INTRODUCTION

AD plant for agricultural waste can be conceptually very different as shown in Figure 1. Plants can be designed for single feedstocks from single farms through to multiple feedstocks from several farms and agricultural industries. On the output side, plants produce gas and digestate. Both of these products can be sold or can be further processed before sale to give products such as heat and electricity from the gas or fibrous soil conditioner and liquid fertiliser from the digestate.

Figure 1: Options for anaerobic digestion
The conceptual design of the system will affect economics through the effect on capital and operating costs and plant revenue. For example, in many cases agricultural wastes attract no disposal fee but other agro-industrial wastes generally do. There is also the possibility of selling the digestate as fertiliser but this requires market development. In some cases the digestate will be returned to farmers who supply feedstock free of charge, in which case it is likely that the farmers will have some financial stake in the plant.

These variations should be taken into account when comparing the costs and revenues associated with various plant. However, for the plants being considered here, there is insufficient data available to cost plant on a common basis. The following analysis uses actual data from real plant with varying configurations. So, when interpreting the information presented, it is important to note that the figures for different plant are not directly comparable. However the information is suitable for identifying general trends.

In common with many types of project with environmental implications, the analysis presented here does not account for all of the costs and benefits. For example the environmental and nuisance costs resulting from current manure handling and treatment methods are not included as they are not given monetary value by the market economy. However projects may be established by farmers, local communities or local authorities, in which case these bodies may be able to realise these environmental values, not as cash flows but through reduced complaints, better local relations and improved environmental conditions. There is also a trend towards increasingly tight environmental controls on agricultural activities which may lead to farmers having to pay to dispose of manures unless they can use treatments to make them suitable for land spreading or sale to others.

A comprehensive economic analysis should include any avoided costs of disposal or avoided environmental costs. However such an analysis is beyond the scope of this technical summary. This technical summary uses costs data for the following plants:

- three Austrian operating farm scale plants (full data only available for one);
- ten Danish operating CAD plants (full data only available for seven);
- two German hypothetical farm scale plants (derived from studies of operating plants);
- one Italian operating farm scale plant;
- three Swiss operating farm scale plant;
- two UK operating farm scale plant and data for a typical proposed CAD plant.

Using this data the following parameters are calculated:

- capital cost per m³ of digester volume;
- capital cost per GJ in the biogas;
- capital cost per kW electrical export capacity.

As the data available is not on a consistent basis, economic analysis such as looking at simple payback, internal rate of return (IRR) or net present value (NPV) would give misleading results. Therefore two generic plant are analysed: a farm scale digester with 25kW electrical export capacity and a centralised digester with 1MW electrical export capacity. Sensitivity analysis is then carried out on these generic plants.
COSTS

Capital cost per m$^3$ of digester volume

Whilst the rate of treatment of organic material in a digester will depend on several factors, such as the nature of the material, the digester temperature and digester mixing, the size of the digester tank can be taken as a proxy for treatment rate. Therefore the capital cost per unit volume of digester gives an indication of the cost for the treatment of a given amount of organic material. Figure 2 shows how cost per unit volume varies between different plants in different countries.

From Figure 2 there appear to be clear differences in the costs of plant between countries. For the farm scale plant, Switzerland and Austria appear to have the highest costs, at between 1000 and 2000 ECU/m$^3$, whilst Italy and Germany have the lowest costs, at under 400 ECU/m$^3$. However this difference is largely due to different technical approaches. Many German plants are constructed by farmers using readily available parts. It is possible that such plants have higher maintenance costs, lower performance and shorter lives but this would require verification (the next section on capital costs per GJ in the biogas does give an indication of performance). The Italian plant is of low cost as it is a relatively simple tank covered with a plastic membrane. The Swiss and Austrian plants tend to be commercially supplied equipment.

A factor which may be driving these different approaches to the technology is that Italy and Germany have no capital grants whereas in both Switzerland and Austria capital grants are available from public funds. So, when considering these costs, it is important to consider the context in which plant are built, the funding available, the use to which the plant will be put etc.

Figure 2: Capital cost ECU per m$^3$ of digester volume (1997 prices)

The data for the centralised AD plant is only from Denmark. Figure 2 does show costs for centralised AD plant in the UK but, as no plant has yet been constructed, the costs can not be considered proven. However the proposed UK plant do appear to be cheaper than the Danish plant.

Comparison between the data for farm scale plant and centralised AD plant does not indicate a clear difference in cost/m$^3$ between these scales. The data does however indicate a clear difference between commercially supplied equipment and plants where the farmers take a large role in plant construction.
Capital costs per GJ in evolved biogas

Capital cost per unit volume provides a measure of cost from the viewpoint of material treatment. However if energy is an important driver, capital cost per unit of energy recovered is a better measure. Figure 3 shows the variation in capital cost per unit energy content of the biogas.

The data in Figure 3 should be treated with some caution as the energy recovered will depend on the feedstocks as well as the digester design. Ideally figures would be used for similar feedstocks but such data were not available.

Figure 3: Capital cost ECU per GJ in the biogas (1997 prices)

As with the capital cost/m³, the capital cost per GJ in the biogas is highest for Austria and Switzerland with Germany and Italy being the cheapest. The difference between these cheaper plants and the more expensive ones has been reduced due to the higher gas yields from the latter. The Danish plant costs have fallen relative to other countries compared to the cost/m³ of digester volume. This is due to the considerable effort the Danes have put into raising gas yields and minimising gas leakages. It is also striking how similar the Danish plant costs are compared to the case for cost/m³. This may be due to the fact that some of the early, smaller plant, which had the highest capital costs/m³ have been able to attract a relatively high proportion of food processing wastes, which give high gas yields, due to their small size.

Capital costs per kW electrical export capacity

Capital cost per kW electrical export capacity gives an indication of the technology’s effectiveness as a renewable energy source.

Figure 4: Capital cost ECU per kW electrical export capacity (1997 prices)
As most of the Danish plants do not generate electricity directly themselves and there are variations in own use for those which do, the electrical generation capacity was calculated from the total gas yield. As Figure 4 shows, this means this indicator closely follows that for capital cost/GJ in the biogas. From Figure 4 plant vary from about 4000 to 50000 ECU/kW. Care must be taken in using these figures. For example the cost data for some of the Danish plant includes various non-standard items such as district heating equipment and heat pumps but does not include generator sets in all cases. Hence the reason for producing the generic cost studies which follow.

**ECONOMICS**

The capital cost of plants only gives part of the picture. Operating and maintenance costs and revenues may also vary. Looking at various economic indicators allows the combined effect of the various costs and revenues to be considered.

Table 1 shows the base case assumptions for two scales of plant. The capital and operating costs are based on the averages from the centralised and farm scale AD plants considered in Figures 2 to 4. For capital cost this used the average ECU/kW electrical export capacity from the centralised and farm scale plants in Figure 4.

**Table 1: Base case assumptions for generic plant**

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<tr>
<th></th>
<th>Centralised AD plant 1MW electrical export capacity</th>
<th>Farm scale plant 25kW electrical export capacity</th>
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</thead>
<tbody>
<tr>
<td>Capital cost (ECU)</td>
<td>9,113,000</td>
<td>500,000</td>
</tr>
<tr>
<td>Operating cost (ECU/y)</td>
<td>643,000</td>
<td>8,800</td>
</tr>
<tr>
<td>Electricity price (ECU/kWh)</td>
<td>0.06</td>
<td>0.06</td>
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<tr>
<td>Heat price (ECU/kWh)</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Digestate sales income (ECU/y)</td>
<td>700,000</td>
<td>20,000</td>
</tr>
<tr>
<td>Gate fee income (ECU/y)</td>
<td>0</td>
<td>0</td>
</tr>
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Simple payback was calculated by dividing the capital cost of the plant by the net annual income. Net annual income is assumed to be the difference between plant revenue and operating costs (excluding financing costs).
The IRR was calculated based on the cash flows (excluding financing costs) over a 20 year plant life. IRR being the discount rate required to give a NPV of zero. This gives an estimation of the cost of capital which can be sustained by the project to just break even over the project’s life. If the actual cost of capital is less than the IRR the project has the potential to make a profit in real terms.

Table 2 shows the calculated payback period and IRR for the plant assumptions in Table 1. In both cases the payback periods are long and the IRRs low, and do not appear economically attractive. However, whilst the assumptions given in Table 1 represent plant with average costs and income, in reality there are many opportunities for improving the economics. For example digesters are available with lower costs than those indicated, higher energy prices may be available, gas yields can be improved and gate fees can be obtained for digesting feedstocks such as kitchen wastes or food processing wastes. Hence it is important to always consider the economics of a particular situation rather than rely on generic analysis.

<table>
<thead>
<tr>
<th>Table 2: Payback and IRR for generic plant base case</th>
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<tr>
<td><strong>Simple payback period (years)</strong></td>
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<tr>
<td>Centralised AD plant 1MW electrical export capacity</td>
</tr>
<tr>
<td>Farm scale plant 25kW electrical export capacity</td>
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To attempt to give an indication as to how the possible variations just discussed might affect economics, sensitivity analysis have been carried out. For each parameter shown in Table 1 the effects of varying its value on payback and IRR has been calculated. Figures 5 to 16 show the results of this analysis. In each case only the parameter shown varies from the base case values shown in Table 1.

**Capital cost sensitivity**

Figures 5 and 6 show the effect on IRR and payback period of reducing the capital cost. Farm scale plant, at the size being considered here, have been built for 150,000 ECU and 1 MW electrical centralised plant are being proposed at around 6million ECU. The figures show that using these realistic costs significant improvements in plant economics can be made compared to the base case.

**Figure 5: Centralised AD plant - capital cost sensitivity**

**Figure 6: Farm scale AD plant - capital cost sensitivity**
Operating cost sensitivity

There is probably less scope for reducing the operating costs in the base case compared to the scope for capital costs. However in some cases, for farm scale plant, farmers do not attribute their time to the plant. This can be an important factor influencing the farmers’ perspective of costs. However, if plant start to become unreliable, farmers are more likely to start regarding the plant as taking up their time.

For centralised plant operating costs may be linked to capital costs so care must be taken when considering these sensitivities. For example automation can reduce operating costs but will increase capital costs.

**Figure 7: Centralised AD plant - operating cost sensitivity**

**Figure 8: Farm scale AD plant - operating cost sensitivity**
Electricity price sensitivity

The base case electricity price of 0.06 ECU/kWh represents a premium price in many countries. In Germany and the UK biogas plants have recently received about 0.075 ECU/kWh and in Italy even higher values. Where there are opportunities for own use of electricity its value is even higher. In this case it is the purchase, rather than the sales price, which should be considered, perhaps giving electricity used a value of 0.1 ECU/kWh.

As well as actual increases in the value of electricity, this sensitivity (in conjunction with the heat price sensitivity) is a proxy for increasing gas yields. For example, increasing gas yield by 10% is approximately equivalent to increasing the electricity and the heat price by 10%.

Heat price sensitivity

Figure 11: Centralised AD plant - heat price sensitivity
The base case price represents an average value which could be expected for selling heat. As with electricity prices, heat has more value if used by the plant owner than if sold. The value of heat will also depend on the available alternatives. The base case value assumes natural gas is available but other alternatives are likely to be more expensive, increasing the value of the heat sold by the AD plant.

**Digestate sales income sensitivity**

Markets for digestate sales are developing. The base case assumes all digestate can be sold at relatively modest prices which is the current situation in most countries. However, as plant operators raise the quality of the digestate, this product can compete more directly with mineral fertilisers and other soil improvers. Where AD plants are part of an organic farming system, the digestate may be able to get certification from the various organic farming associations and hence attract a higher price.

Where farmers use the digestate themselves there will be no cash income. However the costs of avoided mineral fertiliser use can then be included in place of this income.

**Figure 13: Centralised AD plant - digestate sales income sensitivity**
Gate fee income sensitivity

The base case assumes no gate fees are received. In many cases there will be opportunities to treat organic wastes from food processing, local authorities, hotels etc. Some of these waste materials can attract significant gate fees. The opportunities for treating these organic wastes are likely to increase in EU countries as a result of the Landfill Directive which sets targets for reducing the quantities of such wastes landfilled.
As an example of interpreting these sensitivity graphs, consider the farm scale AD plant modelled. In Table 1 the assumed capital cost was 500,000 ECU based on the average of the plants studied. However there are real opportunities to significantly reduce this cost. Plant are available at this scale costing 150,000 ECU. From Figure 6, it can be seen that this reduction has the effect of increasing the IRR from 0.2 to almost 20% and reducing the payback period from 20 to about 6 years. This plant is than looking economically attractive.

Table 3: Optimistic assumptions for generic plant

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<th>Centralised AD plant</th>
<th>Farm scale plant</th>
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</thead>
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<tr>
<td></td>
<td>1MW electrical export</td>
<td>25kW electrical export</td>
</tr>
<tr>
<td>Capital cost (ECU)</td>
<td>7,500,000</td>
<td>150,000</td>
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<tr>
<td>Operating cost (ECU/y)</td>
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<tr>
<td>Electricity price (ECU/kWh)</td>
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<td>0.08</td>
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<td>0.01</td>
<td>0.02</td>
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<td>700,000</td>
<td>20,000</td>
</tr>
<tr>
<td>Gate fee income (ECU/y)</td>
<td>300,000</td>
<td>10,000</td>
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</tbody>
</table>

Table 4: Payback and IRR for generic plant optimistic case

<table>
<thead>
<tr>
<th></th>
<th>Simple payback period (years)</th>
<th>IRR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centralised AD plant 1MW electrical export capacity</td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td>Farm scale plant 25kW electrical export capacity</td>
<td>4</td>
<td>31</td>
</tr>
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To further examine the effects of varying costs and revenues, Table 3 shows the assumed values for a more optimistic scenario which is based on figures which have been achieved in reality.

The values in Table 3 lead to economic plant for both the centralised and farm scale plants as shown in Table 4. Here the centralised plant has a payback period of 7 years and an IRR of 14%, whilst the farm scale plant has a payback period of 4 years and an IRR of over 30%. This demonstrates that AD can be an economic technology if projects are optimised.
CONCLUSIONS

This analysis has examined data for various real plants. Large variations in costs and revenues were identified. These variations are partly a result of different project approaches. For example in Italy and Germany many farm scale plants are of simple design with the minimum of moving parts. Many German farmers construct plants using second hand materials. In comparison farm scale plant in Austria are often supplied by engineering companies who have designed robust plant using more complex control systems.

There are also variations in the basis for the cost data reported. Danish costs often include connections to district heating systems, heat pumps etc. Some plants will have included construction costs, but in other cases the work will have been carried out by the farmer and not costed.

As a result of these variations, generic plant were analysed with costs based on the averages from the real plant data available. The result of this analysis showed that the plants were not economically attractive. However the base case assumptions were somewhat pessimistic and there is plenty of opportunity to improve the economics based on realistic assumptions.

Sensitivity analysis was carried out to show how the economic indicators varied with changing each of the cost and revenue parameters individually. Then the base case plant assumptions were revised to indicate costs and revenues which should be achievable for each of the generic plants. This gave much more favourable results with payback periods and IRR values which are likely to be economically attractive.

The economics of AD plant could be further improved if the environmental benefits of the plant were costed. For example the plant can contribute to reduced greenhouse gas emissions, reduced water pollution, reduced odour pollution. If economic value was placed on these benefits they could be treated as a further income stream to the plant. However undertaking such a valuation of environmental benefits is beyond the scope of this technical summary.

Overall, whilst this summary provides some general indicators of plant costs and economics, it is important to consider the economics of building a plant in the local context. Also, if more detailed international comparisons are to be made, more work is required to collect data on a common basis.
REFERENCES

2. Update on Centralised Biogas Plants, Danish Energy Agency, 1992