Executive Summary
Rye-grass as an Energy Crop Using Biogas Technology

Aim

The overall aim of this project is to prove that rye-grass in the UK is a viable energy crop for conversion to biogas.

Background

Anaerobic digestion is the natural biological process which stabilises organic material in the absence of air and produces renewable energy in the form of biogas (60% CH_4 & 40% CO_2) and digestate, a bio-fertiliser.

Rye-grass is a wet energy crop which can be transferred into useful energy by anaerobic digestion. The key features of such a concept are:

- the UK has one of the best climates in the world for growing grass;
- the high moisture content of grass is not a draw-back since anaerobic digestion is a wet process;
- the primary constituents of the biogas are only carbon, hydrogen and oxygen;
- carbon not transformed to biogas may be sequestered into the soil;
- the process presents a new opportunity for farm diversification without the need to plant new crops or invest in specialised equipment;
- it will provide the UK with an energy crop that will not alter the aesthetic landscape of the countryside.

Project Structure

The main elements of the project are:

- The harvesting of rye-grass from 39 individual experimental plots, 36 plots measuring 10m^2 and three plots measuring 100m^2. The grass plots are assigned to a cutting regime of either two, four, six and eight week cycles, and are cut at 50mm or 100mm. The grass is weighed, samples taken for analysis, and ensiled for storage.
- The operation of two pilot scale digesters fed rye-grass cut from the 10m^2 trial plots. Each digester is monitored 7 days per week, measuring the characteristics of the feedstock, digestate and the volume and quality of the gas. The first pilot anaerobic digester had a volume of 0.3m^3 and ran for the first half of the project. The second system has a volume of 1.5m^3 and ran for the remainder of the project.
- The operation of a 20m^3 biogas plant fed on the rye-grass cut from a large area of grassland. The primary objective of this biogas plant is for engineering purposes in order to move towards the design of a commercial plant.
- The outline design, economics and energy balance of a commercial rye-grass to biogas plant.

Summary of Results

Trial Plots

The trials showed that grass cut on an eight week cycle and cut at 50mm height produced the highest annual dry matter yield. Plots that were applied with digestate produced higher yields than those that received none. The grass plots were found to be nitrogen deficient which was partly indicated by the low yields; this proved that the application of the digestate as a bio-fertiliser using only that produced by the grass would not be sustainable. The report therefore recommends importing farm manure or slurry to give the grass the extra nutrients it requires to produce better yields.

Carbon nitrogen ratios of 15-30:1 are most suitable for anaerobic digestion. The most suitable ryegrass feedstock for anaerobic digestion is grass cut on a two or four week cycle at 100mm. This grass had C:N ratios of 23:1 and 18:1. When storing the grass through ensiling, only small losses of nitrogen and carbon were found resulting in a feedstock that could be stored and used all year round.

Pilot Digesters

The 0.3m^3 digester was designed and built for this project; it ran from September 2003 to December 2004. The innovative design of this digester, in that the heat recovered from the mixing pump was used to heat the digester, meant that if there was a pump failure due to blockages both the heating and mixing was disrupted causing biological problems. It was decided that a tried and tested pilot digester would be used to run the trials with no reliance on pumps to mix and heat the contents of the digester which would allow the grass to digest without interruption. This 1.5m^3 digester ran from January 2005 – May 2005. The mean average gas yields, measured in cubic metres of methane per tonne of organic dry matter, can be seen in Table 1.

Table 1

Date	Digester	Feedstock	$m^3_{CH4}.t^{-1}_{ODM}$
Sept. '03 – Nov '03	300 litre	Silage	325
March '04 – July '04	300 litre	Fresh Grass	229
Jan. '05 – May '05	1500 litre	Silage	357

The project was time limited and trials on fresh grass in the 1500 litre digester were not carried out. Both digesters had a stable and higher methane production when being fed ensiled grass as opposed to the fresh grass which did not produce consistent results.

20m^3 Biogas Plant

The 20m^3 biogas plant has proved a very useful engineering and design tool for the commercial model. Two major changes were made:

1. An external heat exchanger was fitted which meant that the digester has no internal mechanical parts. When the digester calls for heat a pump recirculates the digester contents through a concentric tube heat exchanger, this both heats and mixes the digester contents and is similar to the original 0.3m^3 design.

2. A macerator pump has been added to the feedstock reception tank. The feedstock is mixed and chopped prior to being pumped into the digester; the new macerator is located in the feed line ensuring that particle size is reduced which gives a larger surface area for the bacteria to break down.

Commercial Design

The commercial scale biogas plant has been designed to take in a variety of feedstock both solid and liquid. Results from the pilot digestion trials showed that a digester fed only grass becomes a very delicate environment and less biologically stable compared to a digester that has co-digesting feedstocks.

The feeding mechanism will be a combination of an auger to feed in the solids and a holding tank for the liquid from where it will be pumped into the digester. All tanks are to be covered to maximise methane capture. The gas holder will be incorporated in the top of the digestate storage tank; this will reduce the footprint of the plant without the need for additional floor space for the gas holder. The solid & liquid fractions of the bio-fertiliser will be separated to allow easier handling of the liquid and economic gain to be made from the sale of the solids as a compost material.

The economics of the commercial design, which includes the anaerobic digestion of ryegrass and slurry, only just break even with a 15 year pay back period. This highlights the need to maximise the sales and use of electricity, heat and digestate to make the plant financially viable.

Energy balances and ratios are looked at within this report. The energy balance and ratio of producing biogas from ryegrass on a commercial scale is very positive especially in comparison to bioethanol and biodiesel production, shown by Table 2. This comparison uses the work of Mortimer et al[1,2].

Table 2

Crop	Biofuel	Energy Balance $GJ.ha^{-1}.y^{-1}$	Energy Ratio (input:output)
Wheat	Bioethanol	34.67	1:2.3
Wheat	Biogas	68.48	1:3
Oilseed Rape	Biodiesel	18.25	1:1.8

It is important that the energy balance is considered with the energy ratio; if a crop and fuel combination has a high energy ratio the benefits are limited if the amount of energy returned is small.

Conclusion

Grass harvested on 2 and 4 week cycles at 100mm have good C:N ratios for anaerobic digestion (18-23:1). There is a small lignin and high cellulose contents in grass cut on a 2 week cycle. Cellulose material breaks down rapidly producing biogas a lot quicker than ligneous material which takes much longer to degrade.

The trials have shown that ryegrass requires more fertiliser that it can provide itself through its own digestate. It is suggested that slurry would be an ideal organic

[1] Mortimer, Elsayed, and Horne, 2004, Energy and Greenhouse Gas Emissions for Bioethanol Production from Wheat Grain and Sugar Beet, Sheffield Hallam University.

[2] Mortimer, Cormack, Elsayed and Horne, 2003, Evaluation of the Comparative Energy, global Warming and Socio-economic Costs and Benefits of Biodiesel, Sheffield Hallam University.

fertiliser to provide the grass with the extra nutrients it requires; it could also become an additional feedstock to co-digest with the grass enhancing the digestion process. This is especially important on a commercial scale where maximising methane production is vital.

Ensiling the grass makes it possible to achieve a constant yield of biogas throughout the year. Ensiled grass produced a higher average methane yield of 342 $m^3_{CH4}.t^{-1}_{ODM}$ compared to fresh grass with 229 $m^3_{CH4}.t^{-1}_{ODM}$. It is possible that during the ensiling process the breakdown starts the production of acids beneficial to the anaerobic digestion process.

The maximum feasible methane yield recorded was $3800m^3_{CH4}.ha^{-1}.y^{-1}$, which when converted to electricity would produce $11.7MW_e.h.ha^{-1}.y^{-1}$. This figure could be improved by the introduction of another feedstock to co-digest with the ryegrass, e.g. slurry already imported for grass fertilisation.

At the time of writing, financially it is unlikely that farmers will invest in a farm biogas plant for energy production using ryegrass unless a large capital grant is available. However, the energy balance for biogas production is high, especially when comparing it against the production of biodiesel and bioethanol. Renewable energy is set only to become a bigger issue; the reform of the Common Agricultural Policy forcing farmers to grow crops that have real monitory value, combined with the continuing rise in the price of oil, will make anaerobic digestion a real option for energy production.