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A Renewable Energy Scoping Study

for the

City of Exeter

Scope of report

This report is commissioned by Exeter Low Carbon, a local community initiative and looks at the renewable energy potential in the City of Exeter area. The main focus of the report considers the potential to develop micro-hydro power on the River Exe as it passes through Exeter. The report also looks at the potential for wind power, photovoltaics, solar hot water and anaerobic digestion.

Summary

A number of technologies emerge as potential energy sources within the City of Exeter area. The River Exe contains significant quantities of power, but harnessing that power will be problematic. The environmental and visual impact of conventional turbine technology is likely to cause concern to both the Environment Agency and local planners. There are two turbine types that will minimise the environmental concerns but neither has been tested in these exact circumstances. The Archimedes screw is enjoying a rise in interest but there is limited experience with an 'in weir' application. A new style of turbine under development is not yet ready, but could offer a solution for the River Exe.

Average wind speeds across the city are too low to support commercial exploitation, but there may be scope for wind power on the northern outskirts of the city and on some of the surrounding hills. The proximity of Exeter International Airport may present an issue where there may be concerns about 'radar clutter'.

Solar photovoltaics and solar hot water are considered. Photovoltaics remain an expensive technology although the development of new materials may well bring the cost down in the near future.

Solar hot water is a mature technology and there is no practical reason why there should not be mass take up.

Energy from waste, in particular Anaerobic Digestion, is considered in some detail. Research carried out by a Devon research establishment has seen a 40% increase in output and a 50% reduction in digestate retention time. This coupled with a local engineering company's skills to develop a modular reactor core should see significant improvements in the economics of AD in the near future. This offers exciting possibilities. Perhaps because of the lack of awareness of the possibilities previously, the basic data for feedstock is not available from the local authority records of waste collection. Now would be an ideal time to start to record the volumes of putrescible waste available so that early adoption may be possible once the development stage is complete.

There are a number of emerging technologies that could see application in Exeter or in the Exe estuary; these are mentioned in the appendix.

Exeter cannot be self-sufficient in energy from the renewable resources available locally but there are several opportunities that are well worth further investigation and development.

Introduction

This report has been commissioned by a community group, 'Low Carbon Exeter'. Its purpose is to identify the available renewable energy resource in the Exeter area. Low Carbon Exeter is supported by Exeter City Council who has embraced the concept of Local Action for Sustainability that emerged from the Agenda 21 process of the 1990's. [For further reading go to:- http://www.exeter.gov.uk/ and follow the links through Home/Residents/Environment/Sustainability/Introduction]

Exeter City Council dedicates 2% of the city's car parking revenue to a 'Climate Levy Fund' and has invited community groups to submit ideas for sustainable action. The ideas were posted on the council's web page where local residents were invited to vote. Low Carbon Exeter's proposal to identify the Renewable Energy resource was one of the winning entries.

Why Renewable Energy?

'Energy' is as crucial to life as air, water and food. Indeed food is energy but in a form we can digest. Quite simply without energy there would be no life. Society as we know it today has developed because, since the Industrial Revolution, we have had access to what effectively amounts to unlimited cheap energy. Before the Industrial Revolution society's progress was limited by the energy available from horsepower, water and windmills and human muscle power. Since we have learned how to unleash the countless millions of year's worth of solar energy that has accumulated in coal, oil and gas deposits around the planet, society has been able to expand rapidly. The fabric of today's society is now dependent upon the continuance of energy supplies at this level. In the early post Industrial Revolution days our knowledge of the planet's complex chemistry was limited; arguably we didn't know what we didn't know. Even today our knowledge of the planet's complex chemical interactions is incomplete, but at least we now know that and can actively research to try to fill the gaps in our knowledge. However, we do know that 'Carbon' has played, and continues to play, a crucial role in how planet earth functions. In particular the balance between that proportion of carbon chemically "locked up", rendering it unavailable to react with other elements, and that proportion that is free to react, has a huge impact on the environment. There is ample evidence that over the countless millennia the planet has undergone many changes, indeed change is endemic. This leads some to argue that the changes we currently observe are a function of nature alone and not man's intervention. However there is also evidence that nature induced changes only occur very slowly, and at this rate of change nature can, for the most part, adapt in response. Scientists began to observe changes in the composition of gases in the atmosphere as early as the 1890's [Svante Arrenhuis] and speculated that burning fossil fuels may be the cause. However it was not until the late 1950's that detailed records of carbon dioxide (CO_2) levels in the atmosphere started to be maintained [Keeling Curve]. More recently improved methods of interpreting data contained within ice cores, sediments on the ocean floor and in bogs, have allowed scientists to conclude that atmospheric CO_2 levels are rising at a faster rate than ever seen before in nature.

Should this worry us? Yes. There is incontrovertible evidence that the concentration of CO_2 in the atmosphere has a direct correlation with the temperature of the air. This raising of global temperatures is already having an observable impact on glacier melt and changes to weather patterns. Increased CO_2 absorption by the oceans is increasing the acidity of the sea and this is having an observable impact on the microorganisms that form the base of the food chain. Some 96% of the protein in the human diet can trace its origins back to the oceans! For a full account of the predicted changes, degree-by-degree, read; "6 Degrees – Our future on a hotter planet" by Mark Lynas ISBN: 978-0-00-720904-0 published by Fourth Estate, London.

There is now little doubt that burning fossil fuels is a major factor in 'Climate Change' and therefore we need to limit further CO_2 emissions as quickly and completely as possible. This is recognised by the Government adopting a policy of reducing carbon emissions by 20% by 2020 and by 80% by 2050. This means producing at least 35% of our electricity from renewable resources by 2020. This has implications for every community.

It should be added that mitigating climate change is not the only reason for adopting alternative low carbon energy supplies. Coal, oil and gas are not about to run out, but there is evidence that demand for these fuels is on the verge of exceeding supply. This is due in part to the fact we have already depleted the reserves of 'easy to access' fuel (Peak Oil) and in part due to a lack of investment in the fuel supply chain infrastructure. The relationship between demand and supply is likely to result in an ever-increasing rise in the price of fossil fuel energy. Also as indigenous UK

supplies run short, the UK will become increasing dependant on importing energy from foreign countries. In a world of increasing international tensions it is far from certain we can depend on our energy supplies remaining secure. At a local level 97% of the energy consumed in Devon is imported. By implication the money to buy our energy migrates out of the County. This amounts to some £4.5 billion per annum. (source DCC Sustainable Prosperity Officer - 2006 figures)
The need is to find an affordable alternative energy supply that creates no or very low carbon emissions. The two candidates are; nuclear energy and so called 'renewable energy'.

Nuclear (fission) – The nuclear industry states there is sufficient Uranium in the UK to keep the current level of nuclear generation going for 80 years. However nuclear only produces electricity, as with conventional power stations the heat produced is lost to the environment. But nuclear only supplies ~20% of our electricity demand and electricity is only 15% of the UK's total energy demand. In other words nuclear supplies about 3% of our total energy demand. If nuclear were to replace all fossil fuel use we would need about 200 nuclear power stations.
Nuclear (fusion) – It is suggested that nuclear fusion could supply all our energy needs for ever but at present it appears there is approximately 35 years of development still needed before fusion becomes a reality.
Given the rate at which the concentration carbon dioxide is accumulating in the atmosphere, can we afford to wait that long?

There is no energy shortage, the planet receives enough energy every half an hour to maintain the entire energy needs of humanity for a year. Renewable Energy technologies can harness that energy however that energy is intermittent and dispersed throughout nature; this creates practical limitations on the availability of renewables.
What follows below is a description of the renewable energy technologies available in and around the Exeter area.

Micro-Hydro

The sun's energy heats up the oceans causing water to evaporate. The difference between the amount of solar energy trapped close to the equator and close to the poles causes movements of the air mass (winds). The water vapour is carried by the winds and as the air rises over high ground so the air cools and the water vapour precipitates out to fall as rain. Once the soil is fully saturated the excess rain flows off the land to form rivers that find their way back to the sea. This cycle is endlessly repeatable so long as solar energy continues to cause water to evaporate from the surface of the sea.

Limitations of report

This report is based on a desktop study using computer software (HydrA) and information gained from a site visit on 13th August 2008. The report is not intended to be a full design study, but should be regarded as offering a first order approximation of the potential energy capture, having regard to the barriers (environmental and physical) to development.

The report identifies the practical power available at each site, having regard to the barriers to development, to arrive at a realistic and practical figure for the annual energy capture.

Method

The geographical rainfall catchment area for a given site is defined by interpretation of OS maps. Met Office rainfall data and soil evaporation data from the Centre for Environment and Hydrology, is applied across the catchment to offer a prediction for the available flow. This together with data for the available head at the site allows a prediction of the theoretical potential power output to be calculated. Micro hydro is considered a 'non-consumptive' use of water, whereas abstraction for drinking water purposes, industrial processes or agricultural irrigation are 'consumptive' and reduce the flow available for micro-hydro. Historically many rivers have been over abstracted, and environmental concerns have seen the introduction of the EU Habitats Directives and EU Water Framework Directive, whose purpose is to restore rivers to their natural flow condition. Although micro-hydro is non-consumptive, there are environmental impacts and will be limits to the level of annual energy capture.

Hydropower theory

Hydropower is developed as gravity accelerates water through a vertical distance (head), the power output is a function of the product of both head and flow and may be expressed;

$$\text{Power (kW)} = \text{Head (m)} \times \text{Flow } (m^3/s) \times \text{gravity} \times \text{system efficiency}$$

Gravity is a constant = $9.81 m/s^2$

The gravity and system efficiency for a given turbine/generator set-up is a constant, and can be combined to a single numerical value. For most practical purposes the 'water to wire' output can be simplified and written as;

$$\text{Power (kW)} = 6 \times \text{Head (m)} \times \text{Flow } (m^3/s)$$

Using this formula it is evident different combinations of 'head' and 'flow' can offer the same result.

i.e. $\text{Power (kW)} = 6 \times 10 \times 1 = 60$

Alternatively $\text{Power (kW)} = 6 \times 1 \times 10 = 60$

In the first example the head is 10m and the flow is $1m^3/s$. In the second the head is 1m and flow $10m^3s$. Both give the same result. But if the choice exists, the former offers the more cost effective option, because a turbine capable of accommodating the larger flow will be more expensive than the smaller turbine required in the first example. The first example also demonstrates that smaller flows can do useful work. However, the option may not always exist because the head is a function of the form of the surrounding landscape.

At Exeter the River Exe is close to the end of its journey to the sea and the river is relatively flat. The only head available is that developed at the various weirs along this length of river. Since none of the weirs is more than 2.5 metres high, to capture any significant quantity of power, a large proportion of the flow will need to be utilised.

Annual energy capture is the product of the power available and the time during which that power is available.

Environmental issues

The Environment Agency is the 'Competent Authority' in relation to environmental matters and enforces environmental law in the UK. As part of the EU, the UK adopts EU directives. The relevant directives are; The EU Habitats Directive and the EU Water Framework Directive.

The EU Habitats Directive – The UK government has transposed this legislation and created a number of designated habitats known as 'Special Areas of Conservation' (SAC). [**Special Area of Conservation -** An area classified under the EC Habitats Directive as contributing to biodiversity by maintaining and restoring habitats and species.] A significant part of Exmoor (1895 hectares) is so designated (SAC UK0030148). The purpose is to protect the habitat and a number of species whose survival depends on the habitat remaining healthy. One of the species named in appendix 2 of the SAC is the Atlantic Salmon (Salmo salar).

The environmental impact of Micro-Hydro on Salmon

Salmon are anadromous. [Defn. *Anadromous* means fish, which spawn in fresh water and spend a portion of their lives in the ocean.] Salmon spawn in fast flowing moorland streams, such as those on Exmoor. The young fish spend 2-4 years in the river before migrating down stream (March – June) to the open sea. Here the juvenile fish adapt to salt water and consume the abundant food. Some years later, as adults, they return to the river they were born in and make their way back upstream (July – December), to the spawning grounds. On returning to fresh water they do not feed, and make the journey upstream using the energy reserves stored in their bodies. Salmon are noted for their determination and athletic ability to overcome obstacles, and may be seen jumping up waterfalls and weirs. That said, the extra effort expended in overcoming obstacles, may mean some fish become exhausted and die before reaching the spawning grounds, or make it in such poor condition that they are unfit to breed. In addition Salmon are flow-sensitive; they need a certain minimum flow of water to encourage them to migrate upstream. Flows in rivers naturally vary in response to the volume of water flowing off the land, which in turn depends upon the rainfall. Water flows can be further reduced by water abstraction. Some forms of water abstraction are classified as 'consumptive'. i.e. Where water is taken for public drinking water supplies and some agricultural and industrial uses. Other forms of abstraction, such as for fish farms and micro-hydro are 'non-consumptive' because all the water is returned to the river after a short distance. However, notwithstanding that all the abstracted water is returned to the river, there may be a length of depleted flow that prevents salmon passing that point of the river.

Under the Water Act 2003, the EA have the power to review the levels of abstraction and take measures to 'restore' the flow to the main stream. They also have power to refuse to permit new abstraction licences and the power to further review abstraction levels at periodic intervals.

The EU Water Framework Directive – The UK government has transposed this legislation and created the Water Act 2003. This gives the Environment Agency a duty to investigate the use of water within a river catchment, and power to review the level of water abstraction to restore habitats were necessary. (See the EA website for Restoring Sustainable Abstraction Program (RSAP).) The assessment of rivers is a continuing process and the EA publish their results in a 'Catchment Abstraction Management Strategy' (CAMS) for each river basin.

The River Exe CAMS - is divided into a number of Water Resource Management Units (WRMU). WRMU1 (Lower Exe) extends between the tidal limit at St James weir up to the confluence of the Rivers Exe and Creedy near Cowley Bridge. WRMU1 is relevant to this study.

The CAMS for the River Exe may be found on the Internet and downloaded as a four part pdf at; http://www.environment-agency.gov.uk/commondata/acrobat/cams1_760624.pdf

The following points are of note in relation to water use in WRMU1.

1) Fish Migration – St James Weir is the tidal limit of the River Exe. At low flows this weir used to be a barrier to fish migration, but this has now been resolved.

2) Gauging Stations – The EA maintain a number of flow gauging stations along the length of the River Exe and a number of its tributaries. Flow data is recorded allowing the EA to monitor flow levels and the impact of abstractions. One such gauging station is located at Trew's Weir and is the lowest station on the Exe. Care would need to be taken to ensure any future micro-hydro development did not adversely impact on the gauging station.
3) The EA have a weighting score they allocate to each river. A = ecologically most sensitive to abstraction; D = ecologically least sensitive to abstraction. The River Exe at Exeter attracts a score of 'C'. New licences – Over time, it is likely that 'Climate Change' may alter rainfall patterns and therefore the flow conditions in all rivers. The EA are charged with the duty to periodically review all abstraction licences. To facilitate this, current and new abstraction licences will be time limited to expire on a common date, 31st March 2016. Unless there is a good reason to review the abstraction there will be a presumption of renewal for a further 12 years. (See section 5.5.2 of the River Exe CAMS)
4) The River Exe CAMS is due to be reviewed and an updated strategy published in 2009.

Flood Risk Issues

The River Exe has a long history of flooding. Parts of the city are built on a flood plain, and to alleviate the risk flooding, a number of flood relief channels have been constructed to run parallel with the main river.


River Exe – Flood relief channel above the Mill on the Exe.


River Exe - Flood relief channel exit weir.


River Exe – Flood relief gate at Trew's Weir

Micro-hydro can alter the flow characteristics of a river and thereby introduce a risk of flooding. In the case of the River Exe the flood risk has long be recognised and flood alleviation measures put in place. About 1.5 kilometres upstream from The Mill on the Exe a flood defence scheme commences and runs parallel with the main river. The sill level of the intake weir (below left) is set above the normal river flow level. This ensures the river remains within its natural banks. However, if the flow becomes so high there is a risk of flooding, the excess flow spills over the upper weir and flows down the relief channel. The weir at the lower end (above middle) regulates the flow back into the river just below the Mill on the Exe. Downstream the river is engineered so that the water level can rise yet remain contained between high levees. At Trew's Weir (above right) a flood control gate is incorporated into the weir. Care would be needed to ensure any future micro-hydro development did not adversely impact on the flood risk.

Site Descriptions

Six sites are considered;

1) Cowley Weir (Grid Ref: SX 908 955)
2) Exwick Weir (Grid Ref: SX 906 950)
3) The weir adjacent to the, 'Mill on the Exe'. (Grid Ref: SX 914 926)
4) Cricklepit Mill (Grid Ref: SX 918 922)
5) Trews Weir (Grid Ref: SX 924 916)
6) St James Weir (Grid Ref: SX 930 909)

River Exe – Cowley Weir

River Exe – Above Exwick Weir

River Exe – Weir adjacent to the 'Mill on the Exe'.

Cricklepit Mill – the headquarters of Devon Wildlife Trust.

River Exe - Trews Weir.

River Exe – St James' Weir

The River Exe

The River Exe rises high on Exmoor at grid ref: SS 751 414. It flows east through Exmoor before turning south close by Dulverton, through Tiverton and Exeter to join the English Channel at Exmouth. A number of rivers such as the Barle, Quarme, Haddeo, Iron Mill Stream, Batherm, Lowman, Dart, Burn, Culm, Yeo and Creedy join the Exe along its route. Collectively these rivers drain much of North and East Devon and part of West Somerset.

At Exeter the combined catchment area of the Exe and its tributaries approximates to 1180 km^2. Across the catchment the average annual rainfall varies considerably. Parts of high Exmoor receive in excess of 1985mm whilst some of the lower altitude areas on the Devon/ Somerset border only receive 1100mm. Generally the high altitude areas have sparse vegetation and evaporation due to transpiration is low. The lower altitude areas are under cultivation and support much lusher vegetation so that evaporation due transpiration is much higher. South West Water abstracts water from the River Exe at Exbridge for public drinking water supplies. South West Water and Wessex Water jointly operate Wimbleball Reservoir both as an abstraction point for public drinking water and as a ‘pumped storage’ facility. In times of high flow, water is pumped from the River Exe into Wimbleball to be released in times of low flow to help maintain a minimum healthy flow in the mid and lower reaches of the Exe.

Site Flow Data

Each site is treated separately and in sequence starting at Cowley Weir and working downstream to St. James’ Weir.

Cowley Weir

About 300 metres above Cowley weir the River Exe divides (Grid Ref; SX 911 957). A portion of the flow takes an easterly route through Cowley weir and a portion takes a more westerly route through Exwick weir. The bifurcation point is above the confluence with the River Creedy (Grid Ref; SX 907 956) so the Creedy flow figures are not included. The flow at the bifurcation point is the natural flow in the Exe above this point less the abstraction at Exbridge. The management of Wimbleball is more complex to assess, but it is assumed that there is a net abstraction at the reservoir.

Site flow data - River Exe at Cowley Weir Grid Ref: SX 908 954
Catchment area A = 898 km^2 (Source HydrA)
Average rainfall across catchment R = 1105 mm (Source HydrA)
Average evaporation rate E = 510mm (Source HydrA)
Gross annual flow [A x (R – E)] Q_{gross} = 534,310,000 m^3/y
Mean annual flow $Q_{gross} \div (8760 \times 60 \times 60)$ = 16.94 m^3/s (Q_{mean})
Less abstraction at Exbridge & Wimbleball = 6.00 m^3/s = 11.00 m^3/s
Assumed proportion of flow east route @ 40% = 4.4 m^3/s
Design flow (assume 50% of flow) = 2.2 m^3/s

Head

Cowley weir (right) is a multi-stepped weir descending over six steps each of about 0.3m, giving a combined head of about 1.8m. The benefit of a multi-stepped weir is that salmon can progress up the weir one step at a time and so negotiate the weir more easily. From a civil engineering perspective each individual step is low, so the engineering is less critical than it would be for one big weir. From a micro-hydro perspective it will be more complex to develop hydropower. The amount of power available from a 0.3m head is very low and the weir would need to be re-designed so that the full 1.8m of head is available. This could be achieved by dividing the stream down the middle. One side would retain the original six steps of the present weir; the other side would be re-engineered to construct a weir the full 1.8m height. A turbine would be constructed in the weir and the water would be returned to the main stream at the bottom of the existing weir. This would create a short depleted reach and, depending on turbine type, may need to be screened to prevent fish passing through the turbine.

It is therefore assumed the weir could develop a head of 1.8m. If 50% of the available average flow is assumed the flow through the turbine would be 2.2m^3/s

Power output

Maximum electrical power output = $6 \times H \times Q_{rated}$

= $6 \times 1.8 \times 2.2 =$ **23.76 kW** (say 24kW)

Annual energy capture

Annual energy capture = electrical output x no. hours operational per year x load factor. (The load factor will vary according to the type of turbine installed) (Based on flow being available for 6000 hours per annum.)

Turbine type	Gross annual energy capture kWh/y	Mean annual energy capture kWh/y	Maximum power kW	Rated power kW
See below	180,000	144,000	30	24

Turbine Solutions

As illustrated previously, a high head/low flow combination or a low head/high flow combination can produce the same output result. At Cowley Weir the head is constrained by the topography of the landscape, so a low head solution is the only option. The turbine will therefore need to be able to accommodate an average flow of 2.2 m^3/s. This is a significant flow of water so the turbine will be large and therefore expensive. There are five turbine types that could operate with these head and flow parameters; Francis, Crossflow, Propeller, Kaplan & Archimedes Screw.

The Francis and Kaplan turbines are both complex and expensive to manufacture but can cope with some variability in flow. Neither is fish friendly and will need screening. The Crossflow is a simple construction and can accommodate a range of flow conditions. It runs at high speed and does not need a gearbox for the generator, but being high speed it is not fish friendly and will need screening. The Propeller turbine is simple to manufacture and relatively inexpensive, but is less capable of coping with variable flows. It will also need screening. All these turbines are prone to damage by foreign objects (floating debris carried down stream) if ingested. The Archimedes screw turbine is large but relatively straightforward to manufacture at a reasonable cost. It can accommodate a wide variation in flow conditions and is slow moving. Consequently, it needs a gearbox to drive the generator, but allows fish to pass through the turbine without injury. Indeed some fish farms use Archimedes pumps to move fish from one area to another. The Archimedes screw turbine will accommodate some debris without damage (although not whole tree trunks!).

The final choice of turbine will need an 'in depth' feasibility study and consultation with the Environment Agency to determine their view and agreement. If a short leat is constructed a simple propeller turbine may be appropriate.

Exwick Weir

Exwick Weir is located on the west branch of the River Exe below the confluence of the River Creedy. The flow at Exwick Weir will therefore be the sum of that portion of the flow in the Exe that does not pass through Cowley Weir, plus the flow from the River Creedy. Exwick Weir was originally constructed to impound water to supply a leat that took water to a mill at Exwick. There is no public access to Exwick weir (hence no photograph) so it has not been possible to clarify the water flow position. It is assumed the original leat infrastructure still exists but the mill itself does not use any water flow. There is a small stream at Exwick Barton that appears to discharge into the old leat part way along its length. For the purposes of considering the potential power available at Exwick Weir these flows are assumed to be relatively inconsequential.

Site flow data - River Exe at Exwick Weir Grid Ref: SX 906 950

Catchment area (River Creedy) A = 272 km^2 (Source HydrA)
Average rainfall across catchment R = 915 mm (Source HydrA)
Average evaporation rate E = 550mm (Source HydrA)
Gross annual flow [A x (R – E)] Q_{gross} = 99,280,000 m^3/y
Mean annual flow Q_{gross} ÷ (8760 x 60 x 60) = 3.15 m^3/s (Q_{mean}) [B]
River Exe flow at bifurcation point less % of flow that passes over Cowley weir = 11.00 – 4.4 = 6.6 m^3/s [C]
Combined flow (B + C) = = 3.15 + 6.6 = 9.75 m^3/s [D]
Design flow – assume 50% of [D] = 4.8 m^3/s

Head

The lack of public access to Exwick Weir has necessitated an alternative method of assessment. The weir is clearly visible on ‘Google Earth’ and appears to be a single step. The weir is listed in the Salford Study published in 1987 and is reported to have a head of 2.3m (Source- Salford Study ETSU - SSH 4063 Part 1 site No. 045003) (comment – the Salford Study indicates the correct OS grid reference for Exwick Weir but incorrectly attributes the weir as being on the River Creedy with only the flow from the Creedy catchment. ie it omits that portion of the flow from the Exe that does not pass through Cowley Weir.)

However similar environmental considerations, that apply to Cowley Weir, will apply here. The Google Earth image is not sufficiently detailed to accurately identify whether the weir has a fish pass in operation, or how easy or difficult it is for fish to pass the weir. It is assumed some civil engineering work will be needed to re-model the weir to both develop hydropower and ensure safe passage for fish. It is therefore assumed that no more than 50% of the flow is available.

Power output

Maximum electrical power output = 6 x H x Q_{rated}
= 6 x 2.3 x 4.8 = **66.25 kW** (say 67 kW)

Annual energy capture

Annual energy capture = electrical output x no. hours operational per year x load factor. (The load factor will vary according to the type of turbine installed) (Based on flow being available for 6000 hours per annum.)

Turbine type	Gross annual energy capture kWh/y	Mean annual energy capture kWh/y	Maximum power kW	Rated power kW
Propeller	420,000	397,500	70	67

Turbine solutions

Again this is a low head site and the same five turbine options should be considered as for Cowley Weir.

Mill on the Exe

The weir beside the 'Mill on the Exe' is one of the three large weirs on the Exe as it flows through Exeter. It occupies a prominent position with a new foot/cycle bridge (Millers Crossing) over the river. The weir is in two steps with the upper step (picture right) being located about 100m upstream of the main weir. This weir has a head of just less than 1 metre. There is a modern sluice gate immediately above the weir but it is unclear whether any flow is abstracted here.

The main weir (left) is located beside the Mill on the Exe Public House. The flow descends over the main slope of the weir to a 'plunge pool' then over a smaller step. When in full spate the weir is a spectacular example of waterpower. This main section of weir develops a head of about 2.0m. Because the upper and main sections of weir are separated by 100+ metres it will be difficult to link the two sections. A solution similar to that suggested for Cowley Weir is technically possible i.e. taking a proportion of the flow and channelling it down stream contained between walls, so it is delivered to the main weir about 1 m above its current level, then added to the height of the main weir to offer a head of about 3m. However this will entail significant civil works, will be visually intrusive, and may be unacceptable to both planners and the Environment Agency. Alternatively it would be possible to develop a solution specific to the upper weir alone. But with a head of only 1m or less, the economics may be marginal.

Considering the main weir there are a number of issues;

River Exe – Mill on the Exe Weir looking down sloping face towards plunge pool.

River Exe – Mill on the Exe Weir looking up across plunge pool showing bottom 'step'.

River Exe – Mill on the Exe Weir showing trash rack to intake to Cricklepit Mill?

These photographs were taken in mid August 2008 following several weeks of persistent rain and the river was in full flow, so the turbulence in the water in the plunge pool is plainly evident. Salmon would have little difficulty in negotiating the weir with this much flow, however at times of low flow the depth of water over the weir will be much reduced. To ensure adequate depth of water is always available for salmon movements, a low wall runs diagonally down across the slope of the weir (visible in the picture above left on the right hand edge in the middle distance) to retain flow in this part of the weir. To develop micro-hydro, some of the flow will need to be diverted through the turbine. Traditionally this was achieved by diverting some of the flow impounded by the weir, along a leat following a contour. As the natural bed of the river continues to descend so a head difference is built up. However this means that the river is deprived of that flow until the water is returned further down stream. Such a 'depleted reach' could act as a barrier to fish migration and the Environment Agency will want to ensure that there is always enough water to allow fish to pass. In the lower reaches of a large river, as discussed here, this is less of an issue because there is usually a very large volume of flow and more than enough for both hydro and fish migration. However where a weir already exists, there is an opportunity to utilise the weir itself to embed a turbine, therein avoiding the need to remove any water from the river even for a short distance. In order to get the water to flow through the turbine rather than over the crest of the weir, the sill level of the turbine will need to be lower than the crest of the weir. However, this may mean that in times of low flow all the flow goes towards the turbine, and none is left to flow over the weir for fish movements. This may be overcome by installing a 'notch' in the weir crest, the sill level of which is lower again than the turbine sill. Therefore there will always be water in the notch to facilitate fish migration. It may mean that in certain flow conditions there is insufficient water to flow over the weir crest leaving the face of the weir dry. This will have a visual impact on the look of the weir and may need public consultation.

From a hydro perspective it would be ideal to utilise all the water thereby drying the weir out completely, and leaving only just enough water in a fish pass to allow the passage of fish. However it is acknowledged this is unlikely to be acceptable on environmental grounds, therefore all assumptions in this report are based on taking no more than 50% of the average flow. This will mean that in times of high flow, such as shown in the photos, the excess flow will not be used and some hydro potential will be lost. Conversely in times of low flow there may be short periods when weirs do dry out.

Annual energy capture is based on the assumption that the average flow will be available for 6000 hours per annum. Lower than average flows may still allow some generation whilst higher than average flows will make no difference, because the system will be at full capacity anyway.

The flow at the Mill on the Exe will include the flow from all the tributaries less the abstractions at Exbridge and Wimbleball. Also Cricklepit Mill abstracts its flow from the intake sluice at this weir. The flow taken for Cricklepit is thought to be relatively insignificant in relation to the whole flow in the river, however an allowance is made.

Site flow data - River Exe at the 'Mill on the Exe' weir Grid Ref: SX 914 925

Catchment area A = 1180 km^2 (Source HydrA)
Average rainfall across catchment R = 1105 mm (Source HydrA)
Average evaporation rate E = 510mm (Source HydrA)
Gross annual flow [A x (R – E)] Q_{gross} = 702,100,000 m^3/y
Mean annual flow Q_{gross} ÷ (8760 x 60 x 60) = 22.26 m^3/s (Q_{mean})
Less abstraction at Exbridge & Wimbleball = 22.26 - 6.00 m^3/s = 16.26 m^3/s
Less Cricklepit Mill abstraction (0.26 m^3/s) = 16.26 - 0.26 m^3/s = 16.00 m^3/s [E]
Design flow = 50% of [E] = 8.00 m^3/s

Head

The weir is listed in the Salford Study published in 1987 and is reported to have a head of 2.0m
(Source- Salford Study ETSU- SSH 4063 Part 1 site No. 045004)

Power output

Maximum electrical power output = 6 x H x Q_{rated}
= 6 x 2 x 8.00 = **96.0 kW**

Annual energy capture

Annual energy capture = electrical output x no. hours operational per year x load factor. (The load factor will vary according to the type of turbine installed) (Based on flow being available for 6000 hours per annum.)

Turbine type	Gross annual energy capture kWh/y	Mean annual energy capture kWh/y	Maximum power kW	Rated power kW
Propeller	600,000	576,000	100	96

Turbine solutions

Again a low head site and the same five turbine options should be considered.

Cricklepit Mill

Site flow data - Cricklepit Mill   Grid Ref: SX 918 922

Cricklepit Mill draws it water from the weir at the 'Mill on the Exe'. The leat was covered over in the 1960's but the route runs approximately parallel to West St. to emerge just a few metres before the mill itself. The flow is controlled by a sluice gate at the head of the leat just above Millers Crossing. The leat's physical dimensions will limit its capacity to carry water without risk of flooding. Additional sluices just upstream of the mill control the flow to the two wheels. The flow at Cricklepit is therefore not a function of the size of the catchment and rainfall, but is directly controlled by the sluices. As a consequence, no catchment data is shown. The flow is subject to an Abstraction Licence and the licensed flow is 0.3m^3/s.

Cricklepit Mill can trace its origins back to the 1190's, although by the 1970's it was being used as a store. Following a fire in 1999 the mill has undergone extensive restoration and is now the Headquarters of the Devon Wildlife Trust (DWT). There are two water wheels at the site, one of the original undershot wheels and a recently refurbished Poncelet (a particular style of undershot wheel more energy efficient than a basic undershot) style wheel. Once a month the Poncelet wheel is operated for a few hours for public demonstration. The wheel could be used more regularly but is reported as being too noisy in operation to allow for regular daytime use.


Cricklepit Mill – Leat and control sluices


Cricklepit Mill – spillway showing water flowing through site


Cricklepit Mill – Recently re-instated Poncelet style wheel.

Thanks to the DWT for access.

Head

The head at Cricklepit Mill is developed in the leat that flows down from the Mill on the Exe. The leat has three sluice gates (picture left above) close by the mill. One controls the flow to the spillway (picture centre), one the flow to the newly refurbished wheel (right). A head of about 0.9m is developed.

Power output

Maximum electrical power output = 6 x H x Q_{rated}
= 6 x 0.9 x 0.3 = **1.6 kW**

Annual energy capture

Annual energy capture = electrical output x no. hours operational per year x load factor. (The load factor will vary according to the type of turbine installed) (Based on flow being available for 6000 hours per annum.)

Turbine type	Gross annual energy capture kWh/y	Mean annual energy capture kWh/y	Maximum power kW	Rated power kW
Propeller	12000	9000	2.0	1.6

1.6 kW installed capacity is about right for an undershot wheel. However 12,000 kWh/y will only go part way to meet the DWT's annual electricity demand.

Turbine solutions

At the very low head of 0.9m the options available are either a propeller turbine or an Archimedes screw turbine. The propeller turbine operates relatively quietly so may be the more appropriate but the Archimedes screw may be more photogenic.

Trew's Weir

Trew's weir is located towards the lower end of the Quay. The flow data here will almost exactly match that as at the Mill on the Exe. There is evidence that a former mill occupied the site. Much of the civil engineering works remain and the mill building has been converted into flats.

River Exe – Trew's Weir seen from the west side looking upstream and showing the flood relief gate to the left.

River Exe – Trew's Weir seen from the east bank.

River Exe – Trew's Weir showing the intake to the former mill site.

Similar considerations apply here as apply at the Mill on the Exe. It is reported that the Environment Agency maintains a gauging station at Trew's weir. Any alteration to the flow regime at the weir may impact on the gauging station and the EA may object.

However just above the weir is the entrance to the Exeter Ship Canal. Entry to the canal is controlled by lock gates, which are normally shut. However some flow will pass into the canal to maintain the level. It is assumed that any abstraction into the canal will be insignificant in relation to the gross volume flowing over the weir.

Site flow data - River Exe at Trews Weir Grid Ref: SX 925 915

Catchment area	A	= 1180 km^2	(Source HydrA)
Average rainfall across catchment	R	= 1105 mm	(Source HydrA)
Average evaporation rate	E	= 510mm	(Source HydrA)
Gross annual flow [A x (R – E)] Q_{gross}		= 702,100,000 m^3/y	
Mean annual flow Q_{gross} ÷ (8760 x 60 x 60)		= 22.26 m^3/s (Q_{mean})	
Less abstraction at Exbridge & Wimbleball		= 22.26 - 6.00 m^3/s = 16.26 m^3/s	
Exeter Ship Canal abstraction (0.26 m^3/s)		= 16.26 - 0.26 m^3/s = 16.00 m^3/s [F]	
Design flow at 50% of [F]		= 8.00 m^3/s	

Head

The weir is not listed in the Salford Study published in 1987. The head is estimated to be 2.0m

(There appears to be no figures available for Exeter Ship Canal abstraction)

Power output

Maximum electrical power output = 6 x H x Q_{rated}

= 6 x 2 x 8 = **96kW**

Annual energy capture

Annual energy capture = electrical output x no. hours operational per year x load factor. (The load factor will vary according to the type of turbine installed) (Based on flow being available for 6000 hours per annum.)

Turbine type	Gross annual energy capture kWh/y	Mean annual energy capture kWh/y	Maximum power kW	Rated power kW
Propeller	600,000	576,000	100	96

Turbine solutions

Again this is a low head site and the same five turbine options should be considered as for the above weirs.

St James' Weir

St James' weir marks the tidal limit of the River Exe. This poses a number of problems, for example, the head available at the weir will alter depending on the state of the tide. In addition, this will be the first weir encountered by Salmon returning from sea on their up-river migration to the spawning grounds.

River Exe – St Jame's Weir

River Exe – St Jame's Weir

River Exe – St Jame's Weir fish ladder showing notch.

It is reported in the Exe CAMS that salmon have difficulty in passing St James' Weir and a solution was being sought. That CAMS was published in 2004 and is due to be reviewed in 2009.

Site flow data - River Exe at St James' Weir Grid Ref: SX 930 908

Catchment area	A	= 1180 km^2	(Source HydrA)
Average rainfall across catchment	R	= 1105 mm	(Source HydrA)
Average evaporation rate	E	= 510mm	(Source HydrA)
Gross annual flow [A x (R – E)] Q_{gross}		= 702,100,000 m^3/y	
Mean annual flow Q_{gross} ÷ (8760 x 60 x 60)		= 22.26 m^3/s (Q_{mean})	
Less abstraction at Exbridge & Wimbleball		= 22.26 - 6.00 m^3/s = 16.26 m^3/s	
Exeter Ship Canal abstraction (0.26 m^3/s)		= 16.26 - 0.26 m^3/s = 16.00 m^3/s [F]	
Design flow at 50% of [F]		= 8.00 m^3/s	

Head

The weir is listed in the Salford Study published in 1987 and is reported to have a head of 2.5m (Source- Salford Study ETSU- SSH 4063 Part 1 site No. 045005)

Power output

Maximum electrical power output = 6 x H x Q_{rated}
= 6 x 2.5 x 8 = **120 kW**

Annual energy capture

Annual energy capture = electrical output x no. hours operational per year x load factor. (The load factor will vary according to the type of turbine installed) (Based on flow being available for 6000 hours per annum.)

Turbine type	Gross annual energy capture kWh/y	Mean annual energy capture kWh/y	Maximum power kW	Rated power kW
	780,000	720,000	130	120

Turbine solutions

Again this is a low head site and the same five turbine options should be considered as for previous weirs.

Summary

If all six sites were developed as suggested;

Site	Installed Capacity (kW)	Annual Energy capture (MWH)
Cowley Weir	24	144
Exwick Weir	67	397.5
Mill on the Exe	96	576
Cricklepit Mill	1.5	9
Trew's Weir	96	576
St Jame's Weir	120	720
Totals	**404.5**	**2422.5**

Carbon Savings

Assuming grid electricity emits 0.56 kg of CO_2/kWh (see appendix), then 2,422.5 MWH of hydropower generation would save 1,356.6 tonnes of CO_2 per annum.

Economics

The cost of micro-hydro is always site specific and vary anywhere between £1.2m – 2.2m per MWH installed. There is little point in offering a guess at likely development costs for any of the sites mentioned, as this will need a detailed design study for each site. If all six site listed above were fully developed and the energy were sold to grid @ £120/MWH (This is made up of the wholesale price of electricity plus Renewable Obligation Certificates) would amount to £290,700 per annum. Once operating, micro-hydro sites tend to be long lived and repay their developments costs many times over. But it is necessary to take a long-term view.

NOTE - the wholesale value of electricity varies in line with the cost of primary energy. Oil is used as the primary energy source against which other fossil fuels are also priced. The price of oil varies over time so the figure of £120.00/MWH is used to offer a guide only.

Conclusions

There is currently no power generation (Cricklepit only operates for a few hours each month and then only to demonstrate the wheel) at any of the six sites considered. Experience with 'in weir' Archimedes turbines is very limited in the UK so the EA are likely to be very cautious about this approach. Given that a flood relief channel exists for the Mill on the Exe and Trew's weir these seem good locations to start. With Cowley, Exwick and St James weirs, the question of protecting any turbine from inundation in the event of a flood, will need further consideration.

Recommendations

It is suggested;

- Establish early informal contact with the Environment (see Appendix – useful contacts) The EA prefer to be involved at an early stage so they can identify any 'show stoppers' before you become too heavily committed. They have a statutory duty to protect the rights of existing licence holders and ensure compliance with environmental legislation. The River Exe is a 'Salmon' river and the EA will want to ensure the environment is protected for their benefit. Be aware that recently Her Majesty The Queen has been granted permission to install a hydro scheme on the River Thames at Romney Weir just below Windsor Castle. The original consent was for Francis turbines. However, with the successful installation of the Archimedes Screw Turbine at the River Dart Country Park, the engineers commissioned to construct the scheme on the Thames have recently re-submitted their proposal, requesting permission to change the design to include Archimedes turbines. The planning decision is awaited at the time of this report.

- Establish early informal contact with the Planners. Any development will be highly visible at close quarters and they will want to enquire fully into any application. The planners have a statutory duty to consult with the EA, and may defer you until the EA has made their decision. Planners may want you to undertake a flood risk assessment for each site, and possibly an environmental impact assessment as well.
- Contact Western Power Distribution to establish how much power the local electricity grid can accept without the need to upgrade power lines.

Wind Power

The sun's energy heats up the land and oceans causing the air above to heat up. Warm air is more buoyant than cold air so the air begins to circulate. On a global scale the difference between the amounts of solar energy trapped close to the equator and close to the poles causes movements of the air mass, giving rise to winds.

Limitations of report

This section has been produced based on a desktop study and computer software to estimate the potential annual energy capture.

Method

Using the BWEA wind speed database, the average wind speed at 45m above ground level has been identified. This helps to identify locations around Exeter where it may be economic to install wind turbines. There are many barriers to development and these are discussed.

Wind power theory

Exploiting the power in the wind is an ancient technology, and traditional windmills used to form part of a working landscape in parts of the country, where the absence of high ground meant there was no scope for hydropower. Modern materials and research have improved the design and efficiency of wind turbines, offering scope for significant amounts of renewable energy capture. Any moving body of air contains energy by virtue of the mass of the air and its velocity.

If the average wind speed is known for a site, the annual energy production can be estimated by the formula

$$E\ (\text{kWh}) = 3.2 \times V_a^3 \times A$$

Where V_a - is the average wind speed in metres/sec

A - is the swept area of the turbine blades measured in m^2.

NOTE: this formula should be applied with caution as local conditions may adversely influence average wind speeds.

Source – EWEA, 1991; Anderson, 1992; Beurskens and Jensen, 2001; Open University RE Report, G. Boyle, page 267

The energy contained in the wind is proportional to the cube of the wind speed – double the wind speed gives eight times the energy.

Turbines extract energy from the wind by slowing down the wind that passes through the swept area of the blades, but the wind that passes through the blades soon recombines with the wind that bypassed the turbine, and a second turbine can be installed at a distance of about 20 rotor diameters downwind of the first. For electricity generation, the accepted wisdom used to be that an average wind speed of 7.0m/s was the minimum deemed economically viable to exploit. From an economic perspective, the higher the average wind speed the better. However continuing improvements in the performance of turbine blades and generators, combined with increased volume production and recent rises in the price of crude oil, have made it economically viable to exploit wind speeds of 6.5m/s and upward.

Commercial scale wind turbines (> 500kW)

The photograph shows a typical modern commercial scale wind turbine. Three blades rotate about a horizontal shaft; the pitch of each blade can be altered to optimise the angle of attack to the wind. The shaft supporting the blades drives a gearbox and a generator. The mechanical components are enclosed within a nacelle and the whole hub assembly is mounted on a turntable so the blades can be turned to face into the wind. The hub assembly is mounted atop a tower so the blades are located in a clean airflow. Typically a 1.3MW turbine (illustrated) will stand about 65m to the hub and have blades about 30m long.

Typically blades rotate between 20-30 rpm. Noise - All turbines create some noise. Noise emanates from one or more of three sources; 1) The tips of the blades. As the blades scythe through the air so small vortexes are set up at the blade tip, but these are dependant upon the speed the blade tip cuts through the air. If the blade tip speed can be kept low enough, minimal noise is produced. At a rotational speed of 30 rpm or below any noise is minimal. 2) Gearboxes. Certain designs of turbines need gearboxes but improvements in manufacture have reduced the noise output. Some designs do not need gearboxes at all so this source of noise has been completely eliminated. 3) Blade / Tower interference. As the blade passes the tower a gentle “whooshing” sound can be produced. There is no cure for this for upwind blades but downwind blades do not experience this noise. Fortunately the level of noise is very low and is not generally a problem.

Rotor Flicker – flicker is not normally a problem, but can exist when either the sun is low in the sky, and is viewed when looking through the swept area of the blades. Very occasionally the sun may reflect off the blades. Where a particular property is adversely affected it is possible to programme the turbine to stop whilst the shadow of the turbine passes over the house.

TV/Radio interference – In this day of modern communications microwave links abound. There is no alternative but to map all microwave links and ensure turbines are sited so as to avoid them.

Visual Impact – There can be no doubt turbines are dominant visual features in any landscape. Whether that impact is adverse or not is a matter of subjective opinion.

Loss of tranquillity – In order to eliminate noise from blade tips the rotational design speed is intentionally low. By definition therefore large turbines rotate at slow speeds. Whether these slow moving blades adversely impact on tranquillity is a matter of subjective opinion.

Environmental issues

Bird and Bat strikes - this is a highly emotive subject with very little hard evidence either way. There is ample evidence that birds occasionally fly into stationary objects such as buildings and overhead cables so it seems reasonable to assume that a few also collide with wind turbines. But how do numbers killed in collision with a wind turbine compare with road kills, and death resulting from loss of habitat from building development and or climate change?

The most quoted reference is that of a wind farm in the Altamont Pass, California http://www.countryguardian.net/case.htm#lbirds where it is reported that 200-300 Redtail Hawks and 40-60 Golden Eagles are killed every year. But in a classic case of ‘selective reporting’ certain essential details are omitted. The statistics date back to the late 1980’s. The turbines in question were ‘first generation’ machines with blades that rotated at 72rpm, at this speed they all but disappear in a blur. The turbines were mounted on open lattice towers. Both Redtail Hawks and Golden Eagles are ground feeders that swoop down at speed from a great height to catch ground squirrels. There is little doubt that significant numbers of these large birds, whilst focused on their prey, collided with either the blades or the tower of these older designed machines and were killed or injured. But modern turbines are of a totally different design. There is evidence that certain bat species may be killed by variations in air pressure in the vicinity of turbine blades but since most species feed on insects flying close to the ground the risk is low. The threat is species dependent and an Environmental Impact assessment should indicate whether there is a risk or not. In general terms modern slow rotating wind turbines are no more dangerous to birds and bats than a moving vehicle.

Efficiency

30% power factor – It is stated that for 70% of the time the wind is either not strong enough for the turbine to function, or is so strong the turbine has to shut down for safety reasons. It is argued that the visual impact of turbines outweighs the limited benefit. It is the case that modern wind turbines are designed to capture energy from the wind between certain speeds. As may be seen from the formula above the energy capture is a function of the cube of the wind speed. As the wind slows down so the energy capture drops off rapidly. As the wind speeds up the energy capture rapidly becomes very high. The 'holy grail' of wind turbine design is to produce a machine, the blades of which are light enough to capture the energy in a light breeze, yet strong enough to withstand the pressure of gale force winds. There are limits to the strength of materials, so being able to operate across 30% of the wind regime is actually very good. 'Power factor' and 'efficiency' are two different things but it is worth remembering that the National Grid is even less efficient. For every 100 units of primary energy delivered to a power station, 63 units disappear up the chimney or cooling towers as heat, 5 units are lost in the transformers, a further 3 units are lost in the transmission lines and about 7 units are lost due to inefficiencies in the end use, leaving about 22 units of energy to perform useful work. The energy blowing in the wind is there whether it is harnessed or not. Capturing 30% of it, is 30% more than not capturing any at all, and crucially it is low carbon energy!

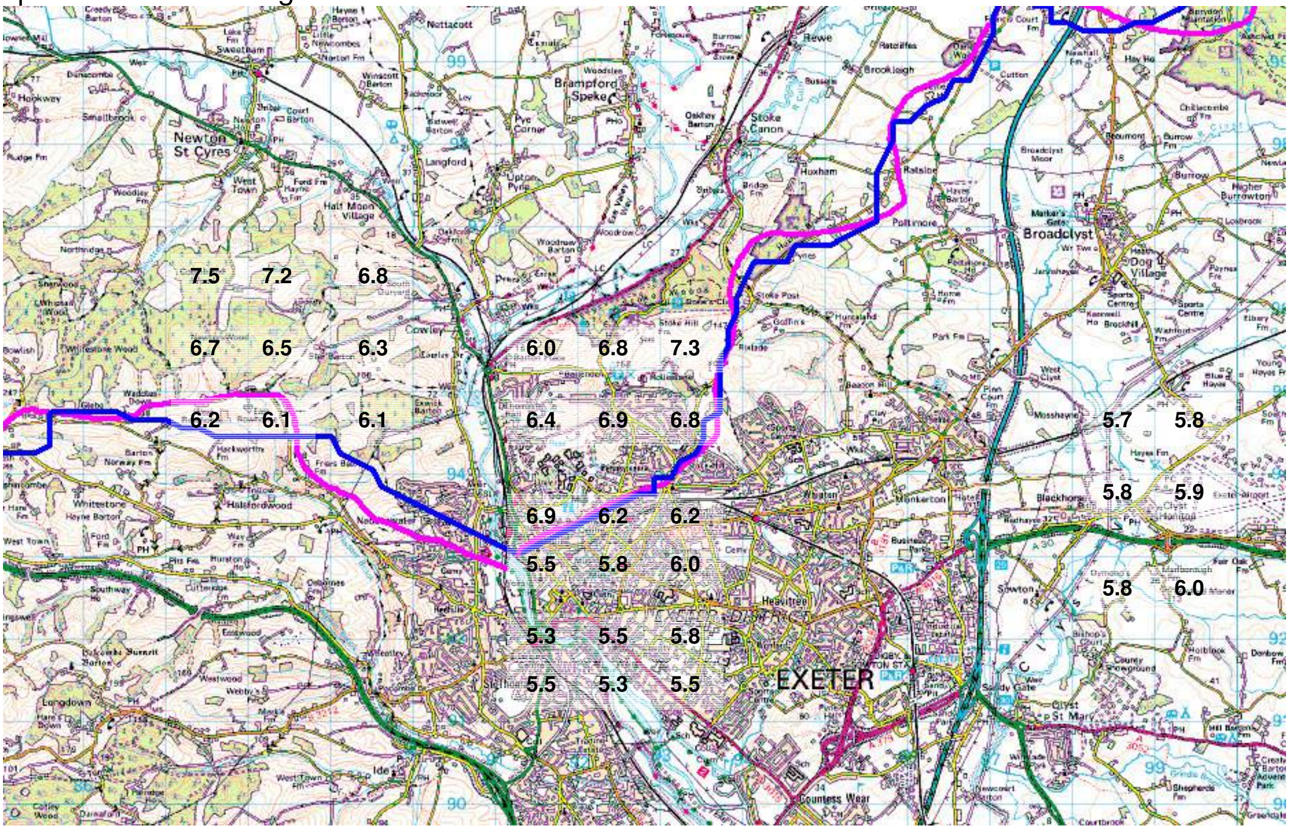
Air Navigation Safety

Exeter International Airport (EIA) lies about 7 kilometres due east of the city centre. The airport has an increasing economic importance in the region. EIA has published a document; 'Safeguarding, Risk Assessment and Land Acquisition'. Section 9.5. states; 'An extended safeguarding area has been established for wind turbine development. This area is a 30km radius from the aerodrome.' http://www.exeter-airport.co.uk/assets/Master%20Plan/9.%20Safeguarding.pdf A 30km radius is an excessive safety margin and needs to be challenged.

Radar interference – Many wind farm planning applications get held up due to objections from the aviation sector on the grounds that large-scale wind turbines cause interference and 'clutter' on air traffic control radar screens. Although the tower of a wind turbine is fixed, the rotating blades can, in some circumstances, cause unwanted radar reflections that may be mistaken for a low flying aircraft. The problem is conventional radar relies on emitting a pulsed beam and detecting the reflections of moving objects. Conventional radar beams sweep in a circle taking several seconds to complete 360°, each time the radar screen is refreshed the blades will have moved and so the image on the screen is recorded as a new object in the sky. A company called 'Cambridge Consultants' have recently demonstrated a new form of radar, 'Holographic Infill Radar'. "Holographic infill radar is a non scanning, continuous tracking 3D radar that can discriminate between turbines and aircraft based on easily observable differences in behaviour". Source – Professional Engineering, volume 21 number 19 page 43. HIR has been tested using the 66m diameter 1.8MW wind turbine at Swaffham in Norfolk and successfully differentiated between turbine and aircraft. This new radar should overcome objections to wind farms within sight of an airport.

The Wind Resource

Assuming the use of commercial scale wind turbines with a hub height of 65m, the average wind speed at 45m above ground level. Source - BWEA - NOABL wind database.



The average wind speed at 45m above ground level varies from 5.3m/s in the city centre to 6.9m/s on the top of high ground at Pennsylvania and Stoke Hill towards the north of the city. Outside the city limits, to the west, Waddles Down experiences an average wind speed of 7.5m/s but is very close to a large communications mast.

The economics of wind turbines

As indicated above, the energy capture is a function of the cube of the average wind speed. Over time, competition between turbine manufacturers, and improvements in design has seen the cost of turbines fall. As a broad rule of thumb, 1MW of installed capacity costs about £1m. (NOTE – there are many factors that determine the cost of a turbine installation, (grid connection, site access etc.) these figures are a general guide only.)

A 1.3MW turbine sited in a 7.5m/s average wind would capture about 3,845MWH/y. If the energy were sold to grid @ £120/MWH the annual income would be £461,400. An identical turbine sited in 6.5m/s average wind will capture about 2,563MWH/y giving an annual income of £307,560. Such a turbine will cost about £1.3m to install and the annual insurance, rates and routine maintenance costs will be very similar. However the turbine in the higher wind speed will generate half as much more income per annum and this could make all the difference between being able to service any loan repayments and interest charges or not.

Commercial scale wind turbines have been around for more than 18 years, banks and other financial institutions are now familiar with the associated risks, and are far more willing to consider lending for the capital cost of installation. The turbine located in the slower wind regime will earn less income, but it will eventually pay off its capital cost and interest charges. Whether it is an economic proposition will all depend upon the loan/equity ratio of the finance package. An average wind speed of 6.5m/s is about the minimum considered economically viable.

Other consideration;

1. As a general rule there is a 400m radius exclusion zone around turbines to limit noise pollution. Given the density of housing there is virtually nowhere within the city limits a turbine could be located and maintain a 400m-exclusion zone.

2. Planners wish to see an exclusion zone equal to the height of the turbine so that in the event of a catastrophic failure of the tower, the turbine will not fall onto anyone or property or across roads. It may be possible identify a few locations that satisfy this criteria.
3. Given the popularity of mobile phones there is now a vast network of communication masts all interconnected by microwave links. Invisible to the human eye these microwave links criss-cross the city and countryside like a dense spider's web. A turbine located directly in the path of a microwave link will cause interference, and having to avoid doing so will rule out a number of potential sites.
4. Exeter International Airport is just 7 kilometres to the east of the city. The main runway is directly aligned with the city causing aircraft on take off, or on final approach, to pass over the city. Any tall structure, particularly when sited on top of a hill, may be considered a hazard to air navigation and will result in objections from the Airport Authority.

Given these constraints there are a limited number of few opportunities for commercial scale turbine within or close to the city. But there are more locations outside, but relatively close to the city, that may be regarded as offering an economic opportunity for the installation of commercial scale wind turbines.

Carbon Savings

Assuming grid electricity emits 0.56 kg of CO_2/kWh (see appendix), then one 1.3MW turbine in a 7.5m/s average wind producing 3,845MWH/y would save 2,153 tonnes of CO_2 per annum.

Conclusion – Commercial scale wind turbines

Because of the various constraints mentioned above the only viable locations within the city are close to the northern boundaries. There are more opportunities on some of the hills surrounding the city.

Medium scale wind turbines (6 – 500kW)

In the UK historically there has been a limited market for this scale of turbine. This is because being over 15m high they are subject to the full planning process as required for the multi-megawatt sized machines. Quite simply the planning process isn't worth the hassle for the potential return from this size of turbine. However, many of the first commercial wind farms installed machines of around this size and are now looking to re-power with the latest multi-megawatt machines. The original machines are about halfway through their life expectancy. Because the cost associated with dismantling and transporting the original machines is about the same as their second-hand value, they are all but giving them away. Although a second-hand machine may be cheap to buy there is still a cost associated with planning, reassembling it and arranging the grid connection.

However these older machines do not benefit from the design developments of recent years so some may be relatively noisy. In other parts of the world there is a healthy market for this intermediate size of wind turbine so there are plenty of new machines to choose from. (Again Google, "wind turbines" or follow the links from the web address above.)

<ins>Costs</ins> - because this scale of machine can vary from cheap second-hand to new, and from 10kW to 600kW, prices vary enormously. Expect to pay anywhere between £50k to £600k. Again minimum average wind speed is crucial! (see Appendix – Energy White Paper)

Small scale wind turbines (1.5 – 6kW)

All the comments above remain true for this scale of turbine. The two most commonly available turbines in the UK are 2.5 – 6kW in size and designed to be mounted on masts about 10-15m high. This eliminates many of the barriers, such as hazard to air navigation and radar interference. Generally they are intended for installation in the countryside but it is perfectly possible to install them within an urban context. Illustrated (right) is a 6kW UK design

installed in the car park of commercial premises in Okehampton. The premises also have solar PV panels on the roof; together with the turbine and passive solar gain the premises import minimal energy from the grid.
Economics – This size of turbine is usually grid connected and mounted on a 15m guyed pole or unstayed mast as illustrated above. Prices vary but the 6kW machine (as illustrated above) costs in the order of £25k. A 6kW turbine in a 6.5m/s wind will capture about 19,200 kWh/y (19.2 MWH/y). 19.2 MWH @ £120/MWH will give an annual income of £2,300. It is assumed that this scale of turbine can be financed without the need for a loan; however there will be insurance, business rates and servicing costs to consider. It will take about 12 years for this scale of turbine to recover its costs. Again the minimum average wind speed is important, if sited in a 7.5m/s wind the turbine will recover its costs in less than 10 years. (see Appendix – Energy White Paper)

Domestic scale wind turbines (< 1.5kW)

Recently one national DIY chain has started selling a 1.5kW wind turbine intended for installation on the roof of domestic dwellings. The unique selling point is the ease with which the installation may be connected to the mains. It is fitted with a standard 13amp three-pin plug and is simply plugged into a suitable socket in the home. If thinking about installing a similar turbine the following issues need to be considered.

1. At 10m above ground level the average wind speed in parts of the city is about 4.0m/s. Since the swept area of these turbines is about 1m^2, the potential annual energy capture is only about 200 kWh/y.
2. By law, every generating appliance connected to the mains must be fitted with a safety device that isolates it from the grid in the event of a mains failure. This is to prevent spurious currents flowing back into the grid system that may cause fatal injuries to the lineman repairing the fault. For this safety device to work effectively it consumes a small amount of current from the grid, therefore in a low average wind speed location it is possible the wind generator could consume more energy than it generates. The minimum average wind speed is crucial.
3. At roof top level there is likely to be a high degree of wind turbulence between buildings and around rooftops, causing the turbine to continually re-orientate itself to each change in wind direction. Because of the gyroscopic effect of the rotating blades, energy is absorbed each time the turbine swings thereby further reducing the net output.
4. Most buildings are constructed to cater for the vertical loads of the building fabric, and not the lateral loads imposed by a wind turbine. Chimney pots are rarely strong enough to withstand the loads of wind turbines. Ensure any fixture is attached to part of the building fabric capable of taking the loads. Alternatively erect the turbine on a mast remote from the house.
5. It is almost impossible to eliminate the transmission of noise into the house from vibration of a house-mounted turbine. Another reason to erect the turbine on a mast and not the house.
6. Turbines do make a noise, consider the neighbours.
7. Planning permission is required. (There is talk of making domestic scale wind turbines ‘permitted development’ but at the time of report planning permission is still needed.)

Domestic scale turbines can be successful when installed in the right situation. Some of the issues mentioned above can be eliminated by appropriate design and there are about 20 different small turbines to choose from. Goggle; “domestic wind turbines” will give plenty of results. Two useful web pages are;
http://www.greenliving.co.uk/Articles/theeconomiccasef.html
http://www.bwea.com/pdf/small/mid-wales-microwind.pdf
Costs – there are so many small turbines available (some are designed for the marine market so are produced in reasonable quantity) the prices vary widely. It should be possible to buy a small system suitable for charging 12v batteries from about £400. Prices may rise up to about £5,000 for larger and more complex systems.

Conclusions – domestic scale wind turbines
On a £/kW installed, smaller turbines are more expensive than commercial scale turbines. Given that domestic scale turbines will be installed lower to the ground the wind speeds are likely to even

lower than for commercial turbines. It therefore seems unlikely there is much scope for domestic wind turbines for the average householder. However there may be some scope for installing this scale of turbine on the roof edge of high-rise office blocks where noise is not an issue and they will be barely visible from the ground.

Conclusions

Whilst not impossible, it does seem unlikely there is much scope to install commercial scale wind turbines in or close to the city. Domestic scale wind turbines may be appropriate for some households in some parts of the city where wind speeds are high enough, if they have a large enough garden to pole mount, and are far enough removed from neighbours that noise is not an issue. There may be some scope for medium and intermediate scale turbines associated with some industrial estates where the visual impact and noise will be less of an issue. It is difficult to quantify how much installed capacity may be possible.

Solar Photovoltaics

Photovoltaic panels consist of cells of very pure silicon that convert sunlight directly into electricity. The voltage produced by each individual cell is very small, so many cells are connected in series to produce a worthwhile output. Silicon is abundant but the process of purifying it to the high standard needed is very energy intensive, so PV panels are expensive. Their high cost has been a major factor in limiting their wider application.

PV cells are manufactured to three standards; Monocrystalline, Polycrystalline, Amorphous.

Type	efficiency	Area needed for 1kW	Annual energy capture
Monocrystaline	20%	6m^2	800 kWh
Polycrystalline	12-15%	10m^2	800 kWh
Amorphous	8-10%	20m^2	900 kWh

PV panels need to be mounted facing the sun. The ideal orientation is facing due south at an angle between 30^o to 40^o to the horizontal with <u>no</u> shadows at all. Any variation from this will reduce the energy capture – given the expense of PV, anything that reduces the output is best avoided. (see Appendix – Solar sundial.)

<u>Costs</u> - A 1 kW array costs between £7000 - £8000 installed. For larger arrays the unit cost per kW installed may come down slightly if installed at the same time.

<u>Payback</u> – If a 1kW array costs about £7,000 and produces about 800kWh/y of electricity, and if electricity is priced at £0.12p/kWh, then the annual value of the electricity captured will be about £96.00. Assuming electricity prices remain constant it will take about 73 years to recover the cost of the installation. NOTE – As electricity suppliers vie with each other to gain market share so deals vary over time. Scottish & Southern has recently been offering £0.18p/kWh. Good Energy offer their 'Home Generation' scheme that pays the same as they charge for electricity supplied irrespective of whether exported to grid or not.

<u>Exeter</u> - has 50,085 homes (Source - Exeter City Council) assuming a half of all roofs are orientated between southeast to southwest, and the footprint of the average house measures about 7m x 8m, the roof area facing the sun will be approximately 28m^2. This will give a roof area of (50,000 ÷ 2 x 28) = 700,000 m^2 available roof space for PV. Assuming monocrystalline PV is installed then 700,000 ÷ 6 = 116,666 kW of installed capacity. With an energy capture of 800kWh/y/kW = 93,332,800 kWh/y (93.3 GWH/y) is theoretically possible. However at £7,000 per kW it will cost a staggering £816,662,000 to install.

Carbon Savings

Assuming grid electricity emits 0.56 kg of CO_2/kWh (see appendix), then 93.3GWH of PV would save 52,248 tonnes of CO_2 per annum.

Solar Hot Water

There are two types of solar hot water panels, ‘flat plate’ and ‘evacuated tubes’. As the name suggests flat plate collectors consist of a flat plate of material coloured black to absorb the sun’s heat energy. Water is pumped through a series of pipes attached to the collector plate to transfer the heat from the collector to a hot water tank. The collector plate and pipes are enclosed in an insulated box with a glazed panel to allow the sun’s energy to enter. Flat plate collectors are relatively low tech so are cheaper than evacuated tubes. However despite the insulation some heat escapes. so overall efficiency is about 60%. Expect to pay from about £3000 + (including installation costs) for a system appropriate to an average sized domestic house.

Evacuated tubes consist of a series of twin walled glass tubes .The air between the walls is pumped out leaving a vacuum and the surface of the inner tube is coloured black to absorb the sun’s heat. This vacuum is effective as an insulator, with the result that 90% of the heat that is collected is captured. The tubes are ‘plugged’ into a manifold to transfer the captured heat to the hot water tank. Because evacuated tubes are more efficient, a smaller collector area is needed, but being higher tech they are more expensive. Evacuated tubes have the advantage that they work even on overcast days. Expect to pay from about £4500+, always getting more than one quote.

Beware of unsolicited mail drops. If you respond to them, the law will not protect you from their high-pressure selling techniques to install expensive systems (£11,000). They may be supplying a ‘Rolls Royce’ collector but in the final analysis hot water is simply hot water – and a cheaper collector system will do the job just as effectively.

Although frequently sited on the roof, solar hot water collectors can be installed anywhere with good access to the sun. Ideally they should face due south at an angle of about 40° degrees to the horizontal, but so long as they are facing between east, through south to west with minimum shadows falling across them, it is still possible to collect up to 90% of the available solar energy. Because solar hot water is much cheaper than PV it continues to be an economic proposition.

Of all the solar technologies, solar hot water has the shortest payback so should be the first technology to consider. Seasonal variation will alter the amount of energy collected. In mid summer the sun is in the sky longer and higher, so a system optimised for summer use will not collect enough energy in the winter. A system optimised for winter use will collect more energy in the summer than can be used with the risk of boiling the water and possibly causing damage to the components. Generally the safest and most economic arrangement is to size the collector for spring and autumn use, giving slightly more than enough hot water in the summer, and slightly less than required in the winter. Since most properties already have some form of water heating, the slight shortage in winter can be overcome by using the existing hot water system. Expect a solar hot water system to supply about 70% of your annual hot water needs. You may need to change your domestic hot water tank to include an ‘indirect’ coil so that the solar hot water can be connected.

It is possible to collect more solar hot water by installing a large accumulator tank (illustrated right). This is a very large hot water tank and capable of storing several days worth of hot water. Initial costs are higher, but the savings are greater. Over the year expect to collect an average of about 440 kWh/m^2 of hot water, although when the sun is shining brightly the instantaneous energy collected may be 790 kWh/m^2.

Where a collector is installed flush with the roof surface and does not protrude more than 200mm and adheres to other conditions, planning permission may not be needed as solar hot water systems can be deemed to be permitted development. However planning permission may be needed for listed buildings and in conservation areas, National Parks and AONB's.

(NOTE – it is often worth installing an accumulator tank with a conventional heating system (oil/gas/biomass) as this will allow the boiler to work hard for a period of time, heat up the tank and then switch off until next needed. This stops the boiler repeatedly switching on and off at short intervals, wasting heat by unnecessarily heating up the connecting pipes.)

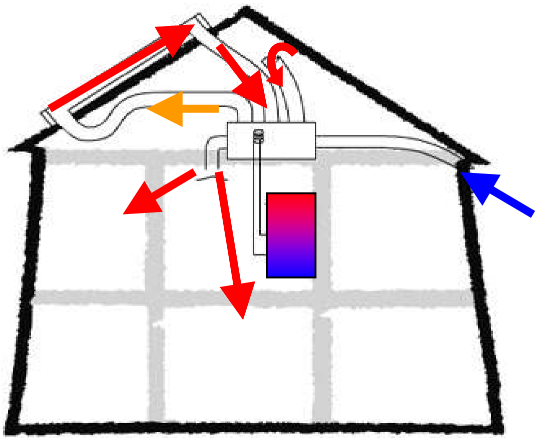
If all 50,085 households had a solar hot water collector of 3m^2 a total of 440 x 3 x 50,000 = 66,000,000 kWh (66 GWH) of energy could be harnessed.

Carbon Savings

The carbon savings will depend on which fuel is being replaced. If all water heating was done by electric immersion heaters the saving would be, assuming grid electricity emits 0.56 kg of CO_2/kWh (see appendix), [66GWH x 0.56 ÷ 1000 = 36,960 tonnes of CO_2 per annum. In reality water heating is more likely to be by oil and gas with a lower CO_2 emission.

Mechanical heat recovery and Solar hot air

One of the issues identified with older houses is the question of uncontrolled air infiltration, and if the property were fully draught proofed, the consequent risk of a build up of stale air. One solution is to install whole house mechanical heat recovery ventilation (MHRV). A heat exchanger, usually located in the loft, collects warm stale air from the loft space and passes it through the heat exchanger before venting it outside. Cold fresh air is brought in and passed through (separate air channels) the same heat exchanger to recover the heat from the outgoing air, and using it to warm the incoming fresh air. About 80% of the heat is recovered. A recent innovation based on MHRV is solar hot air systems. Air is drawn through a collector mounted on the roof and heated as it passes over black heat absorbing plates. The hot air is passed through a heat exchanger and is then ducted to the rooms in the house.



All houses need a change of air supply to maintain a healthy atmosphere. Experience with solar hot air systems in the UK is limited at present and costs vary.

As with solar hot water these systems may be installed as permitted development.

Carbon Savings

It is very difficult to quantify carbon savings for this technology. MHRV systems do need small fans to force the air though the heat exchanger therefore there will be some CO_2 emissions associated with the electricity used. Against this there will be savings subject to the fuel type used to supply the heat.

Energy from waste (Anaerobic Digestion - AD)

'Waste' may be classified in many ways, but in this context it is assumed to comprise residual material after full recycling. Hazardous waste is dealt with appropriately according to its type. In this section the report considers that fraction of the (domestic?) waste stream that is not otherwise recycled or subject to specialist treatment. For the most part this is the organic fraction such as vegetable peelings, left over food and green garden waste.

There is nothing new or innovative about anaerobic decomposition of organic waste, this is an entirely natural process using bacteria that are at large in nature. Typically any waste of organic origin will biodegrade, and in the right circumstances produce biogas (methane - CH_4) as a by-product. Anaerobic digesters make use of this natural phenomenon to capture the methane rather than allow it to escape into the environment. (Methane is 23 times more damaging as a greenhouse gas than carbon dioxide.)

The chemistry of AD is well understood and takes place in four stages;

1) 'Hydrolysis' - bacteria start to break down the organic material into simpler substances (sugars and amino acids).
2) This allows 'acidogenic bacteria' to further break down the sugars and amino acids into carbon dioxide, hydrogen, ammonia and other organic acids.
3) Acetogenic bacteria then convert the organic acids into acetic acid.
4) Finally Methanogenic bacteria convert the acetic acid into methane (CH_4) and carbon dioxide (CO_2). (Depending on the composition of the feedstock, some hydrogen sulphide may be produced as well.)

All four stages can take place simultaneously within a single digestion chamber, but because each stage has its optimum temperature, ph, and ratio of nutrients, a single chamber process is not very efficient. The preferred method of digestion is to use separate chambers for the different stages and to control the conditions to maximise efficiency. At ambient temperatures the whole process may take months, but usually the relevant bacteria work best between either 37^o – 41^o C (Mesophilic), or 50^o – 52^o C (Thermophilic). The Mesophilic process takes about 4 weeks, but the bacteria are more robust and able to accommodate some variations in the composition of the feedstock. The Thermophilic process takes about two weeks, but the bacteria are more sensitive to changes in the composition of the feedstock. Given that waste is produced daily, the processing plant needs sufficient capacity to retain all the waste over the processing period. It follows that a mesophilic processing plant will need about twice the volumetric capacity of a thermophilic processing plant.

Different feedstocks will produce varying amounts of gas. Animal slurries are rich in bacteria, but the animal's digestive system is very efficient in extracting the energy value from its food, so there is little energy left in slurry. On the other hand grass, food waste and green garden waste are rich in energy content, but contain no bacteria. To achieve a good methane output, a mixture of both bacteria and energy rich organic material is needed.

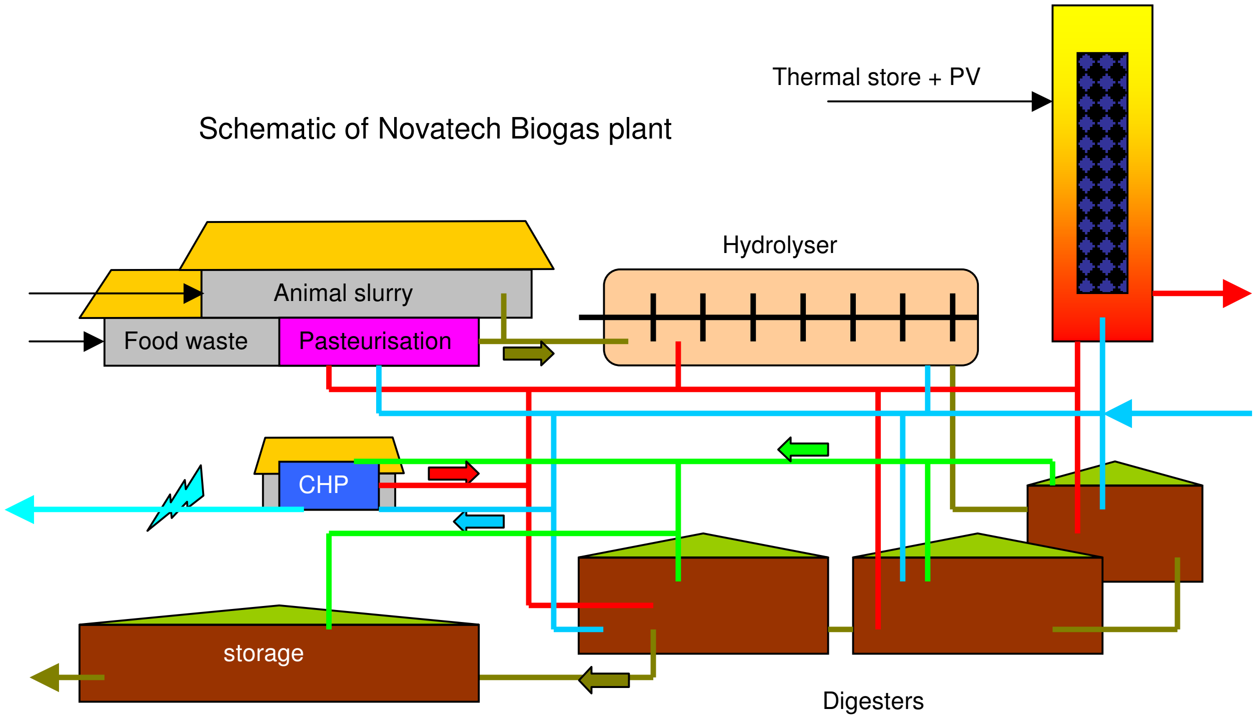
Historically different wastes have been treated in different ways. For example, Human waste is collected via the sewage system. Because humans eat meat, human sewage contains pathogens, and needs specialist treatment to prevent the spread of diseases. Farm animal waste tends to be stored, then, at certain times of the year, spread back on the land in the form of manure. Green wastes tend to be composted. (Composting is the aerobic equivalent of AD) Other waste is taken to landfill where it is buried, excluding air (oxygen). An uncontrolled form of AD takes place resulting in landfill gas being given off. Because landfill sites are at a premium, there is a drive to eliminate waste going to landfill; hence the need to look for better ways to manage waste and recover its value where possible.

Treating waste is subject to stringent regulations to protect the environment and ensure pathogens are adequately eradicated. For example, sewage treatment works are fully developed to deal with that specific waste stream. Sewage treatments works do not wish to receive other wastes that may compromise the integrity of their systems. Farmers have large quantities of animal waste, but do not wish to receive other wastes on their farms for fear of introducing diseases that may affect their animals. It therefore appears that municipal derived organic waste will need its own dedicated treatment process. There is nothing new or innovative about this, nearly every community in

Germany has been successfully operating its own AD plant, in some cases, for over 20 years. The following case studies illustrate a range of methods used.

Case Study 1 **Wolpertshausen** (putrescible waste)

Wolpertshausen is a village in SW Germany and claims to be 73% self-sufficient in renewable energy. This is made up of 880kW of PV (15%), Hydropower (300kW) (8%), Biogas 250kW (25%), Wind 1,200kW (25%) installed capacity. The biogas plant is run by a local company called, 'Novatech' who also install PV and solar hot water.



Schematic of Novatech Biogas plant

The biogas plant operates using local food waste, maize (grown as an energy crop) and cattle slurry. The feedstock is received in one of two reception halls. Photo below left - Food waste is received on the left side and slurry and maize to the right. After pasteurisation the two waste streams are mixed in the Hydrolyser tank (centre) where it is retained for about 1 week. The feedstock passes horizontally through the tank where contaminants such as metals, stones etc sink to the bottom and build up in a sump at the far end of the tank from which they can be removed. The feedstock is then pumped to the first of three digester tanks (picture right) for the acidogenic stage, before being pumped to the two larger digester tanks for the acetogenic and methogenic stages. Tanks 2 and 3 are larger to allow a longer retention time so allow a more complete digestion process. Note the vegetation growing over the tanks (picture right above) so they blend into the landscape. A small amount of feedstock is recirculated to ensure a good supply of bacteria to the whole process. This results in some methane being given off in each tank although the bulk is generated in the third tank. Like the UK, Germany has restrictions on the time of year when the digestate can be spread onto the land, so the final tank is large enough to accommodate six months supply of spent digestate. Although 95% of the methane has already been captured in tanks 1, 2 & 3, the fourth tank also has a cover to capture the remaining 5% of

methane that is given off over the storage period. Although this system is complex, every last drop of methane is collected. The methane is used on the site to power a CHP engine, and electricity is supplied to grid. Some of the heat from the engine is used to maintain the temperature of the digestion tanks, but the bulk of the heat is stored in a huge vertical hot water accumulator tank. The tank is insulated but the exterior is painted with heat sensitive paint so the entire community can see, at a glance, how much hot water is stored. Anxious to maximise the use of space the south facing side of the heat tower is covered in PV!

Case study 2 - **Gehrung GbR, Ostfildern** (putrescible waste)
This is a 100kW biogas plant on a small farm in SW Germany. The farmer keeps cattle and pigs and has a small acreage of land on which he grows maize. Before feeding food waste (pig swill) to pigs was made illegal, he had a contract to collect food waste from local restaurants and residential homes. Once it became illegal to feed swill to his pigs he had a problem; he was contracted to collect food waste but then had no way to dispose of it. His solution, invest in his own biogas plant.

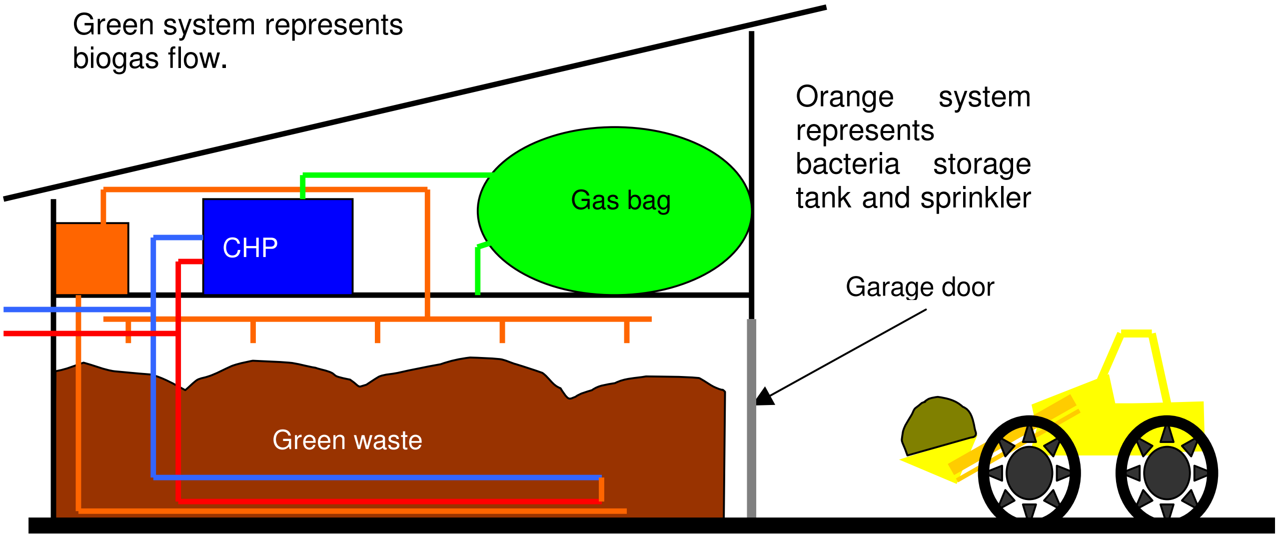
The farmer supplies 'wheelie bins' to all his clients for the waste food. He collects the bins daily using his own lorry, and on returning to the farm the bins are emptied into the pasteurisation unit (picture left). The bins are then steam cleaned ready for the following day. The food pasteurisation unit is housed in a separate building on a different part of the farm and uses waste heat from the CHP engine. Once pasteurised, the food waste is pumped via a pipeline to the mixing vat (centre) where cattle and pig slurry are mixed in. The combined feedstock is then fed by an auger screw into the single digestion tank (under the green domed cover). All stages of digestion take place in the single tank. Retention time is about a month then the digestate is siphoned off into a large open storage lagoon (right) to wait spreading on the land. The electricity is sold to the grid; the heat is used to maintain the temperature of the digestion tanks and is carried via district heat main to the pasteurisation building. The digestate is spread on his own land. The farmer was very strict that the study tour party were not permitted to visit the remainder of the farm where the animals were housed.

In contrast to case study 1, this biogas plant is much simpler, but undoubtedly less efficient at extracting all the methane from the feedstock. Germany operates a system of 'feed in tariffs' so the farmer receives an above average price for his electricity for the first 10 years to pay off his capital costs.

Case Study 3 - **Biomassehof, Langenau** (not putrescible waste)
This is a municipal owned biogas plant designed to deal primarily with green garden waste. Langenau is a town of about 20,000 population in SW Germany. The local council provide a green waste collection service, but residents can also take their green waste to the biogas site (Picture below left). The process is a 'dry fermentation process' but is known locally as the 'garage' process, because the plant looks like a row of lock up garages (centre). Seven hermetically sealed chambers (large enough to drive a fore-end loader into) are located beside each other. The green waste is loaded into the chamber all but filling it. The doors are closed and sealed. Heat from the CHP engines is pumped around pipes, embedded in the concrete floor and walls, to heat the waste. A small quantity of liquid cattle slurry, stored in a separate tank, is sprayed from overhead showerheads to 'inoculate' the green waste with methanogenic bacteria. The inoculant percolates down through the green waste and is collected in a sump and re-circulated. Initially the chamber does contain some air (oxygen) but this is soon consumed and the process becomes anaerobic

within 24 hours. Four days later the second chamber is filled – and so on. The methane is collected in a large gasbag (picture right) extending the whole length of the floor above the digestion chambers. The upper floor also houses the CHP engines and other control equipment.

After 28 days the first chamber is emptied leaving a small amount of digested waste behind to inoculate the next batch. The digested green waste is tipped on a different pile to continue composting aerobically, and finally it is graded and sold as soil conditioner.



Arguably green garden waste is not a biohazard, so straightforward aerobic composting is the simple and cost effective way of dealing with this waste stream. Adding cattle slurry turns otherwise benign waste into toxic material, but the result is added value because AD is essentially composting but without oxygen, thereby allowing methane to be produced and captured. This process is based on a 28 day retention period but if further chambers were added, thus extending the retention time, it may be possible to recover a higher % of methane: It is a question of economics. Gas production starts slowly, reaches a peak, and then tails off again. Additional retention time will allow more gas to be collected, but will require more digester volume, and that has a capital cost implication. So there comes a point where it becomes increasingly less economic to collect more gas. It should be noted that green garden waste is likely to consist of a high proportion of woody material. Cellulose and lignin are difficult to deal with and need additional composting post digestion.

AD Issues

- There will be an educational issue to persuade households to separate their waste. This is already happening with dry wastes such a metals, plastics, paper etc. but may be a problem with potentially noxious material such as organic wastes.
- Existing contractual arrangements: District Councils have a duty to collect waste. County Councils have the duty to dispose of it. They will already have contractual arrangements with waste disposal companies. These companies will have a huge investment in their existing infrastructure and will not want to see their income streams diminished.

AD in Exeter

Exeter already has a bio-digester owned and operated by South West Water at their Countess Wear, Waste Water Treatment Works. The primary feedstock for the plant is human sewage collected from across the city.

Thanks to SWW for access

Picture above left shows one of the two single chamber digesters with the mixing tanks in the foreground. Centre is a methane gas storage holder, and pictured right two of the four CHP engines. Whilst most of the treatment works operates by gravity, there is a large demand for energy to operate tertiary treatment, to ensure the final discharge is clean enough to go back into the tidal section of the River Exe. Across its many sites SWW is the largest single producer of renewable energy in the southwest. However, over all their operations they consume more energy than they produce.

As may be expected, SWW is subject to very stringent monitoring to ensure their final discharge meets quality standards. It seems unlikely they will want to accept waste of uncertain provenance that may disrupt the viability of the bacteria in their digesters.

AD Economics

Recently the Cornwall Agri-food Council (CAC) has commissioned Michael Köttner & Dr. Sigrid Kusch of the International Biogas and Bioenergy Centre of Competence (IBBK) to carry out economic modelling on a range of biogas case studies on Cornish farms. The results tabulated below, make interesting reading.

Study	1	2	3	4	5	6-1	6-2	7	8
Substrate	Cow Grass maize	Cow Poultry Potatoes straw	Cow Grass straw	Cow Grass wheat	Cow potatoes	Pig Cow grass	Pig silage	Cow Horse silage	Cow Maize food
Tonnes/y	2,350	10,405	4,260	6,500	17,670	22,900	28,435	5,060	42,530
CHP installed kW$_e$	75	499	190	104	250	250	499	75	860
Annual Electricity MWH$_e$/y #	393	3180	1165	717	1300	1450	3100	370	5090
Annual heat MWH$_{th}$/y #	362	2690	940	445	825	820	2185	285	3290
Revenue El (£/a) ^	56,985	461,100	168,925	103,965	188,500	210,250	449,500	53,650	738,050
Revenue Th (£/a) >	0	125,890	43,990	20,826	38,610	38,376	102,258	13,338	153,972
Gate fee									62,000
Total Revenue (£/a)	**56,985**	**586,990**	**212,915**	**124,790**	**227,110**	**248,626**	**551,758**	**66,988**	**954,022**
Write Off cost (£/a)	-119,219	-476,692	-271,430	-134,511	-164,064	-208,678	-515,221	-106,331	-934,214
Profit/Loss (£/a)	- 62,234	110,298	-58,515	-9,721	63,046	39,948	36,537	-39,343	19,808

NOTE – this table is loosely based on the Cornish Study. The substrate, volume, installed kW and energy exported are similar and although the table is modified slightly to show the economics more clearly it remains valid.

= energy available for export after self-consumption to run AD process.

^ = assumes wholesale price of electricity 5.5p/kWh + 2 x ROC's @ 4.5p/kWh = 14.5p/kWh = £145/MWH

> = assumes heat sold @ 4.68p/kWh based on 90% of oil price = £46.8/MWH

Write off costs assumes Digesters written off over 20 years, pipes and pumps - 13 years and CHP engine - 7 years. It also includes capital cost amortised over 10 years and wages.

To view the full report go to; http://www.cornwallac.org/renewables/anaerobic-digestion.php

Conclusions – Cornish study

Studies 1-7 rely solely on 'on farm' substrate, only one farmer (Study 8) was willing to contemplate accepting 'off farm' waste onto his farm. Study 1 had no heat demand close by, so would not be able to sell heat, however even with selling heat would not have been profitable. Study 8 was only profitable by charging a gate fee for ‘off farm’ waste. The lessons seem to be where an AD plant operates solely on animal slurry (of whatever type) and grass or maize, it is only profitable if the installed capacity is over 250kW and they can sell the heat. Where food waste is part of the substrate mix, a gate fee needs to be levied.

However three points need to be made. 1) Farmers have a different problem than Local Authorities: Farmers are using low energy animal slurry; in contrast Local Authorities have quantities of higher energy content waste available. Logically an AD system mainly reliant on food waste, with a small % of animal slurry to provide the methanogenic bacteria, may be able to generate sufficient biogas to operate profitably. 2) Of necessity the Cornish Study had to reflect the technology available at the time. 3) The Cornish study had to reflect the value of energy at the time of the study. However the Energy White Paper, currently out for consultation, is looking at the possibility of introducing a ‘Feed in’ tariff’ system for renewable energy projects. If the options under discussion come to pass this could completely alter the economics and AD may become viable. (see Appendix – Energy White Paper)

Exeter waste - Enquiries of Exeter City Council Waste Management Officer indicates 6657 tonnes of green garden waste was collected from recycling centres and DCC collections in 2006/2007. However it is also recorded that 27,118 tonnes of waste was collected from dustbins that were not recycled so went to landfill. There are no recorded details of the make up of this waste, but it is quite likely that a proportion of this waste will be organic and could contribute to an AD system. No figures are available for volumes of food waste collected.

There is insufficient data to predict how much methane could be produced from Exeter’s waste. However if Langenau (see case study 3 above), a town of 20,000 population, can support a dry fermentation process, then Exeter with a 119,000 population should also be able support such a process. None of the case studies above exactly replicates Exeter’s situation, but a hybrid scheme with two reception areas; one for food wastes to be pasteurised and one for green garden waste, together with a methanogenic bacteria agent to inoculate the mixture, may offer an economic solution.

Carbon Savings

It is difficult to quantify the carbon savings from AD. Natural gas emits 0.19kg CO_2/kWh. (see appendix) If the gas were used as a direct replacement for natural gas then the savings would equate to 0.19 kg CO_2/kWh. If the gas is used in a CHP engine then depending on whether the heat can also be used the CO_2 saving could result from both the electricity and fuel to supply heat that might be displaced. But there are further savings, when putrescible waste roots down in the air (composting) CO_2 is released. When putrescible waste rots down without air methane (CH_4) is released, as in landfill sites. Volume for volume methane is 23 times more damaging to the environment than CO_2, therefore using putrescible waste to produce energy will displace a significant volume of environment damaging emissions.

Conclusions - AD

Using existing biogas technology and with current support mechanisms (Renewable Obligation Certificates) , the economic viability of AD appears marginal at best. However using a feedstock that contains plenty of energy (food waste and green waste) may offer better prospects than using all but spent animal waste. Also (see appendices – section on emerging technologies) there are several innovations to improve the density of bacteria and reduce the retention time that should improve the economics significantly. It is unlikely that any Local Authority will wish to experiment with anything perceived as ‘risky’ as their duty is to dispose safely with waste in a cost effective manner. Therefore further research is needed to prove the reliability and economics of improved digestion methods.

An additional thought, - instead of burning methane in a CHP engine, it may improve the economics to produce higher value products by:- exporting the gas to the national gas grid for use as space heating in homes or the methane could be used to produce bio-methanol as a road fuel.

Conclusions

Exeter has scope for a number of renewable energy technologies, but no one technology offers a ‘quick fix’; there is either a serious cost implication, environmental and/or planning constraints for all technologies.

Electricity could be generated at all of the hydro sites investigated within this report. That said the EU Habits Directive would impose environmental constraints on development. Planning could be an issue because any development will be visible. However this need not be an insurmountable barrier, if the people of Exeter decided they wanted to show the world that micro-hydro can have popular support.

Solar PV is a mature technology and could be widely adopted but for its cost. It looks increasingly likely that costs will fall by a factor of ten within the next couple of years. Many houses could then benefit.

Solar hot water is a mature technology and should not present too much of an issue, there is no good reason why this should not be adopted by every individual household today.

Windpower, at whatever scale, is frequently controversial. This is unfortunate, because as the economics of wind turbines improves, lower wind speed sites become viable, and the number of potential sites increases. Wind is the one technology that could supply almost limitless renewable energy. However given the existing constraints, opportunities within the city boundary are limited, but there is more scope on the hilltops around the city.

Anaerobic Digestion has exciting possibilities. Recent developments to improve the economics offer a really good opportunity, but the technology is just not quite ready. Once a fully functioning prototype is proven, it will still take time to convince local authorities to invest. There may be opportunities for the private sector here.

Micro-hydro and AD represent two technologies whose application will challenge the authorities. Archimedes turbines are well established in Europe but are new to the UK regulators and certainly have not been installed ‘in weir’ on this scale. If successful their installation would be something that Exeter could be justly proud of. They would be highly visible at close quarters and there may be a ’green tourism’ spin-off. Again AD is well established in mainland Europe but is only beginning to be adopted in the UK.

For Exeter to meet 35% of its energy demand by 2020 will be a very tall order and need all the opportunities discussed here to be adopted.

Appendices

Solar sundial

Available solar radiation (as a % of the maximum available using a static array) depending on orientation to sun and angle to horizontal.

		West						South						East
		-90	-75	-60	-45	-30	-15	0	15	30	45	60	75	90
vertical	90°	56	60	64	67	69	71	71	71	71	69	65	62	58
	80°	63	68	72	75	77	79	80	80	79	77	74	69	65
	70°	69	74	78	82	85	86	87	87	86	84	80	76	70
	60°	74	79	84	87	90	91	93	93	92	89	86	81	76
Inclination to horizontal	50°	78	84	88	92	95	96	97	97	95	93	89	85	80
	40°	82	86	90	95	97	99	100	99	98	96	92	88	84
	30°	86	89	93	96	98	99	100	99	98	96	94	90	86
	20°	87	90	93	96	97	98	98	98	97	96	94	91	88
	10°	89	91	92	94	95	95	96	95	95	94	93	91	90
horizontal	0°	90	90	90	90	90	90	90	90	90	90	90	90	90

Carbon Savings

Different primary energy sources produce different amounts of carbon emissions per kWh of energy generated. Defra publish conversion tables for Kg of CO_2 per kWh for different fuels and may be found at; http://www.defra.gov.uk/environment/business/envrp/pdf/envrpgas-annexes.pdf The table was last updated in July 2005 and remains valid with one exception. The figure for grid electricity is shown as 0.43 kg of CO_2/kWh, however this figure is dependent upon the mix of primary fuels used to generate that electricity. Since this table was published several nuclear power stations have had to shut down for repairs and the lost generating capacity has been made up by using more fossil fuels. At the date of report (November 2008) the emissions for grid electricity is 0.56 kg of CO_2/kWh. This figure may fall again if and when some of the nuclear power stations come back on line.

Energy Efficiency

This report is primarily intended to assess the potential RE resource available to Exeter. However it would be a failure of duty, to neglect to point out that the least polluting and cheapest energy of all is energy saved. 'Energy Efficiency' has been around for many years and perhaps, as a society; we are suffering from energy efficiency fatigue. We all know we should switch off, turn down, boil only just enough water for our cup of tea, and turn the tap off whilst cleaning our teeth etc. Yet there are still homes with filament light bulbs, no draught excluders on letter box flaps, no cavity wall filling, no, or insufficient loft insulation, and stand by lights on. We all know it makes sense, yet at a subconscious level, 'energy efficiency' is associated with 'miserliness'. Renewable Energy on the other hand is associated with 'conscious free' energy use. There is nothing more enjoyable than luxuriating in a nice hot bath secure in the knowledge that the hot water came free, heated by the sun from the solar panel on your own roof. Energy Efficiency measures and Renewable Energy should always be used together. Neither on their own guarantee reduced use of 'brown' energy or any real carbon emission savings.

Renewable Obligation certificates (ROC's)

ROC's are the mechanism by which the UK government support renewables. It is widely accepted that most renewable technologies have a capital cost implication. The oil producing nations know full well that they have a finite resource that will run out one day. They are fully aware that there are alternative energy sources that could replace oil, and therefore OPEC controls its production so as to maintain the price of oil to ensure that renewables cannot compete, so they maximise their profits whilst they can. ROC's are a premium paid to renewable energy generators to close the pricing differential between fossil fuels and renewables.

In order to encourage the uptake of renewables, the government has given the energy utility companies an ever-increasing target to supply more renewable energy. Failure to meet these targets results in a fine. Likewise heavy industry has been set targets to reduce its energy consumption, again enforced by a system of fines. The money collected from the fines is redistributed to renewable energy generators; one ROC is paid for every MWH of electricity generated. When ROC's were first introduced each ROC was valued at £30.00, but ROC's are a tradable commodity, and the value varies according to how much renewable energy is generated in relation to the current target set by the government. The ROC system is administered by OFGEM.

Energy White Paper

At the time of report an Energy White Paper is out for consultation. It is not intended here to go into detail. Go to:- http://www.berr.gov.uk/energy/whitepaper/page39534.html Understanding the policy framework for supporting renewables in the UK is essential reading for anyone contemplating becoming a small generator. But be warned there is a lot to read and it is not for the faint hearted. One of the proposed changes is to the banding of Renewable Obligation Certificates (ROC's). Go to:- http://www.berr.gov.uk/files/file39569.pdf - section 5.3.1. page 151. Another option being considered is to adopt 'Feed in tariffs' along the lines already in operating in several EU member states. Go to:- http://renewableconsultation.berr.gov.uk/consultation/annex-feed-in-tariffs-for-small-scale-electricity/annex to have your say. (Google, "Feed in tariff" to find more information.) As an alternative to paying ROC's, one option being put forward is to support small generators (<50kW installed capacity) by paying them £400.00/MWH. If adopted this could make all the difference for technologies such as AD.

Useful contacts;

Hydro
Environment Agency

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National Permitting Centre – Team Leader
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e-mail: tamsin.sutton@environment-agency.gov.uk

The Environment Agency like to be involved in any proposed micro-hydro development at an early stage so they can identify any 'show stoppers' thus avoid wasted effort with a proposal.

Archimedes Screw Turbines

Archimedes Screw Turbine installed embedded in the downstream face of a weir with by-pass channel alongside.
www.ritz-atro.de

Archimedes Screw turbine installed at a weir but not embedded in the face of the weir.

Archimedes Screw Turbine installed at River Dart Country Park. Screw is a double helix 10m long by 2.0m diameter. Set at an incline of 22° to the horizontal and develops 48kW.

Archimedes Screw Turbine installed at River Dart Country Park. Showing water flow in segments between blades.

Screws can be manufactured up to 10m in length and accommodate flows up to 5500l/s. The screw is able to accommodate variable flows by adjusting its speed of rotation. At the top of the turbine shaft is a multi stage step up gearbox, with a final drive to the generator mounted above the gearbox. The turbine at the Dart Country Park is set at the end of a leat fed by a flow impounded at a weir some 300m upstream.

The River Dart Country Park turbine is the first Archimedes Turbine in the UK and was installed by a local hydro engineer. Contact Chris Elliot, e mail; chris@westernrenew.co.uk
Web; www.westernrenew.co.uk