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ENERGY AND SEWAGE

Water and energy management are important and interrelated issues. Sewage treatment, that is, the physical, chemical and biological processes used to clean industrial and domestic wastewater, has improved significantly over the past 20 years, with approximately 75% of UK rivers now of good biological and chemical quality. However, the energy required to treat sewage to this standard is high; the water industry is the fourth most energy intensive sector in the UK. Further tightening of water quality standards suggest energy costs will increase. This POSTnote evaluates options for sewage treatment in terms of energy conservation and renewable energy generation.

Background

Over 10 billion litres of sewage are produced every day in England and Wales[1]. It takes approximately 6.34 gigawatt hours of energy to treat this volume of sewage[2], almost 1% of the average daily electricity consumption of England and Wales[3]. The actual energy used will depend on the quality of sewage and intensity of treatment required. Typically, there are three stages of treatment:

- Primary. Solids are physically settled out.
- Secondary. Bacteria convert organic matter to a carbon-rich sludge.
- Tertiary. Further treatment may be used to remove more organic matter and/or disinfect the water.

Effluent is discharged to fresh, ground or coastal water. Sludge is applied to agricultural land (62%), incinerated (19%), used for land reclamation (11%) or used for other purposes, such as composting or landfill (8%)[4].

In the UK, water services are provided by ten, privatised, combined water and sewerage companies in England and Wales with separate, public bodies serving Scotland and Northern Ireland. Their responsibilities include providing sewerage and treating sewage to "Consent to Discharge" limits to meet water quality standards. Standards are set by the environmental regulator[5] and are informed by European directives, national legislation (see Box 1) and local water quality objectives. Consents specify where and what volume of effluent may be discharged and the concentration of any substance, such as ammonia, it is permitted to contain. Failure to meet these limits can result in fines for the water company. The water services regulation authority, Ofwat, sets an upper limit on what water companies may charge water users. The price takes costs, such as treating sewage to the consented standards, into account.

Box 1. Policy Context

The Water Framework Directive (WFD)

The WFD (2000/60/EC) (see also POSTnote 259) provides a new framework for water quality regulation and incorporates and updates some existing EU directives, such as the Urban Wastewater Treatment Directive, Bathing Water Directive and Groundwater Directive. It requires inland and coastal waters to achieve "good chemical and ecological status" by 2015. Environmental objectives are to be set for each river basin district according to local needs and pressures.

The EU Sludge Directive

The EU Sludge Directive (86/278/EEC) encourages and regulates reuse of sludge on land. It aims to reduce health hazards by prescribing sludge treatment, placing restrictions on the type of crops that may receive sludge and controlling the heavy metal content of sludged soils. Revisions to the Directive to tighten quality standards, such as metal limits, are under consideration[6].

The Energy Review

The Department of Trade and Industry's energy review, published in June 2006, outlined the Government's forward programme for energy conservation and supply. Strategies for generating 20% of electricity from renewable sources by 2020 include strengthening incentives such as the Renewables Obligation. This obliges electricity suppliers to source a rising percentage of electricity from renewable sources. In 2005, waste (including sewage sludge) combustion and biogas accounted for 10.8% and 4.2% respectively of all UK renewable energy[7] (see Current Technologies for Energy Production below).

The Water-Energy Relationship

Energy is used to abstract, treat and distribute drinking water; collect, treat and discharge sewage and manage sewage sludge. In 2006, the water industry embarked on a collaborative study with the Carbon Trust[8] to monitor energy use. Insufficient data were available to assess accurately the actual energy intensity of each step of the water cycle. However, there is no doubt that as our demand for water increases, so does the total amount of energy needed to complete the cycle. Therefore, the efficient use of both water by consumers and energy by the water industry can provide energy benefits.

Options to increase water efficiency include:

- Metering. In 2005 - 2006, approximately 28% of households in England and Wales were on metered water charges[9]. Metering enables water companies to monitor input and usage and to identify leakage from the difference between the two. Water companies may now make a local case for compulsory metering in water scarce areas under the 1999 Water Industry Act.
- Incentive programmes. For example, the Government's Enhanced Capital Allowance scheme enables business to recover some of the capital spent on energy saving or water conservation technologies.
- Reusing water. "Greywater" from bathing, laundry and washing dishes can be reused to flush WCs. This may provide savings of around a third of daily household water demand.

Options to increase energy efficiency of water treatment include:

- Choosing low-energy treatment options. However, local constraints may limit choice (see Box 2).
- Replacing machine parts, such as pumps and motors, with more efficient versions.
- Optimising processes using sensor technology. For example, pumping can be adjusted according to flow.

Implementing the latter two measures at pumping stations can produce energy savings of 30 to 50%[10].

Energy Generation Issues

There are mature, widely-practised technologies for generating fuels from sewage treatment and research has identified future methods for exploiting sewage as an energy resource (Fig.1). In 2005 – 2006, the amount of renewable energy generated on water industry sites was 493 gigawatt hours - 6.4% of the total energy used to treat water and wastewater.

Current Technologies for Energy Production

Sludge Incineration

UK production of sewage sludge is over 1 million tonnes of dry solids per year, most of which is applied to agricultural land as a soil conditioner, reducing the need for fertiliser. Sludge may also be incinerated, with the option of energy recovery. However, to incinerate sludge, it must be dry enough to burn with no extra energy input other than that needed to fire up the incinerator. It therefore needs dewatering, using energy intensive processes such as centrifugation or thermal dehydration. Centrifugation requires less energy but surplus heat from incineration that can be used for thermal dehydration.

There has been strong opposition from some sections of the public over incineration of wastes due to fears about impacts on human health. At present, reuse of sludge via application to land is generally considered a more acceptable option. However, the quantity of sludge produced is increasing while the area of available farmland in the UK is decreasing. This increases energy costs as there is more sludge to be transported, usually via lorry, to more remote locations. Future revisions to the EU Sludge Directive (see Box 1) may further restrict application. Therefore, incineration may be increasingly practised in the future.

Box 2. Increasing Sludge Production

Here, two common techniques for secondary treatment are compared in terms of their energy consumption and potential for renewable energy production. Either may be an appropriate option depending on local considerations, such as space, quality of sewage and level of treatment required.

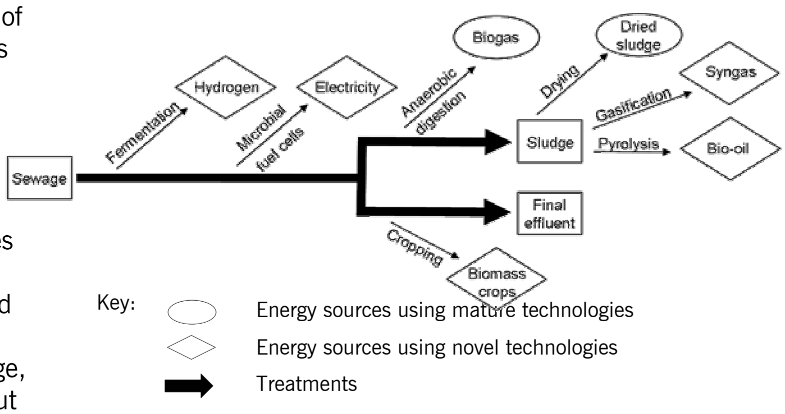
Option 1: Percolating Filter Bed

Sewage is trickled over stones where micro-organisms feed on organic matter producing a cleaner effluent. Sludge builds up on the stones and is periodically washed off. Percolating filter beds require little energy input but are relatively inefficient and take up large areas of land. They produce minimal sludge so potential for energy generation is low but there is also a smaller volume of sludge to be transported and disposed of. This treatment is most suitable for small, rural treatment works.

Option 2: Activated Sludge Processing (ASP)

Air is bubbled through tanks of sewage to encourage the growth of micro-organisms that feed on organic matter. Sludge settles on the bottom of the tank, separating it from the cleaned effluent. ASP is a faster, more effective process but requires up to three times the energy of percolating filter beds[11]. However, a greater volume of sludge, and therefore renewable energy, may be produced, partially offsetting the energy cost. Most suitable for large, urban treatment works where space is limited, this technique is becoming the standard method for secondary treatment.

Figure 1. Renewable energy sources from sewage



Biogas

Biogas production from sewage sludge treatment, via a process called anaerobic digestion, is already a well-established means of generating energy in the UK. Bacteria use organic matter in sludge to produce a mixture of methane (60 – 65%), CO_2 (35 – 40%) and trace gases. Impurities, such as hydrogen sulphide and water, are removed and the resulting biogas is then commonly used in boilers or combined heat and power (CHP) systems. For example, anaerobic digestion facilities are being developed at United Utilities' Davyhulme sewage treatment plant that will provide 90% of the site's power via CHP. Biogas may also be used for other applications, such as vehicle fuel, if CO_2 is also removed. In Linköping in Sweden, trains, buses, taxis and some private cars run on biogas. Anaerobic digestion also reduces the solids content of sludge by up to 30%, reducing the energy costs involved in its transport.

Addition of other organic materials such as food or abattoir wastes, to the digester can increase the volume and quality of gas yields. However, the process must then comply with additional regulation, such as the EU Animal By-products Regulation (EC 1774/2002), which may involve fitting additional units, such as pasteurisation units, to existing facilities. Application of residual sludge to land may also be restricted if it contravenes the EU Sludge Directive (see Box 1).

Future Technologies for Energy Production

There are several novel technologies that produce energy or fuel as a by-product of sewage treatment, although further work is needed to improve performance, reliability and cost-effectiveness.

Conversion of sludge to oil and gas

Under carefully controlled conditions and extreme temperatures (450 – 1000°C), sludge may undergo chemical reactions to produce fuels that may be used for energy production. Processes include gasification, which produces syngas (similar to natural gas), and pyrolysis, which produces bio-oil (similar to diesel oil). There is interest in these as potential alternatives to incineration of sludge. However, operational costs are high, particularly those of maintaining high temperatures, and conditions must be carefully controlled to prevent formation of harmful by-products, such as hydrogen cyanide. Several pilot schemes at sewage treatment plants have suffered problems such as these, including a gasification scheme at Anglian Water's plant in Wellingborough and a pyrolysis scheme at the Water Corporation's plant in Perth, Australia.

Biomass Crops

In Northern Ireland, sewage sludge, equivalent to almost 3,000 tonnes dried solids, is applied as fertiliser to willow plantations[12]. The trees are periodically coppiced and the wood used for fuel. Research into applying partially-treated, liquid sewage to biomass crops is also underway[13]. Passage of the sewage through the soil acts as a final polishing step for treatment, degrading organic matter, reducing nitrogen and phosphorus and producing a cleaner effluent. Little energy is required and capital and operational costs are low. However, it is not yet known how efficient this system will be at removing pollution and there must be appropriate land available.

Hydrogen from Sewage

There is much interest in hydrogen as a fuel (see POSTnote 186) because it can be produced from a wide range of materials and provides power with minimal air pollution. One source is organic wastes, such as high-carbohydrate wastewater from breweries. Bacteria use organic matter to produce hydrogen by fermentation. However, yields to date have been low, typically less than 15% of the maximum theoretically possible[14]. Also, applications for hydrogen, such as fuel cells, are not yet in widespread use.

Microbial Fuel Cells

These devices offer the possibility of simultaneous sewage treatment and energy production, with water, CO_2 and inorganic residue as by-products. Bacteria use organic matter to produce electricity. To date, lab-scale microbial fuel cells have been developed that are able to power small devices, such as pocket-sized fans.

Water Quality Issues

The measures required to attain "good status" as prescribed by the WFD have not yet been fully developed. However, the water industry is likely to have to undertake additional, energy-intensive sewage treatment to reduce levels of pollutants such as nitrates, phosphates and priority substances (including metals and certain pesticides). Densely populated, water-stressed areas may be put under particular pressure (see Box 3).

Box 3. Case Study: Ashford, Kent

Sewage treatment is increasingly problematic for densely populated communities in water scarce areas, such as south-east England. Low-flowing rivers can be very sensitive to pollution from sewage effluent.

Ashford in Kent is expected to double in size by 2031. Ashford's sewage treatment plant and parts of the sewerage network are already close to capacity. The River Stour, which receives effluent from the plant, suffers from low seasonal flows. A study of sewage treatment capacity in Ashford concluded that upgrading the conventional treatment plant was preferable to adding two new facilities with low-energy, "natural" treatment technologies[15]. This was due to cost (economies of scale favour one large treatment facility) and reliability (natural systems have not been proven to be effective at this scale).

However, there are other low-energy options for improving river quality around Ashford, including:

- Sustainable Urban Drainage Systems (SUDS). SUDS offer the multiple benefits of providing rainfall drainage, mitigating flood risk, improving water quality, providing a habitat for wildlife and potentially being an amenity resource.
- Biomass crops as a final polishing step for sewage effluent. The Environment Agency is supporting pilot schemes to look at the viability of this treatment[13].
- Agri-environmental schemes (see POSTnote 254) to reduce impact of diffuse pollution on waterways.

Endocrine-Disrupting Chemicals (EDCs)
This group of chemicals can disrupt the endocrine system, that is, the system in animals and fish that produces and responds to hormones. Environmental sources include some pesticides, industrial chemicals, pharmaceuticals and natural hormones in human and animal waste. EDCs in rivers have been found to have adverse effects on the reproductive organs of some fish species, especially downstream of sewage effluent discharges. Many EDCs are already subject to bans or other regulation and there is ongoing research into their effects and methods of control. Some options for removal from sewage, such as oxidation using ozone, are extremely energy intensive.

Faecal Pollution
The EC Bathing Water Directive (76/160/EEC and recently revised in 2006/7/EC) aims to protect public and environmental health from faecal pollution at bathing water sites. In the UK, a common means of achieving this is disinfection of sewage with ultraviolet (UV) radiation. This is an effective but energy intensive treatment. In 2006, Northumbrian Water applied to the Environment Agency to stop UV disinfection of sewage discharged to coastal waters outside the bathing season at six treatment plants. They claim this will reduce energy usage by over 5 gigawatt hours per year. Surfers against Sewage[16] strongly oppose the proposal on the grounds that it will pose an unacceptable risk to non-bathing season water users of contracting a sewage related illness. At the time of going to press, no decision had been made on the proposal.

Regulatory Issues
Government strategies for energy conservation include regulation and incentives for business, such as the EU Emissions Trading Scheme (EU ETS) and Climate Change Agreements (CCAs) for energy intensive sectors and a proposed scheme for large, non-energy intensive sectors, such as supermarket and hotel chains. Participants in the EU ETS and CCAs agree to meet energy efficiency or carbon emissions targets and receive financial rewards for doing so. The Government is yet to decide on measures for large, non-energy intensive sectors, but options include a mandatory emissions trading scheme (Energy Performance Commitment) and a voluntary system of benchmarking and reporting. To date, the water industry has not taken part in any existing scheme and, as a major user of electricity, it would not easily fit into the scheme for large, non-energy intensive sectors.

Constraints to Innovation
The House of Lords Science and Technology Report on Water Management, published in June 2006, noted a low level of funding for research and development within the water industry, with overall spending just 0.3% of annual turnover in 2004 – 2005. It suggested that economic regulation acted as a disincentive to investment because water companies were forced to focus on short-term returns. Another recent report[17] identified the inflexibility of environmental standards during trials of new technologies as a further barrier to innovation. However, lack of co-ordination between water companies, suppliers, regulators and policy makers was thought to be a more important issue.

Sewage treatment has to operate within the structures of water quality and economic regulation. This can limit options for energy conservation and energy generation. The water industry is cautious about committing to targets that may conflict with existing requirements.

Overview
- Energy conservation is possible through the twin practices of efficient water use by consumers and efficient energy use by the water industry.
- There are well-established renewable energy options, such as biogas, and novel technologies, such as gasification, for sewage treatment. Many need further investment and research.
- Economic and water quality considerations are key drivers for the water industry. Integration of energy-related objectives into the existing regulatory framework will be necessary.

Endnotes

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3 Based on DTI, 2005, *Regional electricity consumption statistics.*
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