carried out will be discussed in detail in the next section. Indicative cost projections can also be obtained. (20)

2.9.7 Chimney Height.

When biomass fuels are burnt to produce heat, by products are produced and leave the system via a chimney stack. These pollutants increase levels of background pollution at ground level, and different countries set limits on these levels. The higher the chimney height, the less intense the pollution becomes at ground level, due to dispersal as the pollutants fall.
Normally New Lanark could not build such a structure. Fortunately there is a solution
At the southerly end of New Lanark the Retort House remains as a building used for storage. Built next to Dundaff Linn in the early 19th century the building was used to convert coal into gas. The coal came from Rigside some six miles away, and the gas was used for lighting. Prior to this whale oil lamps and tallow candles were used and these were considered responsible for some of the disastrous fires that occurred on several occasions. The first was Mill No 1 in October 1788, and Mill No 3 in November 1819.

Fig 12   The Retort Building with Dundaff Linn behind

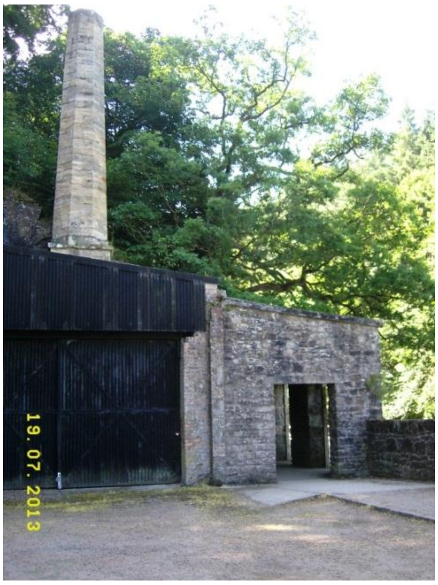


Fig 13   The Chimney as it is today.

(Note the unusual octagonal shape)

2.9.8 Biomass Fuels.

Biomass fuels are available in many forms. The best known type is wood, which is available from many sources. Virgin Wood usually comes from forestry, while wood processing units have by products that can be used for fuel. Energy crops such as willow and eucalyptus are popular , as are oil crops (rape, linseed and sunflower)

Slurry and industrial residues can also be used, and food residues also make a contribution

The transportation of biomass fuels adds to the carbon footprint of the supply, so it is important to source fuel as locally as possible.

The Carbon Trust have produced a practical guide for potential users and reproduced below is a table showing typical fuels and how they are commonly used. (21)

Fuel format	Utilisation
Logs	Most commonly used in small-scale systems (<50 kW_{th} – domestic to light commercial scale) requiring daily input to load the system with fuel.
Bales	Generally either manually fed 'batch-firing' systems below 300 kW_{th} (as above, requiring daily input to load the system with fuel) or alternatively very large (multi-MW_{th}), automatically-fed heating/CHP plant.
Chipped/shredded wood	Typical fuel for most automated biomass systems (50 kW_{th} – multi-MW_{th} applications).
Pellets	Most commonly used in smaller or urban systems (light commercial <150 kW_{th}) due to their greater energy density (at larger scales the higher cost of wood pellets compared to woodchip becomes significant). Wood pellets are also used for 'co-firing' within existing electricity power stations.
Woodworking off-cuts/ sawdust	Some biomass plant is specifically designed to burn co-products from the wood industries such as furniture off-cuts and sawdust.
Cereals/grains	Some biomass plant can burn common agricultural commodities such as oats and spent grain.

Table 4. Fuel format versus Utilisation

Important aspects of biomass fuels are its chemical content, its moisture content how much ash does it produce and how mechanically durable it is

Also of high importance is the calorific value of the fuel. Again this information is available from the Carbon Trust Guide.

Fuel	Net CV1 MJ/kg	CV kWh/ kg	Bulk density kg/m^3		Energy density by volume MJ/m^3		Energy density by volume kWh/m^3	
			Lower	Upper	Lower	Upper	Lower	Upper
Woodchips @ 30%	12.5	3.5	200	250	2,500	3,125	694	868
Log wood (stacked – air dried: 20%MC)	14.6	4.1	350	500	5,110	7,300	1,419	2,028
Wood – solid oven dried	18.6	5.2	400	600	7,440	11,160	2,067	3,100
Wood pellets	17	4.7	600	700	10,200	11,900	2,833	3,306
Miscanthus (bale – 25%MC)	12.1	3.4	140	180	1,694	2,178	471	605
House coal	29	8.1	850		24,650		6,847	
Anthracite	32.1	8.9	1,100		35,310		9,808	
Oil	41.5	11.5	865		35,898		9,972	
Natural gas	-	-	-		36		10.13	
LPG	46.9	13.0	500		23,472		6,520	

Source: Gastec at CRE Ltd. and Annex A, Digest of UK Energy Statistics 2007

Table 5 Heat and Physical Density of different Fuel Types

2.9.9 Types of Biomass Plant.

Biomass Plant is normally classified by the way the fuel is passed into and through the burner.

Moving Grate plant. In this type fuel is fed into the boiler by means of an auger. The floor of the burner sloes downward and is made up of several sections which moves in sequence towards the bottom of the burner. They are able to cater for fuel with a very high moisture content and are normally used for the higher end load operation, 300kW-1MW
Below is a diagram of the layout of a moving grate system and a table giving the advantages and disadvantages of this type of boiler.

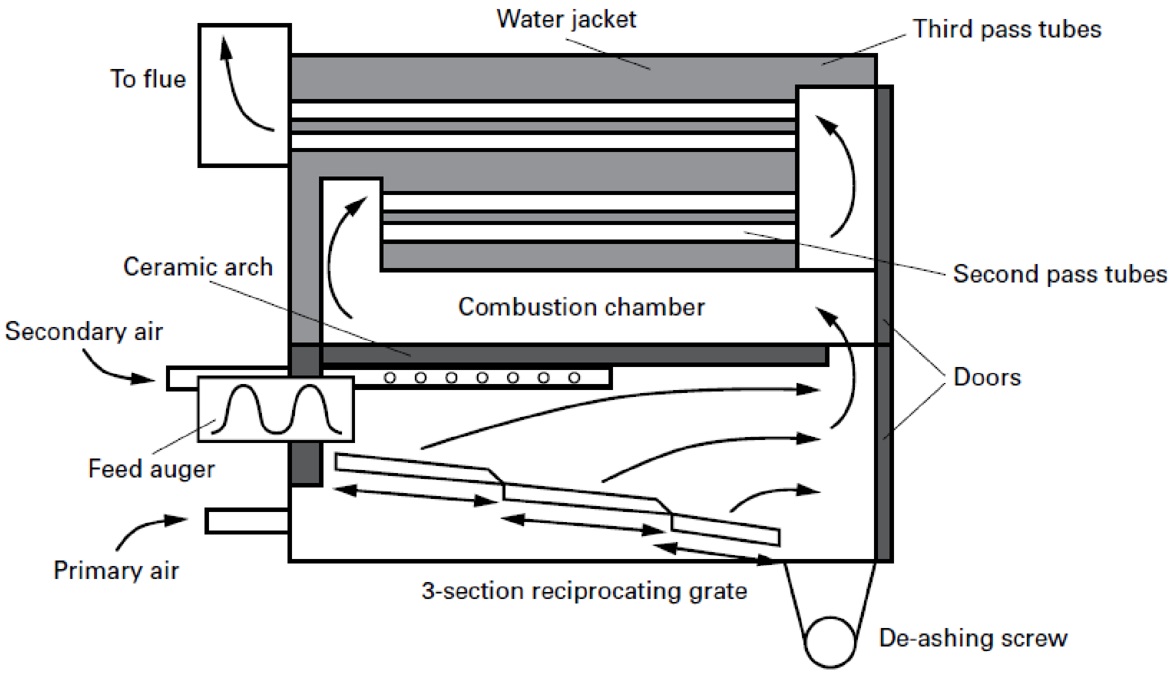


Fig 14 Moving Grate Boiler

Advantages	Disadvantages
• Wide tolerance of fuel type, moisture content (up to 60%), and particle size. • As a result of wide fuel tolerance, cheaper fuel may be procured, helping to offset higher capital cost. • Positive movement of fuel down grate avoids clinkering and blockages. • Well-regimented combustion leads to high efficiency.	• Relatively large fuel inventory in the plant leads to a slow response to load swings, although modulating controls improve controllability. • Large amounts of refractory (heat reflective) material on wet wood plants can result in a long warm-up time from very low to full-load (up to 2 hours). • Prolonged low-load mode operation can result in higher maintenance costs and reduced efficiency as a result of tarring of heat exchangers and condensing gases. • More complex design and bulky components can lead to higher capital costs.

Table 6 Moving Grate Advantages and Disadvantages

Underfed Stoker Systems.

These systems feed the fuel from underneath the boiler using an auger. The wood passes through a domed area where it dries and then splays into the burning area. They commonly use wood pellets or woodchips. Output is between 25- 300kW.

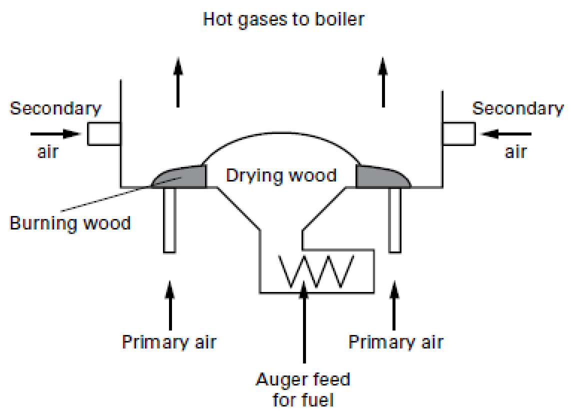


Fig 15 Underfed stoker system

Advantages	Disadvantages
• A smaller combustion area and less refractory material means that these types of plant have a smaller spatial footprint. • Commonly dual fuel plants, therefore providing flexibility of operation[41]. • In total capital cost terms (£/kW, installed) they are cheaper than the moving grate systems due to the simpler design and exclusion of refractory material.	• Due to the smaller combustion bed, the plant require lower fuel moisture content – typically 20-35% – rising to 40% if the plant has some refractory material lining the combustion chamber. • Due to the smaller combustion bed and lower moisture content tolerances, these systems require consistently good quality fuel. As a result they are best suited to applications where site owners are confident of securing good quality fuel (<35% MC).

Table 7 Advantages and Disadvantages with Underfed Stoker System

Stoker Boilers

The third popular area is the stoker boiler. In this system an auger feeds the fuel in from the side and through a drying area,. Beyond this the fuel is burned and the ash falls out the far end. Cast iron liners reflect the heat. Heat output is typically 30-500kW. This type of system is less expensive than the previous two, due to its simple structure.

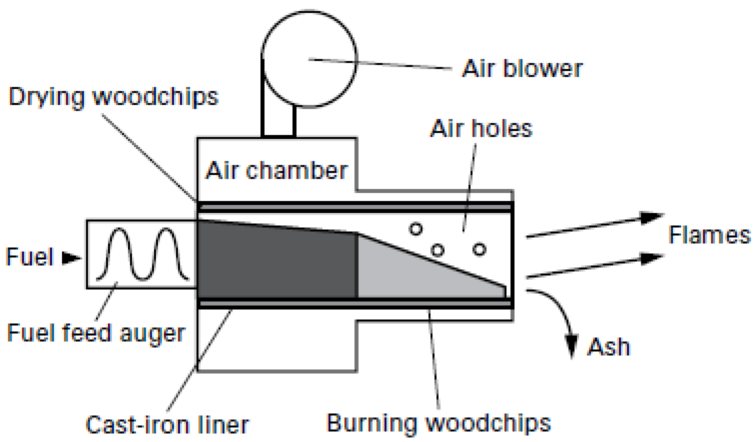


Fig 16 Stoker Boiler

Advantages	Disadvantages
• Small fuel inventory makes for relatively rapid response to load swings. • The heat generated on slumber (when there is no heat requirement and the unit is simply maintaining ignition with as little heat output as possible) is very low. • Often lower cost than plane grate or moving grate systems.	• The fuel must be fairly dry: preferably <30%, never more than 35%. • The fuel particle size and moisture must be consistent: the small, intense combustion zone is easily disrupted. • In the lowest cost, smaller units, no separate provision for primary and secondary air supply exists, limiting the opportunity for fine-tuning to the needs of varying fuel.

Table 8 Advantages and Disadvantages of a Stoker System

3 Analysis of Sustainable and Renewable Energy in the Mechanics Workshop.

3.1 Mini Hydro System.

Analysis of Income and Expenditure over a 20 year period.

The analysis was carried out using an Excel spread sheet.

The costs were taken as outlined in the guide on small hydro from the British Hydro Association, shown in the table below. (22)

	Low head	High head
	£1000s	*£1000s*
Machinery	100 – 200	100 – 150
Civil works	100 – 250	80 – 150
Electrical works (no grid connection)	30 - 50	30 – 50
External costs	20 - 50	20 – 50
Total:	**250 – 500**	**230 – 400**

Table 9 Costs for a mini hydro system

The costs estimate was:

Machinery	£200,000 (Top end of range)
Civil Works	£50,000 (Mill lade , outflow and weir in place)
External costs	£25,000 (Mid way option)
Electrical Works	£25,000 (There is already electrical connection)

The generated income was based on 100kW being generated for a full year.

£1,000 a month was chosen as the cost of maintenance

The inflation rate for FIT was based on the Retail Price Index, currently 2.4%

Interest rates are currently low but expected to rise, so 10% was chosen.

Inputs		Outputs over 20 YEARS	
Capital investment	£300,000	**Total interest paic**	-£69,881
Operating costs	£12,000	**Total tax paid**	£1,735,647
Inflation rate	2.500	**Total generated income**	£5,290,493
Tax rate	35.000	**Total operating co**	£388,188
Interest Rate	10.000	**Loan** pay back tim	6
Percentage of payback from net profit	100.000	**Total** net Profit	£3,223,345
		Capital repaid	£415,117
Generated Income	£143,595	Project surplus	£2,808,227

After year	Investmen balance	Interest d	Op Expend	Total expenditur	Generation Income	Gross Profit	Tax due	inflatic 2.5	tax rate 35	interest ra 10.000	Net Profit	Capital repaymen	percent profits payback	interest multiplie 0.1
1	£330,000	£33,000	£12,000	£45,000	£143,595	£98,595	£34,508	2.5	35	10.000	£64,087	£64,087	100	0.1
2	£265,913	£26,591	£12,300	£38,891	£147,185	£108,294	£37,903	2.5	35	10.000	£70,391	£70,391	100	0.1
3	£195,522	£19,552	£12,608	£32,160	£163,472	£131,313	£45,959	2.5	35	10.000	£85,353	£85,353	100	0.1
4	£110,169	£11,017	£12,923	£23,940	£167,559	£143,620	£50,267	2.5	35	10.000	£93,353	£93,353	100	0.1
5	£16,816	£1,682	£13,246	£14,927	£171,748	£156,821	£54,887	2.5	35	10.000	£101,934	£101,934	100	0.1
6	-£85,117	-£8,512	£13,577	£5,065	£176,042	£170,977	£59,842	2.5	35	10.000	£111,135	£0	0	0.1
7	-£85,117	-£8,512	£13,916	£5,405	£180,443	£175,038	£61,263	2.5	35	10.000	£113,775	£0	0	0.1
8	-£85,117	-£8,512	£14,264	£5,753	£184,954	£179,202	£62,721	2.5	35	10.000	£116,481	£0	0	0.1
9	-£85,117	-£8,512	£14,621	£6,109	£189,578	£183,469	£64,214	2.5	35	10.000	£119,255	£0	0	0.1
10	-£85,117	-£8,512	£14,986	£6,475	£194,317	£187,843	£65,745	2.5	35	10.000	£122,098	£0	0	0.1
11	-£85,117	-£8,512	£15,361	£6,849	£199,175	£192,326	£67,314	2.5	35	10.000	£125,012	£0	0	0.1
12	-£85,117	-£8,512	£15,745	£7,233	£204,155	£196,921	£68,923	2.5	35	10.000	£127,999	£0	0	0.1
13	-£85,117	-£8,512	£16,139	£7,627	£209,259	£201,632	£70,571	2.5	35	10.000	£131,061	£0	0	0.1
14	-£85,117	-£8,512	£16,542	£8,030	£214,490	£206,460	£72,261	2.5	35	10.000	£134,199	£0	0	0.1
15	-£85,117	-£8,512	£16,956	£8,444	£219,852	£211,408	£73,993	2.5	35	10.000	£137,415	£0	0	0.1
16	-£85,117	-£8,512	£17,380	£8,868	£225,349	£216,481	£75,768	2.5	35	10.000	£140,713	£0	0	0.1
17	-£85,117	-£8,512	£17,814	£9,302	£230,982	£221,680	£77,588	2.5	35	10.000	£144,092	£0	0	0.1
18	-£85,117	-£8,512	£18,259	£9,748	£236,757	£227,009	£79,453	2.5	35	10.000	£147,556	£0	0	0.1
19	-£85,117	-£8,512	£18,716	£10,204	£242,676	£232,472	£81,365	2.5	35	10.000	£151,107	£0	0	0.1
20	-£85,117	-£8,512	£19,184	£10,672	£248,743	£238,071	£83,325	2.5	35	10.000	£154,746	£0	0	0.1
21	-£85,117	-£8,512	£19,663	£11,152	£254,961	£243,810	£85,333	2.5	35	10.000	£158,476	£0	0	0.1
22	-£85,117	-£8,512	£20,155	£11,643	£261,335	£249,692	£87,392	2.5	35	10.000	£162,300	£0	0	0.1
23	-£85,117	-£8,512	£20,659	£12,147	£267,869	£255,722	£89,503	2.5	35	10.000	£166,219	£0	0	0.1
24	-£85,117	-£8,512	£21,175	£12,664	£274,565	£261,902	£91,666	2.5	35	10.000	£170,236	£0	0	0.1
25	-£85,117	-£8,512	£21,705	£13,193	£281,430	£268,237	£93,883	2.5	35	10.000	£174,354	£0	0	0.1

If all the income was used to pay off the loan, the scheme would be in profit after 6 years.

Taking 50% of the profit to pay back capital would leave the project in profit after 9 years.

Capital investment	£300,000	Total interest paid	£124,122
Operating costs	£12,000	Total tax paid	£1,665,445
Inflation rate	2.500	Total generated income	£5,290,493
Tax rate	35.000	Total operating co	£388,188
Interest Rate	10.000	Loan pay back tim	9
Percentage of payback from net profit	50.000	Total net Profit	£3,092,970
		Capital repaid	£349,384
Generated Income	£143,595		
		Project surplus	£2,743,586

3.2 Crucial Influences on Cost Analysis.

There are two major influences in the above model. The first is the expected generated income, and the second is the issue of supply sustainability.

- Generated Income. The above values were based on the figures available from the Government in 2014. The current tariff for generation is 14.03p/kWhr guaranteed for 20 years from the date the scheme is accepted. The export tariff is indexed linked annually. From 2014 it is currently set at 4.77p/kWhr. This is based on hydro power in the village not exceeding 500kW
- Water supply according to SEPA figures would appear to be good. They give details of current river levels for the Clyde and an example is shown below. Tulliford is

upstream from New Lanark.(23)

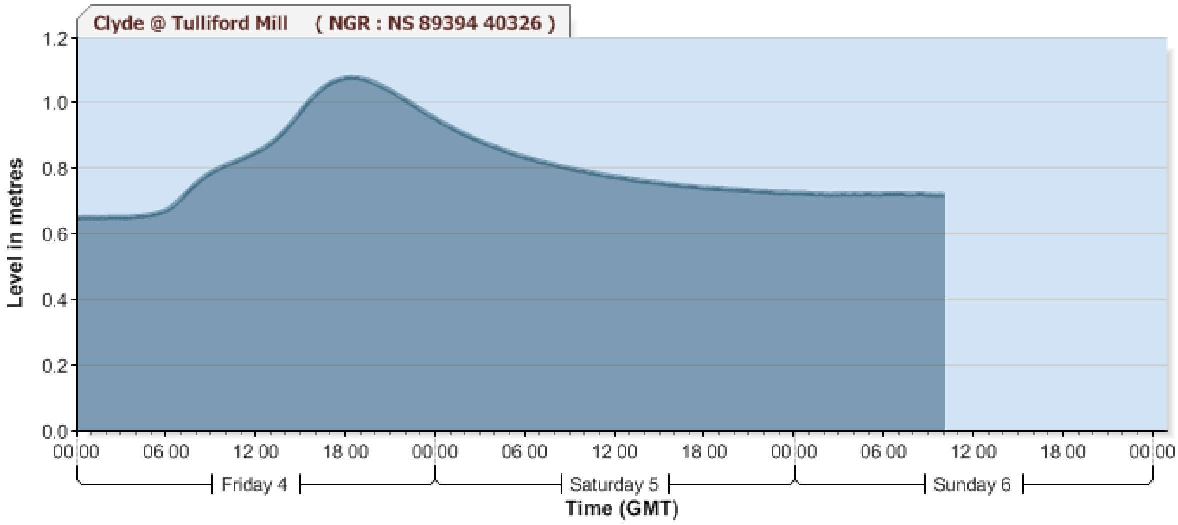


Table 10. River Clyde level near New Lanark Sunday 6th July 2014.

Time (GMT)

Station Name	Clyde@Tulliford Mill
Level Data (.csv)	Click here
Gauge Datum (mAOD)	173.7
Catchment Area (km2)	933
Record Start Date	January, 1969
Highest Level on Record	2.844 m @ 12/12/1994 05:45
Lowest Level on Record (m)	0.321
Average Level on Record (m)	0.584
National River Flow Archive Link	Click here
SEPA Hydrology Office	East Kilbride
Comments	

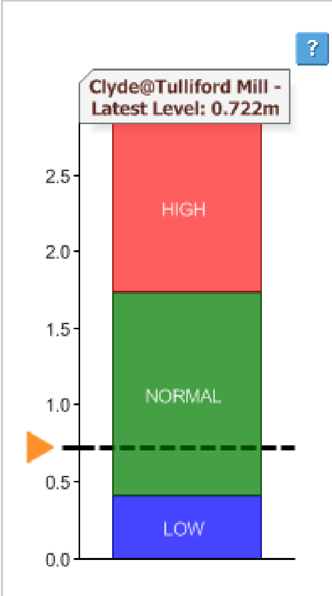


Table 11 Historical River Clyde levels.

The above data is from Tulliford Mill about 1.5 miles upstream from New Lanark . It shows a plentiful supply of water even when it reached its lowest level of 0.321m over the last 45 years. The data shown refers to information for three days in April 2014.

There is also an issue with the Power Station at Bonnington, about a mile upstream from New Lanark. If this station is switched off for any reason, the water supply to the turbines is closed at the head of the feed. Water returning to the river from the outflow of the station ceases, and is only replaced when the level at the weir rises sufficiently to flow over the top. This can take between 35 to 45 minutes to occur and water available for the hydro scheme at New Lanark can disappear, causing it to close down. In some conditions Bonnington can trip out several times in a day. Admittedly such occasions are rare and unpredictable, but inevitably these impinge on the generated annual income in the village.

If river levels are low, diverting 10cubic metres per second via the village hydro scheme can leave the river almost empty over the 1km section between the head sluice at the Dundaff weir , and the lade output by the hotel. To protect river life the New Lanark system is stood down and the hydro water left in the Clyde. It is estimated that such outages could reduce the overall potentially generated income by about 1%

The impressive pay- back time and the substantial profits generated over the 20 years of the incentive period would suggest such a scheme should be given immediate consideration before the rates are reduced as time passes.

The FIT would stem and would apply for such an installation as it would not affect the existing arrangement in place. It would be considered a separate system and would have its own eligibility period . Extensions to FIT accredited installations

2.69. Where a FIT installation is extended using the same technology type, the extension is assessed as a separate Eligible Installation. If successfully accredited, the extension will be assigned a separate eligibility period and separate tariff code based on the aggregate TIC of both the extension and existing FIT installation[35]. In this situation, the eligibility date and the eligibility period of the extension will be based on the commissioning date of the extension. The original installations eligibility date, tariff, and eligibility period will not be affected. Both installations will, however, share the same FIT ID[36] on the Central FIT Register (CFR) - the register on which all installation details are stored.

(Department of Energy and Climate Change April, 2013) (28)

There is also another advantage. The Accountant Firm leasing the building from the Trust buy their Electricity from Scottish Power and pay £20,000 - £25,000 a year. It mainly drives a number of storage heaters. If the lease was increased by £12,500 a year but electricity was supplied by the Trust, this too could add to the value of the project.

Finally the existing storage heaters could be retained, causing the minimum disruption to the users of the building.

3.3 Conclusion

The hydro extension would appear to offer everything that the Trust could wish for. The ability to supply electricity to a large building would enhance its reputation as an environmentally friendly body. The revenue earned over the 20 years period could be

invested in further extension to the scheme or for installing other forms of heating that may suit the building better. Hydro generation is very clean, highly sustainable and reliable. It brings part of the historical power system back into use.
Hydro equipment has a long life, often in excess of 80 years, and requires low level maintenance.
The drawback is normally the high cost of construction work involved in capturing then transmitting the water. In this particular case the infrastructure is in place

4. Biomass System Analysis.

4.1 Establishing the Minimum Chimney height.

Introduction.

When biomass fuels are burnt to produce heat, by products are produced and leave the system via a chimney stack. These pollutants increase levels of background pollution at ground level, and different countries set limits on these levels. The higher the chimney height, the less intense the pollution becomes at ground level, due to dispersal as the pollutants fall.
The EU Waste Incineration Directive, Article 5 quotes: "Incineration and coincineration plants shall be designed, equipped built and operated in such a way as to prevent emissions into the air giving rise to significant ground-level air pollution, in particular exhaust gases shall be discharged in a controlled fashion and in conformity with relevant Community air quality standards by means of a stack the height of which in calculated in such a way as to safeguard human health and the environment".

(*Directive 2000/76/EC of the European Parliament and of the Council of 4 December 2000 on the incineration of waste*, Official Journal L 332.

According to DEFRA (Department for Environment, Food and Rural Affairs) a recommended method of calculation of chimney heights is available in a 1993 guidance note:

HMIP 1993 *'Guidelines on Discharge Stack Heights for Polluting Emission. Technical Guidance Note D1 (Dispersion)' ISBN 0 11 752794 7. This document is now out-of-print, but is available from the British Library. It provides a simple but versatile method for calculating the minimum permissible chimney height to safeguard against short-term air quality impacts, for any pollutant species. It allows for building downwash effects but not terrain effects.*

There is at present no universal standard for defining chimney stacks, different countries having different methods for producing guidelines. The European Union has set targets for background levels of pollution thresholds.

CEC (Commission of the European Communities), 2008*: Directive 2008/50/EC of the European Parliament*
and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe. Official Journal of the European Union, L152, 1-44.

These levels are shown in Table 12

Some of these limits have since been revised downwards, eg the present levels for Pm10 has dropped from 0.05 mg/m3 to 0.03mg/m3.

In Biomass boilers using wood pellets as a fuel, the four main pollutants are oxides of Nitrogen, Carbon Monoxide, Sulphur Dioxide and Particulate matter. Sulphur Dioxide emission tends to be very low and is often disregarded.

These pollutants can be reduced by introducing mitigating features, so good design is essential when planning to install a biomass boiler.

Background levels of pollutants were estimated for New Lanark based on the readings made in nearby Lanark. (www.scottishairquality.co.uk). These only record NO_2 at a location in the town centre at a junction controlled by traffic lights. The mean level of approx. 0.08mg/m3 was halved for New Lanark, giving pollutants of one fifth of the guideline limits.

Background levels for New Lanark were defined as follows:

NO_2	0.04 mg/m3
CO	2 mg/m3
Particulates	0.006 mg/m3

Table 12 Back ground levels of pollution New Lanark

Table 1 Air quality target and limit values for air pollutants under EU legislation

Pollutant	Concentration	Averaging period	Legal nature	Permitted exceedances each year
PM2.5	25 $\mu g\ m^{-3}$	1 year	Target value entered into force 2010-01-01, limit value enters into force 2015-01-01	Not applicable
SO_2	350 $\mu g\ m^{-3}$	1 hour	Limit value entered into force 2005-01-01	350 $\mu g\ m^{-3}$ not to be exceede 24 hours per year
	125 $\mu g\ m^{-3}$	24 hours	Limit value entered into force 2005-01-01	125 $\mu g\ m^{-3}$ not to be exceede 3 days per year
NO_2	200 $\mu g\ m^{-3}$	1 hour	Limit value entered into force 2010-01-01	200 $\mu g\ m^{-3}$ not to be exceede 18 hours per year
	40 $\mu g\ m^{-3}$	1 year	Limit value entered into force 2010-01-01	Not to exceed an annual avera of 40 $\mu g\ m^{-3}$
PM10	50 $\mu g\ m^{-3}$	24 hours	Limit value entered into force 2005-01-01	50 $\mu g\ m^{-3}$ not to be exceeded 35 days per year
	40 $\mu g\ m^{-3}$	1 year	Limit value entered into force 2005-01-01	Not to exceed an annual avera of 40 $\mu g\ m^{-3}$
Pb	0.5 $\mu g\ m^{-3}$	1 year	Limit value entered into force 2005-01-01 (or 2010-01-01 in the immediate vicinity of specific, notified industrial sources; and a 1.0 $\mu g\ m^{-3}$ limit value applied from 2005-01-01 to 2009-12-31)	Not to exceed an annual avera of 0.5 $\mu g\ m^{-3}$
CO	10 $mg\ m^{-3}$	Maximum daily 8-hour mean	Limit value entered into force 2005-01-01	Not to exceed a maximum dai 8-hour mean of 10 $mg\ m^{-3}$
C_6H_6	5 $\mu g\ m^{-3}$	1 year	Limit value entered into force 2010-01-01	Not to exceed an annual avera of 5 $\mu g\ m^{-3}$
O_3	120 $\mu g\ m^{-3}$	Maximum daily 8-hour mean	Target value entered into force 2010-01-01	Maximum daily 8-hour mean 120 $\mu g\ m^{-3}$ not to be exceede 25 days averaged over 3 years
As	6 $ng\ m^{-3}$	1 year	Target value entered into force 2012-12-31	Not to exceed an annual avera of 6 $ng\ m^{-3}$
Cd	5 $ng\ m^{-3}$	1 year	Target value entered into force 2012-12-31	Not to exceed an annual avera of 5 $ng\ m^{-3}$
Ni	20 $ng\ m^{-3}$	1 year	Target value entered into force 2012-12-31	Not to exceed an annual avera of 20 $ng\ m^{-3}$
PAHs	1 $ng\ m^{-3}$ [a]	1 year	Target value entered into force 2012-12-31	Not to exceed an annual avera of 1 $ng\ m^{-3}$

[a] It is expressed as concentration of Benzo (a) pyrene

Table 13 Limit values for air quality.

4.2 Calculating the Minimum Height for the Biomass Boiler Chimney at New Lanark using the D1 Guidelines.

The guidelines begin by establishing the Pollution Index for the boiler.

This was based on using a 300kW boiler, KWB Powerfire TDS 300.

The data available from KWB was limited in detail, but information was available in a paper published by Maia Anzola 1n 2012 in pursuit of her Master's Degree at Strathclyde University. (24)

Test results for the KWB TDS POWERFIRE 300 biomass boiler.

Nominal heat output (kW)	286	
Flue gas temperature (°C)	115	
Flue gas velocity (m/s)	1.4	
Dry flue gas mass flow (m3/h)	393	
Recommended chimney height (m)	13	
	mg/MJ 1)	mg/m3 2)
NOx (as NO_2)	88	130
CO	14	21
Dust	4	5
Organic Carbon	<2	<2

Step 1. Calculate the Pollution Index for the Biomass boiler system.

The P_i for each pollutant is calculated using the formula:

$$P_i = D/(G-B)$$

Where D represents the discharge rate in mg/s

G represents the limit volume levels in m3/s

B represents the background levels in m3/s.

The total P_i is the sum of each of the calculated Pollutant Indexes.

Step 2 Calculate the heat release Q from the stack in MW.

Here $Q = V.\frac{(1-(T_a/T_f)}{2.9}$

Where: V represents the Volume flow in m3/s

Ta is the Ambient temperature in ^oK

T_f is the flue temperature in ^oK

The calculated value of Q leads to two conditions:

When Q< = 0.03MW

Where 0.03< Q<100MW

Step 3 Calculate the uncorrected chimney height for buoyancy Ub in m.

Here $Ub = 10^a. PI^{b.}$

If Q <= 1.0 MW a = -1.11 - (0.19 x log10Q)

b = 0.49 + (0.005 x log10Q)

For Q> 1MW a = -0.84 - (0.1 x exp(Q0.31))

b= 0.46+(0.0011*exp(Q)^3.2)

The buoyancy depends on how warm the pollutants are. The more heat the lower the density so they will rise higher. Expected values for Ub are between 1m and 200m.

Step 4 Calculate the Uncorrected Discharge stack height due to flue gas momentum.

It is also a factor in flue stack heights to be aware of how the momentum of the flue gases has on how high they will soar into the air. The faster a bullet leaves a gun, the further it tends to go.

Firstly in this section the discharge momentum M is determined using the equation:

$M = (T_a/T_f) \times V \times w$ in m4/s2

Where T_a, T_f and V are as defined in step 2.

w is the gas discharge velocity in m/s and is calculated knowing the diameter of the chimney.

From the D1 Guidelines

$$\log_{10}U_m = x + (y.\log_{10}P_i + z)^{0.5}$$

Where $x = -3.7 + (\log_{10}M)^{0.9}$

$y = 5.9 - 0.624.\log_{10}M$

$z = 4.24 - 9.7.\log_{10}M + 1.47(\log_{10}M)^2 - 0.07.(\log_{10}M)^3$.

Step 5 Find the uncorrected stack height U

Here U is the lower value between Ub and Um

Step 6 Find the corrected stack height C.

This final calculation makes a correction to the height calculated by taking into account the height and breadth of all buildings at a distance of 5times the calculated value of Um.

Firstly: Find the value of **Hmax ,** the height of the highest building within the allotted distance of 5Um .

Secondly for each building find its value K which is the lowest value of its height and width.
Thirdly for each building find its K value which is K=H+ 1.5K. where H is the building height.
Finally establish the largest value of K known asKmax.

Step 7 Find corrected value of height (C).

1. If U> T max, then: C = T max..
1. If U < T max, then: $C = H\ max + (1-(H\ max/T\ max))\{U+(T\ max - U).[1-A^{(-U/Hmax)}]\}$

A= 1 when Ub>Um
A=1 if Q< 0.03MW, otherwise A=Um/Ub.

The D1 Guidelines throw up some calculations which are not difficult to perform, and which readily lend themselves to be inserted into an Excel programmes that can produce answers very quickly by entering some data to hand.
In the case of New Lanark this approach was adopted and the results show the existing stack is more than suited to the operation Appendix 2.

4.3 Estimating the total area required to house equipment.

The former Retort Building is where the boiler and associated equipment is to be housed.

The building is show in the picture below, and has the dimensions of 11m wide, 9m deep and the height starting at 4m and rising to 5.8m. There are no windows in the building and access is through two large sliding metal doors

Fig 17 The Proposed Location for the Biomass Boiler System.

This section of the feasibility study is to examine if there is sufficient room to house the equipment and store the fuel. As with the investigation on the suitability of the existing chimney, assessing the retort building's suitability is another crucial part of the project.

Material produced by the Carbon Trust has proved to be very useful.
The Carbon Trust is a body set up in 2001. They describe their mission in their website http://www.carbontrust.com/about-us .

Our mission is to tackle climate change by accelerating the move to a sustainable, low carbon economy that delivers jobs and wealth. We can help organisations put sustainability at the heart of their business strategy and gain a competitive advantage in the market.
Created in 2001, we have developed into a world-leading and trusted expert in low carbon issues and strategies, carbon foot printing and low carbon technology development and deployment. We offer more than 10 years of unparalleled experience in the low carbon sector.

In 2005 they decided it would be appropriate to highlight the significant role that biomass heating could play in the UK. In 2006 they launched the Biomass Heat Accelerator to increase awareness and understanding of biomass heating equipment. Consulting with manufacturers, installers, UK and European Government, and other experts in the field, one aspect of the accelerator was the production of a Publication called "**Biomass heating: A practical guide for potential users**" (25) This document was prepared by Black and Veatch Ltd, and was the Trusts first major publication from the Biomass Heat Accelerator (BHA).
The Trust also teamed up with The University of Strathclyde and the Campbell Palmer Partnership to produce a **Biomass Boiler System Sizing Tool**. This is basically a Microsoft Excel workbook, designed to undertake a pre- feasibility study on non- domestic biomass boiler systems operating between 50kW and 3MW. It was developed in part to overcome one of the shortcomings in biomass boiler systems, namely the poor performance and low efficiency of many of the early systems due to poor design and sizing.

The Sizing tool and its associated manual, along with the Practical guide can be downloaded free from the Carbon Trust.

Images of the Mechanics Workshop, New Lanark.

Left looking North.

Below looking West.

As indicated earlier, the Mechanics Workshop is a two story building and a basement. The basement is empty, and the upper two stories have a combined floor area of about 1000m^2. They are presently rented to I&A Stewart Ltd, a firm of Chartered Accountants. The building has medium insulation, single glazed windows, and has an average occupancy of around 26 people.

It is used 5 days a week between the hours of 8am till 6pm.

Currently the heating employed is electric. They operate 11 x6kW heaters and 7x 4kW heaters, a peak load for heating of 94kW.

The electricity is supplied direct from Scottish Power, since the present hydro generated village supply was considered unable to cater for such an extra load. The annual bill varies from between £20,000 and 25,000 depending on the severity of the winter.

Having used this as a model for Hydro Power feasibility, it will now be modelled for Biomass Heating.

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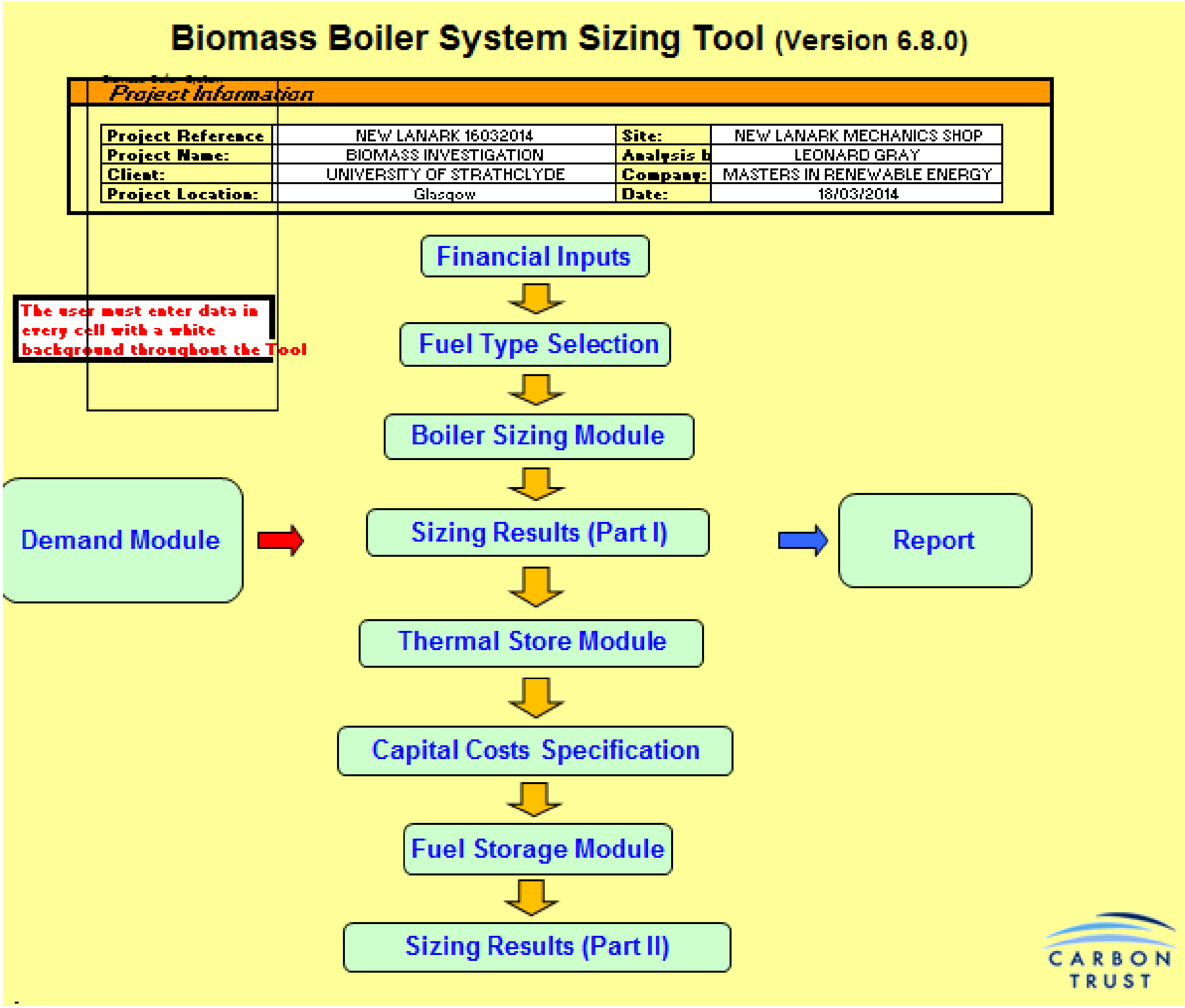
4.4 Biomass Boiler Sizing.

The tool is downloaded and saved on a computer. When opened, it is important to enable macros. The opening sheet is shown below.



4.5 Demand Module.

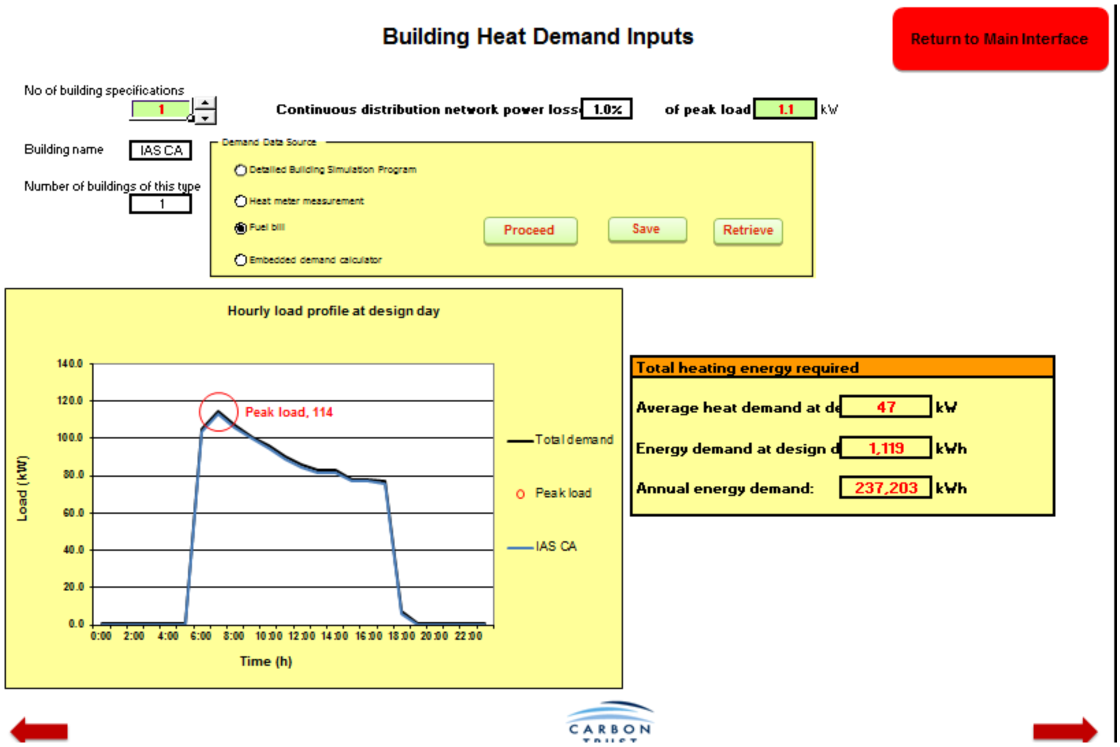
Specifying the Building.

A biomass heating system may have to cater for a number of different types of buildings, and up tp ten different types can be specified. In this particular investigation there is only one to be considered. It has been labelled IAS, and four different methods of obtaining the supply demand can be used. These are

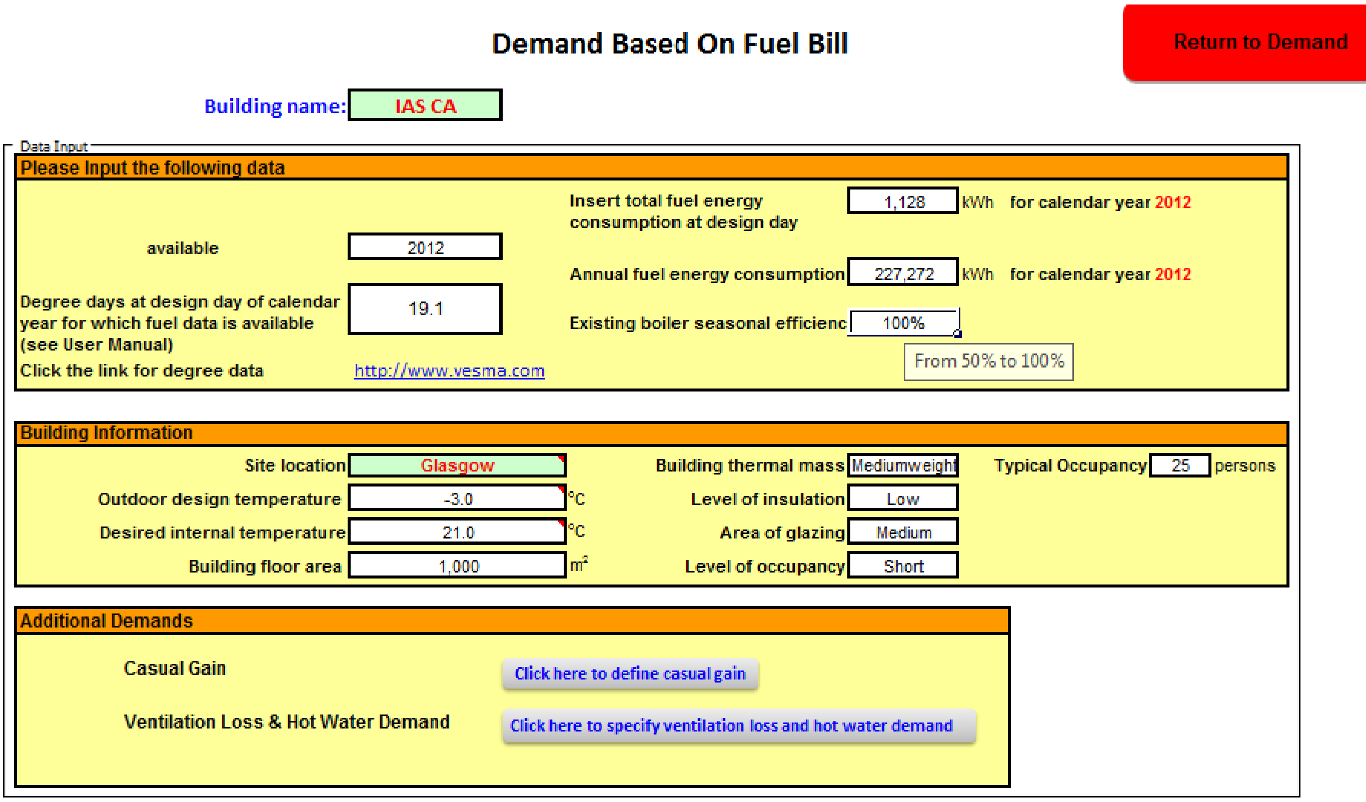
- Data from a building simulation programme
- Heat measurement data

- Data from fuel bills
- Using the embedded demand calculator.

Since the yearly fuel bills are available, this method was selected.



Clicking on the ‘proceed’ box allows the necessary data to be supplied.



It was decided to use the fuel bill data for the year 2012.

The Design Day was the coldest day in 2012was on the 11th December 2012. The degree day for that date was 19.1. A degree day is a measurement of the number of degrees the average temperature for a day was below 15.5°C,

For example if on a given day the average temperature was 10.5°C, then the degree day for that day would be recorded as 5. The lower the average temperature for a day is, the higher the degree day figure becomes. This allows heating engineers to estimate how much heating is required.

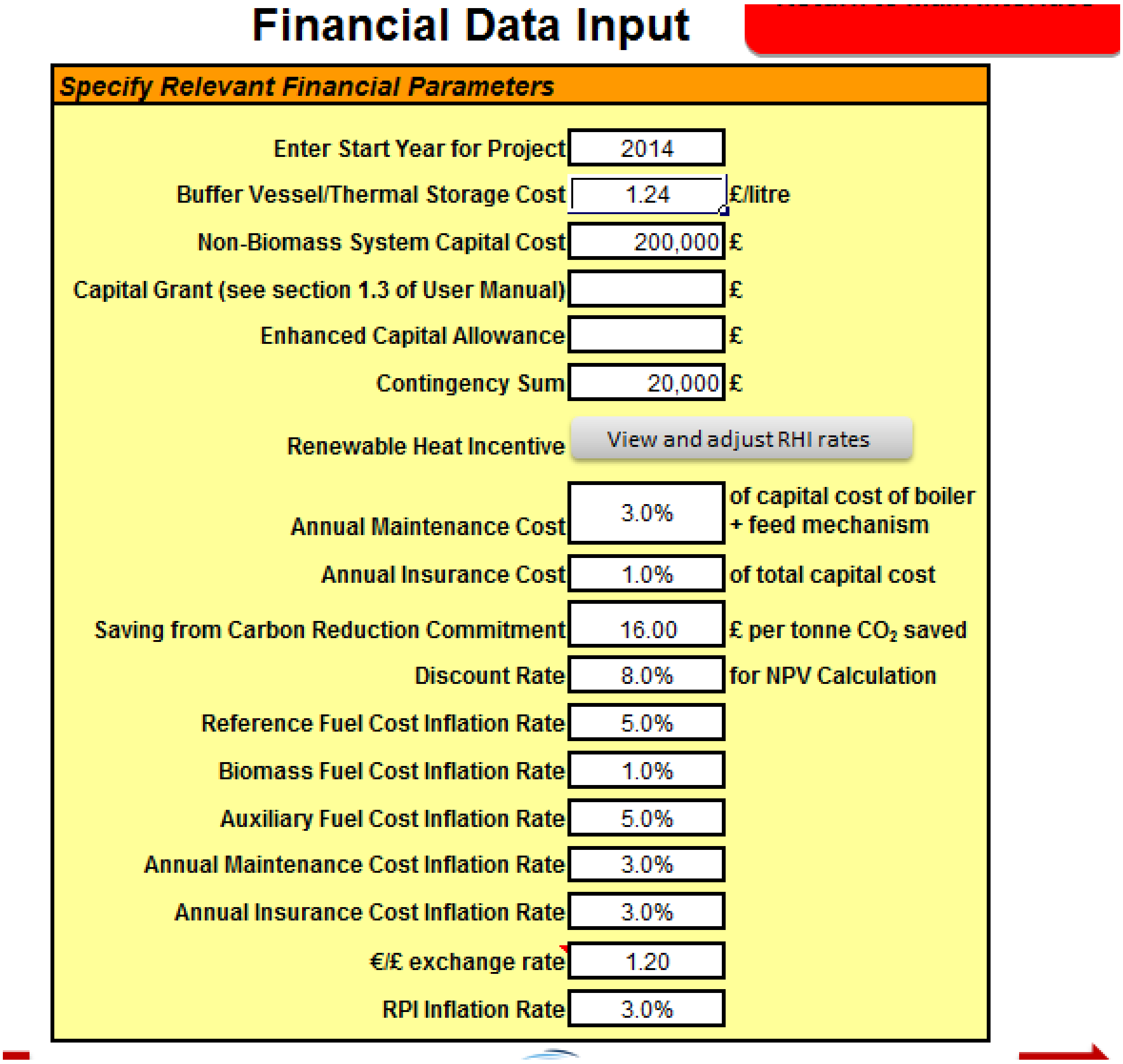
The annual fuel energy consumption was estimated from an annual fuel bill of £25,000 at a cost of £0.11 per kWhr.

The building type was selected from drop down options.

The efficiency of the heating system using electrical heating was taken at 100%

Returning to the input demands section and selecting ‘Save’ gave the calculated results for the demand profile for the building

4.6 Financial Inputs..



Financial Data Input

Specify Relevant Financial Parameters		
Enter Start Year for Project	2014	
Buffer Vessel/Thermal Storage Cost	1.24	£/litre
Non-Biomass System Capital Cost	200,000	£
Capital Grant (see section 1.3 of User Manual)		£
Enhanced Capital Allowance		£
Contingency Sum	20,000	£
Renewable Heat Incentive	View and adjust RHI rates	
Annual Maintenance Cost	3.0%	of capital cost of boiler + feed mechanism
Annual Insurance Cost	1.0%	of total capital cost
Saving from Carbon Reduction Commitment	16.00	£ per tonne CO_2 saved
Discount Rate	8.0%	for NPV Calculation
Reference Fuel Cost Inflation Rate	5.0%	
Biomass Fuel Cost Inflation Rate	1.0%	
Auxiliary Fuel Cost Inflation Rate	5.0%	
Annual Maintenance Cost Inflation Rate	3.0%	
Annual Insurance Cost Inflation Rate	3.0%	
€/£ exchange rate	1.20	
RPI Inflation Rate	3.0%	

The default figures supplied with the tool have been adjusted to take account of the inflation that has occurred since 2008. A figure of 3% per anum has been adopted.

The non biomass capital cost was estimated at £200,000, involving the installation of a water fed radiator system and a gas boiler.

No Capital Grant was assumed nor enhanced Capital Allowance, as using these would disqualify from participating in the Renewable Heat Incentive.

4.7 Fuel Type

The tool offers a choice between Woodchip or Wood pellets. Back in the 1980s there was considerable debate about what video format was the one to chose when buying a video recorder. Betamax from Sony was better, but the JVC VHS system won the battle. One major biofuel supplier said a similar battle was ongoing over Woodchip versus Wood pellet!

For this project wood pellet fuel has been chosen. Two factors inluence this choice:

- Wood Pellet has a much greater Energy density than Woodchip. Typical figures would be between 2833 kWh/m^3 and 3306 kWh/m^3 for Wood Pellet compared to 694 to 868 kWh/m^3 for Woodchip. This is important if storage space is restricted. Also if delivery has to be made in bags, then the higher energy density of Wood Pellet could reduce the frequency , hence the cost of delivery.
- Wood Pellets flow much easier than Woodchip, so this allows greater flexibility with feeder systems to boilers.

There are many suppliers of wood pellets in Scotland. One of the biggest is Pentland Fuels Limited who can deliver loads of 3 tonnes at a time at a cost ex VAT of £245 per tonne delivered. This cost is used in subsequent calculations.

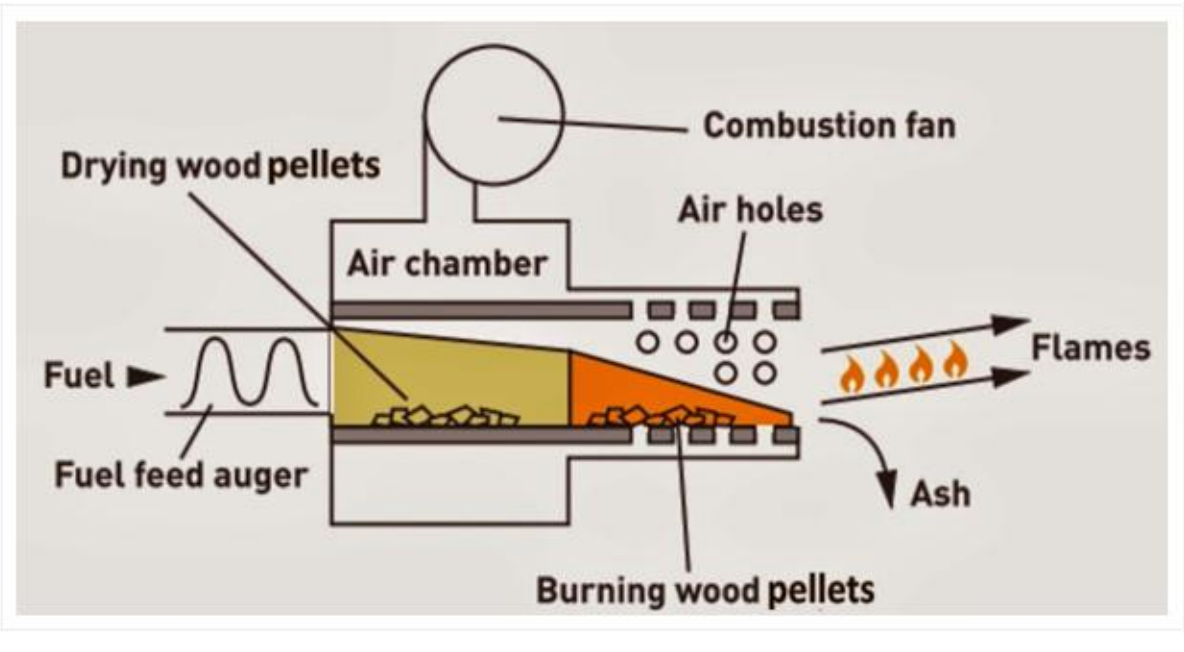
Pallets of 1 tonne are the only feasible way of delivering the fuel to the site. As can be seen from the picture below, there are two low arches which restrict large vehicles access to the retort building.

Fig 18 One of the retaining arches impeding access to larger vehicles.

Pallets can be offloaded on the far side of the arch above and transported to the Retort Building some 60m away.
Ideally a cheaper option would have been delivery by tanker vehicle which can blow the wood pellets through a hose to the hopper storage area, but such distances are too large to be practical

4.8 Type of heating system.

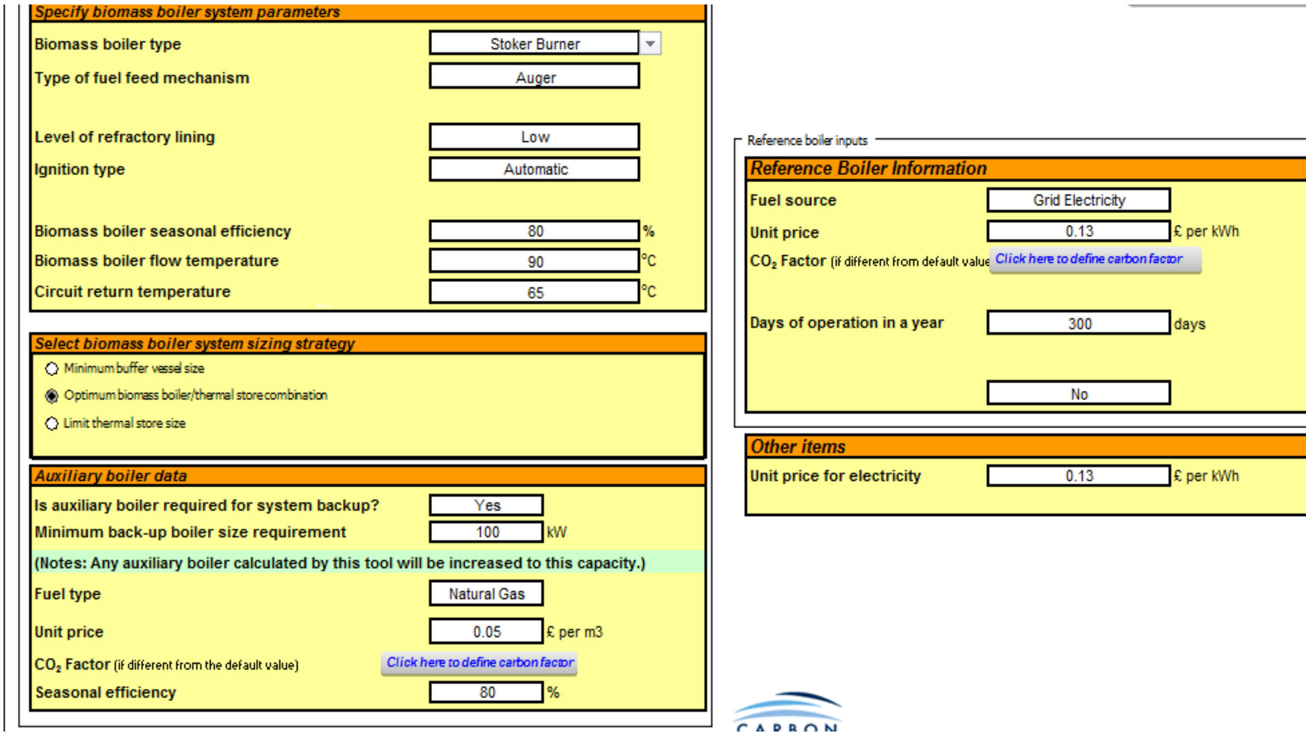
In this section a type of biomass boiler type requires to be chosen. Three options are given, Stoker Boiler, Underfed Stoker or moving grate. Moving grate systems were not chosen as they are more suited to higher output ranges between 300kW-1MW+. They are most frequently used to burn unseasoned softwood. The less sophisticated stoker burner system was chosen over the underfed stoker. Its lower cost makes it a popular choice for smaller boilers operating in the range 30kW-500kW.
A schematic diagram is shown below outlining the main areas of the stoker boiler



The level of refractory lining was chosen as low due to the low moisture level of the fuel specified. An auger feed mechanism was specified.

The efficiency of the boiler was taken as 80%, though this is erring on the low side
Fumo boilers from Denmark claim a 93% efficiency on their smaller industrial boilers (93kW). (25) **Auxiliary boiler**

The reference boiler refers to the existing storage heating system, and an auxiliary boiler was chosen to be a natural gas system.



Selection of the Options for the Biomass Boiler System.

An auxiliary boiler may be required to add extra output if the biomass boiler system is unable to deliver, eg. on times of exceptionally high heating demand. The lower the output from biomass heating, the greater number of hours is required to be supplemented by the auxiliary boiler.

If the auxiliary boiler has also to act as a backup boiler should the biomass heating fail, then a much higher output boiler is required. The rating of the auxiliary boiler is then taken as one that could supply a peak load. From the energy demand module the peak load was 92kW. The backup boiler was therefore rated at 100kW.

4.9 Selecting the biomass boiler strategy.

There are three basic options to consider when adopting a biomass boiler system.

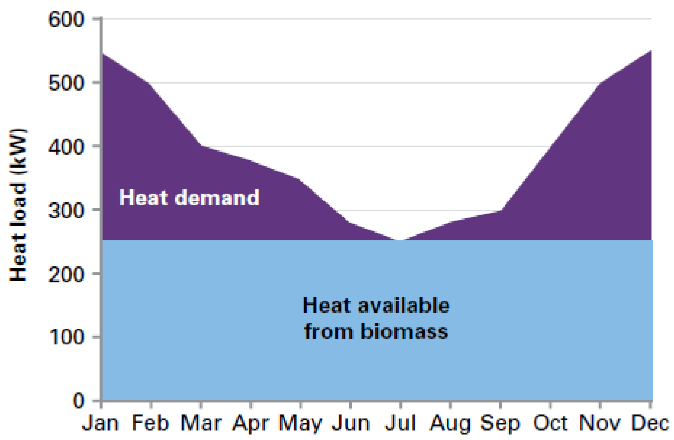
- Using the boiler to provide the **base load.**
- Sizing the boiler to cater for the **peak load.**
- Sizing the boiler for **optimum performance** somewhere between the two extremes.

These are illustrated in the following diagrams taken from the Carbon Trust guide for potential biomass users ref CTC012.

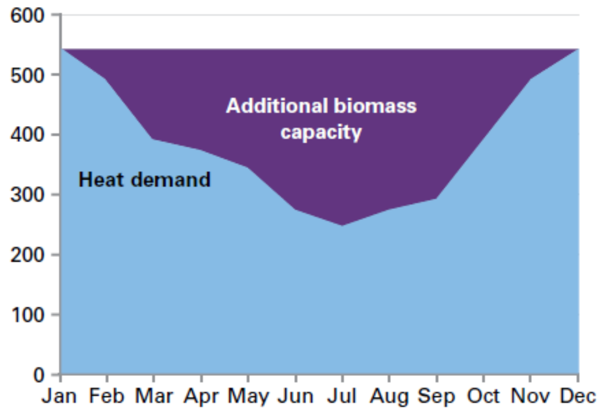
The base load model relies on the areas above base load being supplied by a fossil fuel source. If the annual demand is fairly constant, the biomass system would provide the vast majority of the heating. In the Mechanics Workshop this is not the case

Peak load sizing removes the need for an additional boiler and allows 100% of the heat generated to come from biomass. This gives rise to savings on fuel costs and reduces carbon emissions. The main disadvantage of this approach is certain load profiles involve underusing the boiler for periods of time.

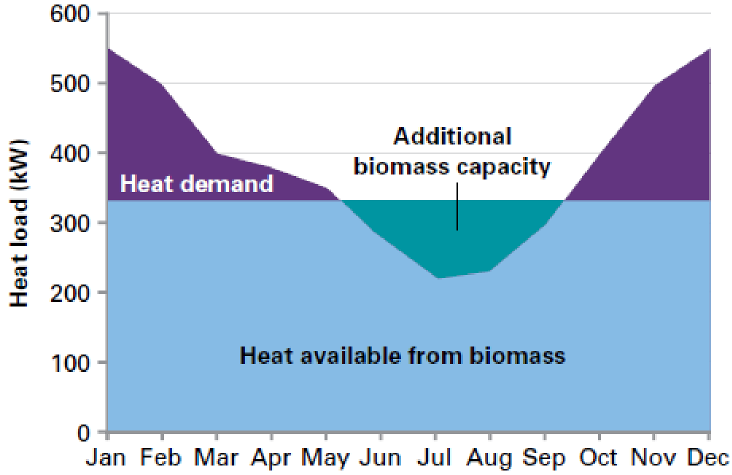
Optimising the boiler output to some point in between the peak load and base load allow the output from the boiler to be reduced, therefore saving in capital expenditure. A smaller auxiliary boiler can make up for any shortfall.



Base load sizing.



Peak load sizing



Optimum sizing

If a thermal store vessel is used fed from heat from the biomass boiler, then this can reduce the reliance on the auxiliary boiler. All biomass boiler systems require to use a buffer vessel which removes heat from the boiler when the load does not require it. If a thermal store is combined with a buffer vessel the biomass boiler can match the load for a much longer time.

For this feasibility study if is intended to use the optimum biomass boiler with a thermal store option. As can be seen in fig . this option has been selected. This will allow a good check on the space required for all the equipment and to see if the size of a thermal store needs to be limited.

4.10 Backup Boiler.

It is considered prudent to include a backup boiler for the Mechanics Workshop.This gives continuity of heating if the biomass boiler requires to be serviced. It also gives an alternative to Biomass should the future reliability of Biomass boilers is called into question. This would enable a gas type boiler to be installed in the basement of the Mechanics Workshop and could provide a valid alternative to biomass when the RHI is removed after 20 years. It is customary to size a backup boiler to supply the peak annual load which is about 100kW.

4.11 Sizing Results Part 1.

The next sheet calculates the size of the biomass boiler. Whenever this sheet is selected, the sizing calculated is based on a boiler rated at 80% of peak load.

Two graphs are produced, one showing the percentage of biomass heat used for a given siize of biomass boiler, together with the size of heat storage vessel.

The graph below this displays the annual load duration curve. It gives the number of hours in the year when the heating demand is higher than the vale chosen. So for a boiler rated at 80% peak load, from the graph it can be seen that heating demand will be greater than 41% for 1500 hours in a year.

What is of interest is the minimum output level of the boiler. This is 23% based on the turn down ratio of the boiler. The graph shows that for only 4000 hours a year is the demand higher than this level. Therefore in summer months the demand is below the minimum level the boiler can supply. The Carbon Trust recommends at least 5,500 hours above the minimum boiler output. The 80% of peak is too large to accommodate summer operation.

Vary biomass boiler rating capacity

Biomass boiler size: 73 kW

Percentage of peak load: 80 %

Peak Load at design day (kW): 92 kW

Biomass boiler size @ 80% of peak load(kW): 73 kW

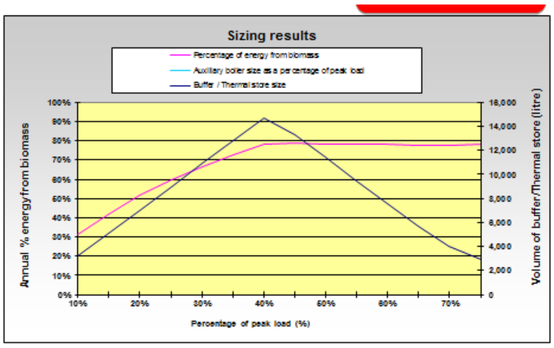
Sizing Strategy selected: Optimum boiler/thermal store

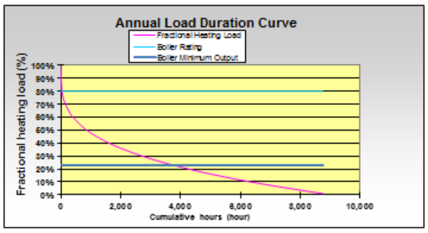
Save the results with different options by pressing the following buttons

Option 1 Option 2 Option 3

	Option1	Option2	Option3
Sizing strategy	Optimised	Optimised	Optimised
Percentage of peak load (%)	80 %	44 %	54 %
Biomass boiler capacity (kW)	73 kW	40 kW	50 kW
Minimum buffer vessel size (litre)	200 litre	100 litr	100 litre
Thermal store size incl. min buffer vessel (l	2,000 litre	13,800 litr	9,700 litre
Percentage of energy from biomass (%)	79.0 %	78.6 %	78.3 %
Auxiliary boiler size (kW)	100 kW	100 kW	100 kW
Total system cost (£)	301,259 £	291,786 £	294,390 £
Annual fuel cost from biomass (£)	10,269 £	10,210 £	10,181 £
Annual fuel cost if use conventional sourc	23,636 £	23,636 £	23,636 £
Annual cost saving (£)	22,079 £	19,625 £	20,400 £
Simple payback (years)	13.6 yrs	14.9 yrs	14.4 yrs
20year IRR	13.1 %	11.7 %	12.1 %
20year NPV (£)	136,903 £	94,600 £	107,860 £
Biomass fuel type	Wood pellet	Wood pellet	Wood pellet
Boiler ignition type	Automatic	Automatic	Automatic
Estimated RHI payment (1st Year)	8,958 £	6,450 £	7,199 £

Refer to Section 1.5.2 of User Manual for detailed instructions on how to interpret these results.





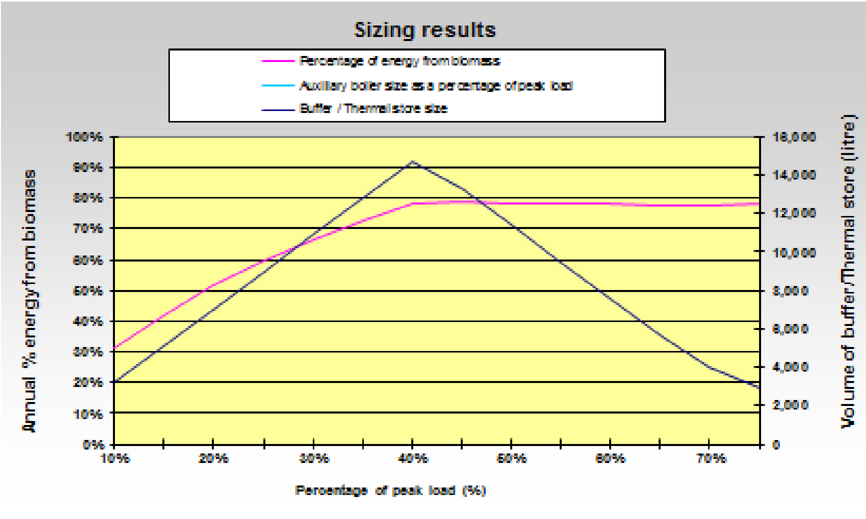
Decrease the thermal store size!

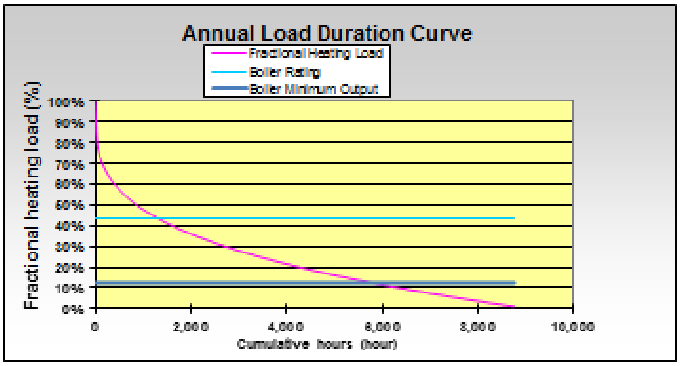
Reducing the boiler size to 44% produces a much better profile for minimum load operation. Now it can be seen that the cumulative annual hours has risen to around 6000 hours. The smaller boiler requires a larger heat storage vessel, and because less fuel is now required, the RHI input is lower and the payback time slightly longer. The percentage heat supplied by biomass is still around 79%.

A third option was tried for a 50kW boiler.

It was decided to use the 40kW boiler to examine the sizing for the equipment to see if it could all be housed within the retort building

4.12 Sizing results for the 40kW Biomass Boiler with Optimum Thermal Storage Vessel





Vary biomass boiler rating capacity

Biomass boiler size:	40	kW	
Percentage of peak load:	44	%	10 20 30 40 50 60 70 80%
Peak Load at design day (kW):	92	kW	Sizing Strategy selected:
Biomass boiler size @ 80% of peak load(kW):	73	kW	Optimum boiler/thermal store

Save the results with different options by pressing the following buttons

Option 1 Option 2 Option 3

	Option1	Option2	Option3
Sizing strategy	Optimised	Optimised	Optimised
Percentage of peak load (%)	80 %	44 %	54 %
Biomass boiler capacity (kW)	73 kW	40 kW	50 kW
Minimum buffer vessel size (litre)	200 litre	100 litr	100 litre
Thermal store size incl. min buffer vessel (l	2,000 litre	13,800 litr	9,700 litre
Percentage of energy from biomass (%)	79.0 %	78.6 %	78.3 %
Auxiliary boiler size (kW)	100 kW	100 kW	100 kW
Total system cost (£)	301,259 £	291,786 £	294,390 £
Annual fuel cost from biomass (£)	10,269 £	10,210 £	10,181 £
Annual fuel cost if use conventional sourc	23,636 £	23,636 £	23,636 £
Annual cost saving (£)	22,079 £	19,625 £	20,400 £
Simple payback (years)	13.6 yrs	14.9 yrs	14.4 yrs
20year IRR	13.1 %	11.7 %	12.1 %
20year NPV (£)	136,903 £	94,600 £	107,860 £
Biomass fuel type	Wood pellet	Wood pellet	Wood pellet
Boiler ignition type	Automatic	Automatic	Automatic
Estimated RHI payment (1st Year)	8,958 £	6,450 £	7,199 £

Thermal Storage Vessel Size.

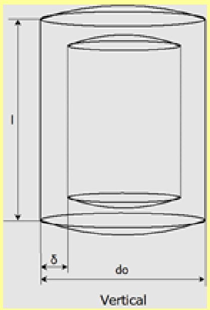
The sizing tool has calculated a vessel of 13,800 litre is required for this boiler.

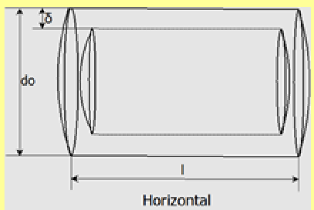
Thermal Storage Vessel For Biomass Boiler System

Return to Main Interface

Parameter specification for thermal storage vessels

Number	1	
Location	Indoor	
Position	Horizontal	
Length/Height (l)	3.6	m
Outer diameter of each vessel (d_o)	2.5	m
Insulation thickness (δ)	100	mm
Insulation type	Polyurethane	





Volume and heat loss results

Required Tank Volume	13800	litre
Specified Tank Water Volume	14126	litre
Design Day Heat Loss	13	kWh

Assumptions:

Thermal storage vessel is in cylinder shape.

Heat losses due to radiation and convection are neglected.

The dimensions for the vessel are entered with the unit being housed inside the building. It was chosen to be horizontal and a length of 3.6m chosen. For a diameter of 2.5m the tool accepted these dimensions.

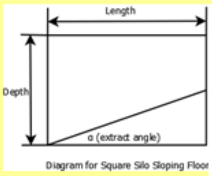
4.13 Biomass Storage.

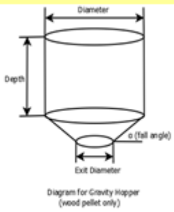
The final major piece of plant required to be sized is the storage unit required to hold the pellets. Having sized the boiler to supply the heat demand, the tool has also calculated how much fuel per day will be consumed.

Three options are given: a square shaped silo with sloping floor, a gravity hopper, a Walking Floor or a V shaped silo. As stated earlier, pellets would need to be delivered by pallets, and the bags emptied into the storage vessel. For this reason a sloping floor square shaped silo was selected to allow manual loading of pellets.

User Inputs

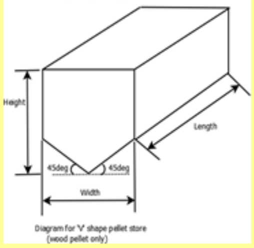
Biomass type name	Pellet1	
How many days storage do you need at winter design day?	24	days
Storage option	Square silo sloping floor	
Biomass consumption at design day	1,119	kWh





Dimensions for the Selected Storage

Storage type	Depth/ Height	Width/ Diameter	Length	Fall angle to the horizontal	Exit diameter	Extractor angle	Storage volume
	m	m	m	degrees	m	degrees	m^3
Square silo sloping floor	1.7	2.5	2.5	N/A	N/A	10	9.7



Notes: Please adjust the user inputs for storage dimensions to match the "storage volume" with the "required storage volume".

Suggested Biomass Storage Option

Required Storage Volume	9.1	m^3
Storage Capacity	6.6	tonnes
Cost per delivery	1,446	£

24 days' supply of fuel were required to be stored, calculated to require a storage capacity of 6.6 tonnes. Pentland fuels (http://pentlandbiomass.com/) currently supply loads of 3 tonnes per delivery. They are a local and well respected supplier. Initially three deliveries would be required, and when the spare pallet was used a further delivery would be requested, ensuring the silo always had 24 days' supply available.

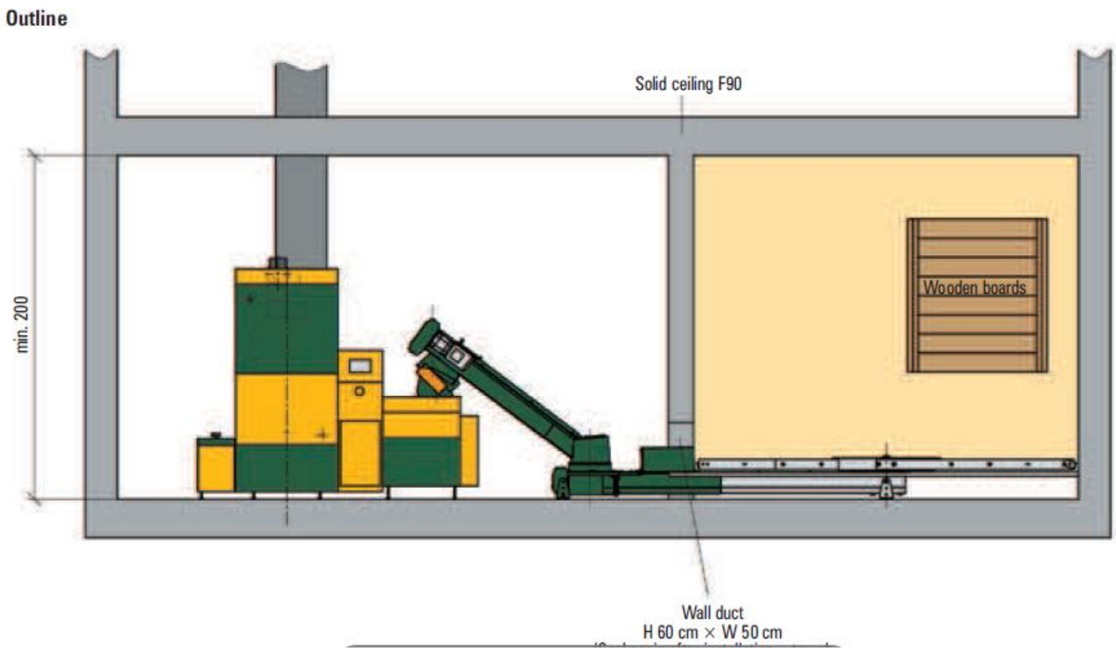
4.14 Boiler Room size.

The final area of equipment to be fitted into the retort building is the biomass boiler itself. It would be the intention to house this in a small room next to the room housing the storage silo.

It would be useful to site the boiler room next to the chimney stack in the middle of the southerly wall.. By cutting scaled paper to represent the boiler room area, along with that of the silo, the thermal store and the spare pallets, it can be seen that there is sufficient room to place all the equipment along the southerly wall.

The dimensions for the boiler area came from KWB where their brochure gives layouts for a 40kW biomass boiler.

This is illustrated in fig 19 and 20 below.



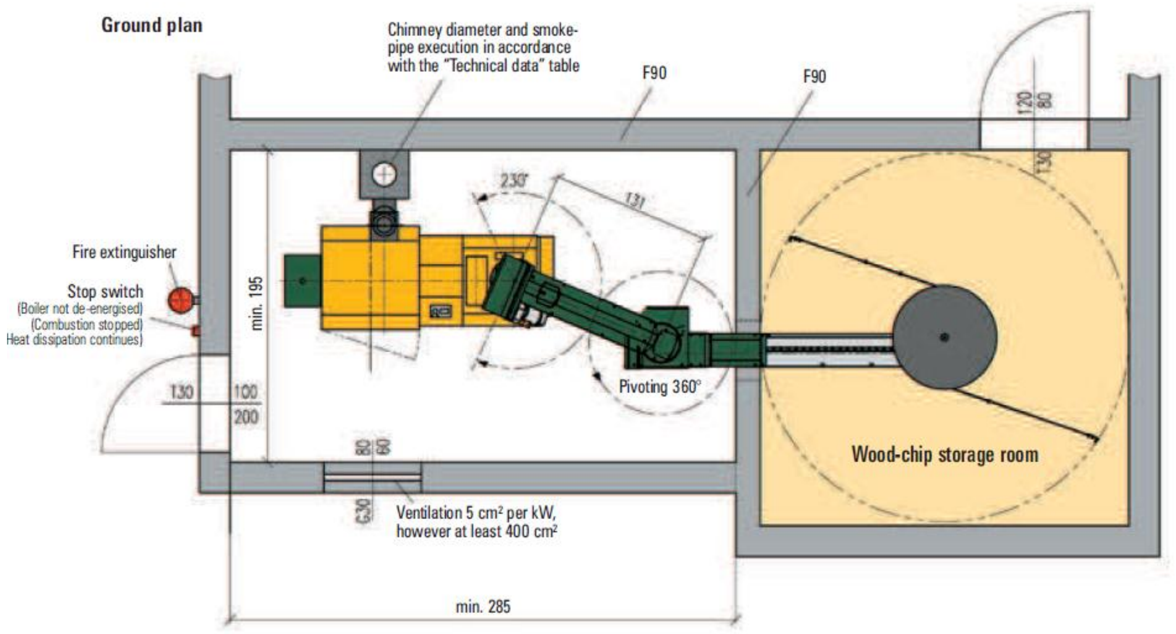
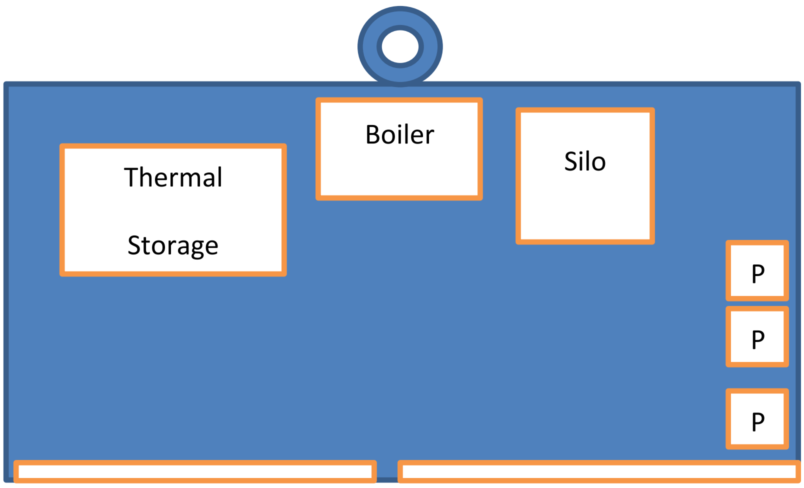


Fig 19 and 20 Boiler room layout, Elevation and Plan Views

Fig 21 Below an indication of the space used up with the biomass equipment.



Entrance Doors

4.15 Financial Implications.

The sizing tool can undertake the final part of the feasibility study. It should make it clear on the assumptions we have made whether the project could be justified on financial grounds. From the results of the sizing tool it can be seen that the cost of a little under £300,000 will take nearly 15 years to pay back from the savings achieved.

On top of this cost recovery there is also a perceived benefit by reducing CO_2 emissions. The whole feasibility study is summarized in a four page document. See Appendix 2

4.16 Conclusions on Biomass Boiler Study.

4.16.1 Reliability.

Biomass Heating is a sustainable energy source never used before in the Village. It is also a fairly new method using a rather old process. Man has been burning wood for thousands of years to supply heat for warming and cooking. To use modern technology to achieve this is new and raises questions on the reliability of such systems.

It is generally accepted that Scandinavian and Austrian built boilers have the longest track records and the best reputation (26) They are also more expensive. The life of such boilers is between 18 and 20 years.

The reliability of two similar boilers can be different due to poor installation. The correct sizing of the boiler rating and the size of the heat storage unit is essential to proper operation. If this is wrongly carried out the reliability will suffer.

The quality of the fuel is also crucial and a good local supplier is essential. In Scotland we have at least four within a 40 mile radius from the site. Their integrity is well known and would appear to be easy to deal with.

Cleaning and maintenance is also important. Most boilers require an annual maintenance service and regular cleaning.

Good control systems can make the boiler burn efficiently and this too can greatly increase the reliability.

The storage and handling of the fuel must be carried out properly. It must be kept dry, and it must be handled carefully as wood pellets are being employed, and they can disintegrate into dust if they suffer mechanical abuse. There is concern that unloading pallets then transporting

them to a fork lift truck then loading into a hopper may cause damage, despite assurances this need not be the case.
Laying out the plant must be done in such a way that service access is readily available.
Keeping the chimney flue clean and clear is important. Six monthly cleaning is required A cherry picker may be able to do this but this aspect would need further investigation. Finally a good maintenance contract with the manufacturer needs to be considered after the standard two year warranty runs out.

4.16.2 Summary.

The Biomass Option for the Mechanics Workshop shows a high capital cost, due mainly to the fact that there is no wet heating system in place. The high capital estimate was based on fitting radiators throughout the building and installing a gas supply. This would give the building a much better alternative source of energy, albeit using fossil fuels and raising carbon emissions. It does mean a longer payback time, almost 14 years, but an overall profit would be produced throughout the RHI period of 20 years.
The capital cost for non-biomass was estimated on the high side.
The reliability and maintenance issues and the labour intensity for fuel delivery are negative aspects, as is the cleaning of the chimney and the frequent ash removal. The chimney calculations applied to a much larger boiler than is actually required anticipates the possible extension to the buildings across from The Mechanics Workshop.

5. Conclusion

5.1 Review of the initial quest

New Lanark Trust have to be congratulated in their mission to make as much use of renewable energy sources as they could find possible. For many years groups have come to visit the village to see the developments produced to generate sustainable energy. So successful have they been means to have the opportunity to find more methods to investigate was a challenge in itself.
All the way through the investigations have been an awareness of the limits imposed by Planning restrictions. There is a sense that sometimes a solution is just not worth pursuing, either due to time constraints or more commonly the financial cost of obtaining expert advice.
The village buildings have nearly all had a planned use, with the exception of the Retort Building. This 19th century unit sits in a small edge of the village, and receives

hardly a glance as people turn their back on it to marvel at the water cascading over Dundaff Linn.

It was a delight to investigate the feasibility of installing Biomass heating in the nearby Mechanics Workshop. The tenants were highly unhappy with the only heating option available, Electricity bought from a supplier! To be able to produce a scheme that would reduce their heating bills and at the same time return an empty building back to duty was tempting. The Trust has often said New Lanark is a working village not a museum. It would also offer the Trust a chance to add to their portfolio a new renewable source.

The need for a chimney and storage for fuel had to be solved in a discrete way by the Retort Building and sized of plant and volumes of fuel seemed an impossible task to estimate. Luckily the Biomass Sizing Tool was presented and an initial feasibility was conducted. It showed it could work for the Mechanics Workshops, although limitations were made evident.

Fuel delivery is an issue due to the arches that guard the road approaching the Retort Building and as yet no cheap and efficient method of delivering fuel pellets in bulk has been worked out.

Reliability and cost associated with maintenance are difficult to find details on. Installers will tell potential customers the benefits and avoid any mention of pitfalls. The relatively short life of the boiler, (just under 20 years) seems rather low.

The economics are also difficult to envisage into the future. The proposed Biomass system uses more fuel than at present, but as the costs are lower per unit and the RHI further subsidises the cost, it is uncertain if the system will be viable in 20 years' time. One great spin off is the fact that the suggested system will have a gas boiler feeding a water heating system, and this will be covered by the savings made by the scheme.

Continuing on the theme of using Industrial Archaeology as a working entity, the same applies to the hydro scheme. New Lanark seem to be very lucky in having a working hydro facility with spare capacity. Once again is the opportunity to turn the water power system into a money generating scheme. Mini hydro schemes have high feed in and generating tariffs because of the high capital costs involved in building a weir and a lade. New Lanark does not face this burden. The calculations showed a very quick payback period, and the life time working of a hydro turbine is high, around 80 years and has low maintenance costs associated. Fears about having to demolish an outside wall to gain access to the basement seem to be unfounded if a Cross flow turbine is used and assembled within the basement. Financially hydro is by far the more attractive, but there is also a case for Biomass restoring a building to doing a worthwhile job, and perhaps delivering heat to the buildings across from the Mechanics Workshops to the small business units.

5.2 Future Investigations.

By far the most exciting thing to happen in the immediate future is the opportunities afforded during the restoration and refurbishment of Double Row. Making most of this unit available for housing gives the Trust a chance to investigate the incorporation of energy sensors and metering to control energy consumption throughout the year. It is often pointed out that in Nursery Buildings the windows are often thrown open to remove the heat built up from the communal gas system!

The Hotel is a major source of heat energy and removing the heat from used bathwater would be worth considering.

The heat insulation in parts of the village could well do with some investigation. Modern standards far exceed those that were state of the art 25 years ago.

New Lanark is certainly not a museum. It is a vibrant community that is happy to blend the old with the new in a measured and thoughtful way. It is hoped this Thesis may contribute in some small way to support those who have kept a dream alive.

Appendix 1.

Spreadsheet results for Chimney calculation.

CALCULATION FOR CHIMNEY HEIGHT AT RETORT BUILDING NEW LANARK.
Leonard Gray 7th August 2014

TEMPERATURE OF FLUE GAS	Tf	388	K	
AMBIENT TEMPERATURE	Ta	283.15	K	
DIAMETER OF VENT AT DISCHARG RGE/m		0.5	m	
AREA OF STACK/M2		0.19635	m^2	
DISCHARGE VOLUME FLOW m_3/s (V)		6.55	m3/s	
FLUE GAS VELOCITY	w	33.35888		
Discharge Rate for Pollutants	D		Units	MANUFACTURER'S DATA.
NO_2		130	mg/m3	851.5 mg/s
CO		21	mg/m3	137.55 mg/s
Particulates		5	mg/m3	32.75 mg/s
Guidelines for Pollutants	G			
NO_2		0.2	mg/m3	Table D4 IPPC H1
CO		10	mg/m3	Table D4 IPPC H1
Particulates		0.03	mg/m3	Table D4 IPPC H1
Background Concentration	B			
NO_2		0.04	mg/m3	Estimated from
CO		2	mg/m3	Air monitoring
Particulates		0.006	mg/m3	Lanark

<u>Calculation of Pollution index</u>

From D1 Guidelines Pi = Discharge Rate D/ (Guideline Level G - Background LevelB)

PI NO_2	5321.875
PI CO	17.19375
PI Particulates	1364.583
Pollution Index	**6703.65**

Q= 0.6104 MW

Calculation of Ub (Uncorrected Discharge Stack Height for buoyancy)

From the D1 Guidelines: $Ub = 10^a \times Pi^b$

where: If Q <= 1.0 MW   a = -1.11 - (0.19 x log10Q)
b = 0.49 + (0.005 x log10Q)

If Q > 1.0 MW   a = -0.84 - (0.1 x exp(Q0.31))
b= 0.46+(0.0011*exp(Q)^3.2)

a=	**-1.0693**	Ub=	0.085259 x	74.26607
b=	**0.4889**			
Ub =	**6.3318**			

Calculation of Um (Uncorrected Discharge Stack Height for momentum)

The discharge momentum is calculated using the equation given below

$$M = \frac{Ta \cdot V \cdot w}{Tf}$$

M = 159.455 m4/s2

From the D1 Guidelines
log10Um = x + (y.log10Pi + z)^0.5

where: x = -3.7 + (log10M)^0.9

y = 5.9 - 0.624.log10M

z = 4.24 - 9.7.log10M + 1.47(log10M)^2 - 0.07.(log10M)^3

Therefor   x = -1.6646
y = 4.5256
z = -10.742

Giving   log Um = 0.899459   **Um = 7.9334 m**

The calculated uncorrected height of the chimney stack is the lower value of Ub and Um, in this case Ub = 6.33m.

This value has to be corrected taking account all buildings at a distance of 5 Um from the chimney stack

In this case the nearest building is over 50m away so there is no need to make any corrections.

It follows that the corrected height of the chimney stack C = 6.33m

APPENDIX 2.

Biomass Sizing Tool Report.

Report on Biomass Project for	UNIVERSITY OF STRATHCLYDE
Project Reference Number	NEW LANARK 16032014
Project name	BIOMASS INVESTIGATION
Site	NEW LANARK MECHANICS SHOP
Prepared by	LEONARD GRAY
Company	MASTERS IN RENEWABLE ENERGY
Date	18/03/2014

TECHNICAL SPECIFICATION

Biomass Boiler		
Size	73	kW
Type	Underfed Stoker	
Ignition	Automatic	
Efficiency	80%	
Fuel feed System	Auger	
Fuel	Wood Pellets	
Minimum boiler ouput	21	kW
Buffer Vessel and Thermal Storage		
Minimum buffer vessel size	200	litres
Capacity ratio	3	litres/kW
Annual energy from biomass	79.0	%
Size of thermal store (incl. min buffer vessel)	2,000	litres
System Temperatures		
Flow	90	°C
Return	65	°C
ΔT	25	°C
Auxiliary Boiler		
Size	100	kW
Fuel	Natural Gas	
Efficiency	80%	
Reference Boiler		
Fuel	Grid Electricity	
Efficiency	60%	
Fuel Storage		
Number of days storage required	28	days
Storage volume required	10.62	m^3

ENERGY & CO_2 ANALYSIS

Biomass Boiler System with optimum biomass boiler/thermal store combination

Reference System		
Energy Used by Reference Boiler	183,954	kWh
CO_2 released by Reference Boiler	94.0	tonnes/year

Biomass System		
Energy Used by Biomass Boiler	195,506	kWh
Energy Used by Auxiliary Boiler	52,984	kWh
Annual Biomass Consumed	48	tonnes/year
Total CO_2 released by Biomass System (include auxiliary boiler)	21.4	tonnes/year

Annual Savings		
Energy Saving	-64,535	kWh
CO_2 Saving	72.6	tonnes/year

Design Day Load Profile

Time	kW
00:00	1
01:00	1
02:00	1
03:00	1
04:00	1
05:00	1
06:00	84
07:00	92
08:00	86
09:00	81
10:00	77
11:00	72
12:00	69
13:00	66
14:00	66
15:00	62
16:00	62
17:00	62
18:00	6
19:00	1
20:00	1
21:00	1
22:00	1
23:00	1

FINANCIAL ANALYSIS

Start Year for Project	2014	
Boiler sized to meet	79.0	% energy from biomass

Indicative Range of Capital Costs		
Capital Cost	81,259	£
Likely Maximum Capital Cost	105,636	£
Likely Minimum Capital Cost	56,881	£

Capital Cost Breakdown based on Indicative Capital Cost		
Boiler	24,934	£
Fuel Feed System	3,416	£
Fuel Storage	7,344	£
Boilerhouse	27,620	£
Buffer Vessel	2,200	£
Flue	2,733	£
Design,PM & Commissioning	3,586	£
Delivery	1,195	£
Pipework	683	£
Electrical & Controls	1,537	£
Auxiliary Boiler	6,010	£

Costs, Grants & Loans		
Non-Biomass System Capital Cost	200,000	£
Capital Grant	0	£
Enhanced Capital Allowance	0	£
Contingency Sum	20,000	£
Carbon Trust Zero Interest Loan	0	£
Net Capital Cost	-98,741	£
Biomass Fuel Cost (1st Year)	10,269	£
Auxiliary Boiler Fuel Cost (1st Year)	247	£
System Electricity Cost (1st Year)	912	£
Renewable Heat Incentive (1st Year)	8,958	£
Net Annual Fuel Cost (1st Year)	2,470	

Assumptions		
Annual maintenance cost	3.0%	
Annual Insurance cost	1.0%	
Discount Rate	8.0%	
Reference Fuel Cost Inflation Rate	5.0%	
Biomass Fuel Cost Inflation Rate	1.0%	
Auxiliary Fuel Cost Inflation Rate	5.0%	
Annual Maintenance Cost Inflation Rate	1.0%	
Annual Insurance Cost Inflation Rate	1.0%	
Saving from Carbon Reduction Commitment	0.00	£/tonne CO_2 Saved
	0	£/year

FINANCIAL ANALYSIS - continued

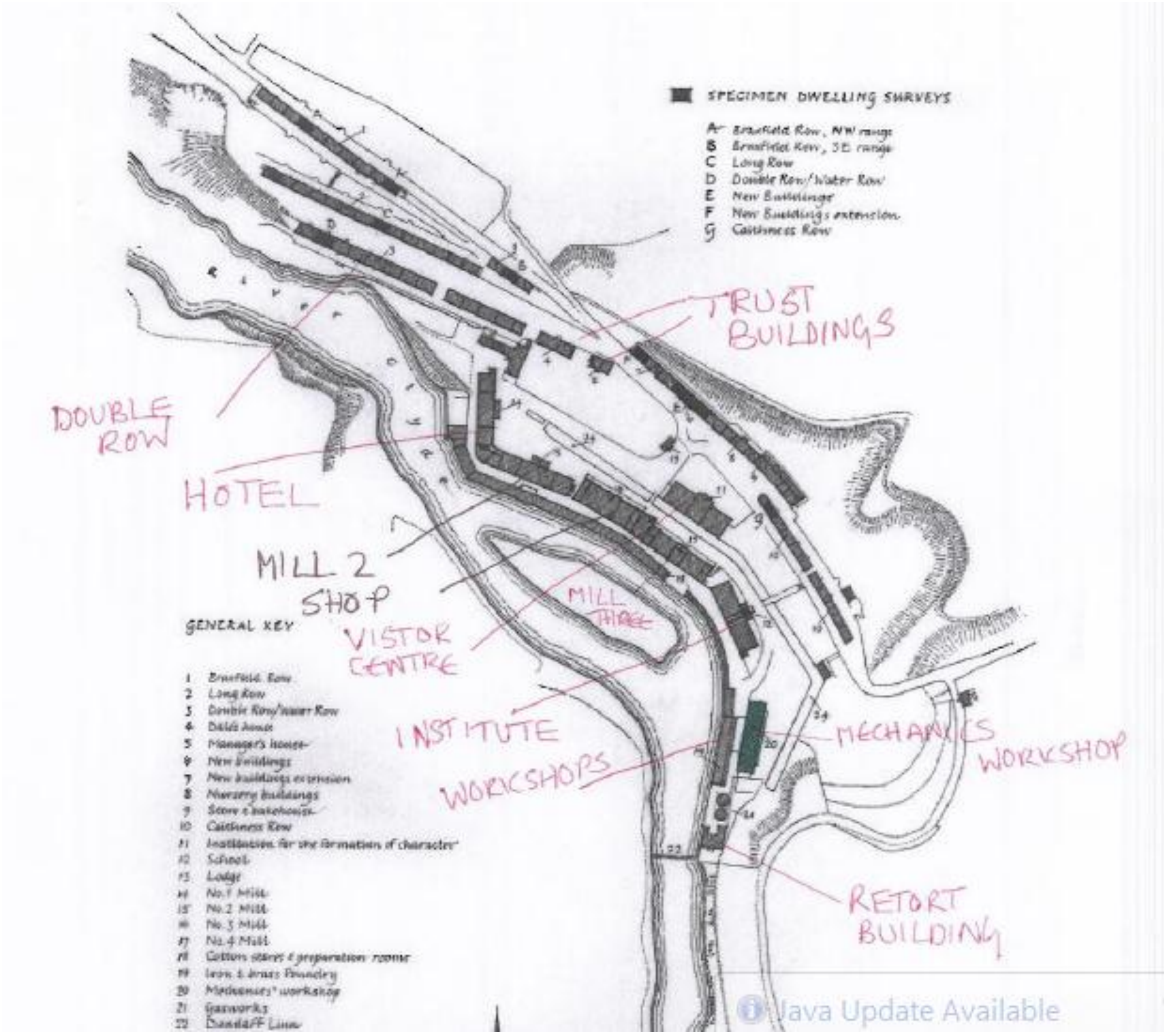
Cashflow & Savings Analysis

Simple Payback Period 14 years

Year	Cash Flows (£)	Internal Rate of Return	Net Present value (£)	Net Annual savings (£)
0	-271,886			29,373
1	29,012	-89%	-245,022	30,692
2	30,380	-61%	-218,976	32,076
3	31,816	-39%	-193,720	33,529
4	33,323	-25%	-169,227	35,054
5	34,906	-15%	-145,470	36,653
6	36,567	-8%	-122,427	38,332
7	38,311	-3%	-100,073	40,094
8	40,141	0%	-78,386	41,942
9	42,062	3%	-57,345	43,881
10	44,078	5%	-36,928	45,915
11	46,194	7%	-17,116	48,050
12	48,415	8%	2,110	50,289
13	50,745	9%	20,769	52,638
14	53,190	10%	38,878	55,102
15	55,756	11%	56,454	57,686
16	58,448	11%	73,515	60,398
17	61,272	12%	90,075	63,242
18	64,236	12%	106,150	66,225
19	67,345	13%	121,754	69,355
20	70,608	13%	136,903	72,637

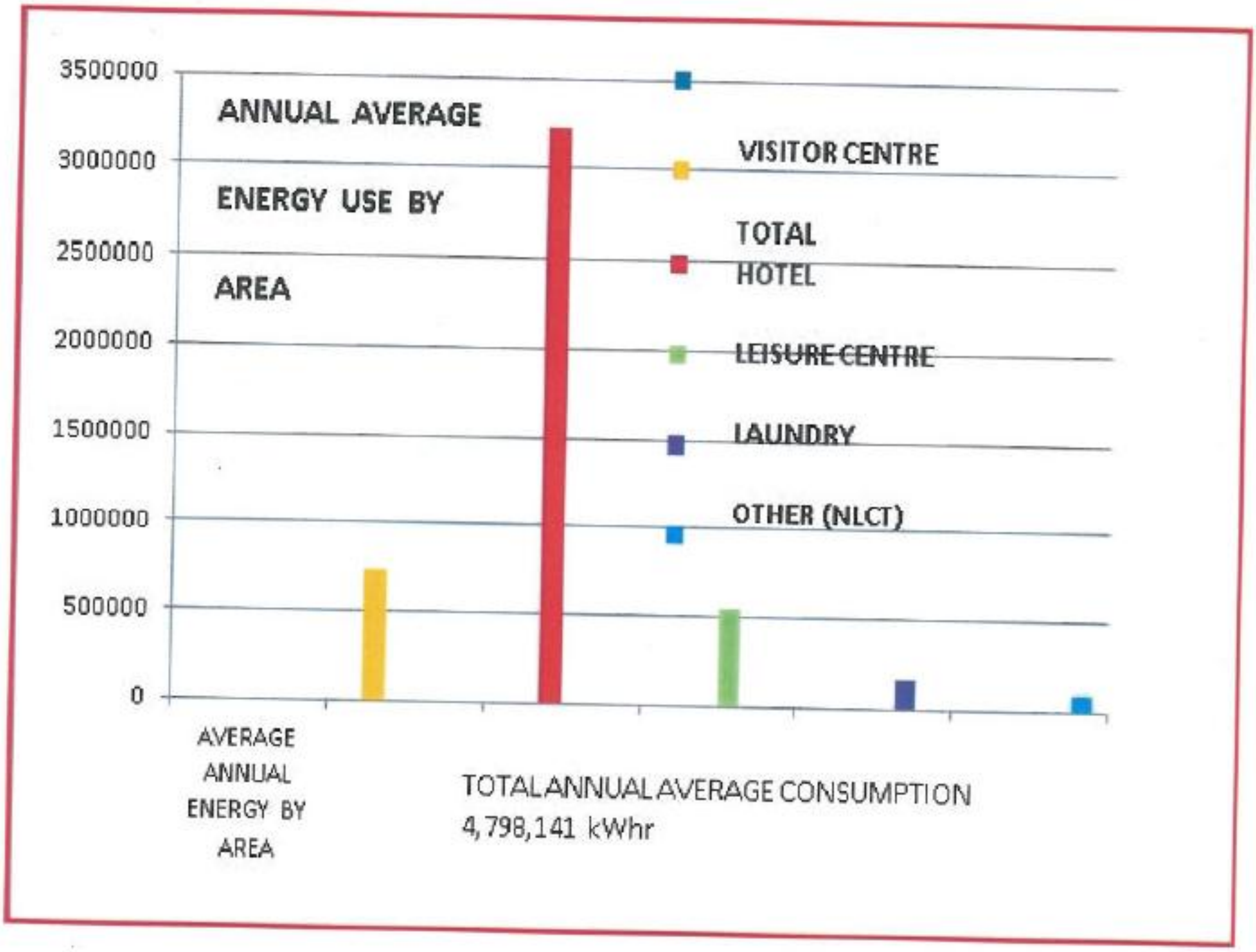
APPENDIX 3

Map of New Lanark showing Trust Buildings



APPENDIX 4

New Lanark Trust Annual Expenditure by Area (2010)



Appendix 5

Generation tariff >2014.

Energy Source	Scale	Type / Rate	Tariff (p/kWh)	
			< 30/9/14	> 1/10/14
Anaerobic digestion	≤250kW		12.46	11.21
Anaerobic digestion	>250kW - 500kW		11.52	10.37
Anaerobic digestion	>500kW		9.49	9.02
Hydro	≤15 kW		21.12	19.01
Hydro	>15 - 100kW		29.72	17.75
Hydro	>100kW - 500kW		15.59	14.03
Hydro	>500kW - 2MW		12.18	10.96
Hydro	>2MW - 5MW		3.32	2.99
Micro-CHP	<2 kW	(limited)	13.24	13.24
Solar PV	≤4 kW	Higher rate	14.38	14.38
Solar PV	≤4 kW	Medium rate	12.94	12.94
Solar PV	>4 - 10kW	Higher rate	13.03	13.03
Solar PV	>4 - 10kW	Medium rate	11.73	11.73
Solar PV	>10 - 50kW	Higher rate	12.13	12.13
Solar PV	>10 - 50kW	Medium rate	10.92	10.92
Solar PV	>50 - 150kW	Higher rate	10.34	10.34
Solar PV	>50 - 150kW	Medium rate	9.31	9.31
Solar PV	>150 - 250kW	Higher rate	9.89	9.81
Solar PV	>150 - 250kW	Medium rate	8.90	8.90
Solar PV	≤250kW	Lower rate	6.38	6.38
Solar PV	>250kW - 5MW		6.38	6.38