# Review of Small Scale, Community Biogas in the Industrialized World

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## Abstract

Although there is a wealth of large scale anaerobic digestion (AD) in rich countries and small scale AD in poor countries, small scale is uncommon in rich countries. It is considered uneconomical for energy or fertilizer production, and the landfill and sewage infrastructure and associated regulations can reduce the incentive further. Numerous studies have shown negative cost benefit analysis for community scale digesters. Still, one may expect to find AD technology on a small scale, similarly to household and community composting, home brewing of alcohol, bio-diesel production and composting toilets. As cheap energy becomes scarcer, local waste treatment and fertilizer and energy production may become more attractive. Decentralized anaerobic digestion is considered the most sustainable organic waste and wastewater treatment option for society. Already many community groups in the UK are interested in AD on a small scale. This paper reviews working, planned and attempted (very) small scale anaerobic digestion in the developed world, and provides an economic assessment such technology. We find that although traditional, financial assessment of such small units is often unfavourable in the industrialized world, an integrated, non traditional economic assessment shows much potential for such units. Possible opportunities and paths are suggested for the community sector to utilize such technology.

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This report has been produced to provide members of the Community Composting Network (CCN) with a background on small and decentralized anaerobic digestion projects and opportunities to use this technology. The CCN is a network of non-for-profit organizations engaged in community composting, primarily in the United Kingdom.

The author is now producing an MSc thesis on this topic at Wageningen University in the Netherlands and continues to collaborate with the CCN.

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## Introduction

Anaerobic digestion is a natural process in which biomass is consumed by micro-organisms in the absence of oxygen. This process can produce energy in the form of biogas, and safe, stable fertilizer in the form of digestate. The chemistry and biology of the process has been explained in detail (Fry and Merrill 1973; House 2006; Wikipedia 2008) and can be aided by mixing, heating and inoculating the mixture, inside of a sealed tank.

Anaerobic digestion has been exploited to produce biogas and fertilizer for hundreds, perhaps thousands of years by the Chinese, Assyrians and Persians. In the 19$^{th}$ century, biogas from sewage was used to light streets in Exeter, England and in the late 20$^{th}$ century biogas was used to fuel hundreds of vehicles across Sweden and millions of homes' cookers in India, as reviewed by (Tietjen 1975; Harris 2008; Sjoholm 2008).

The benefits of anaerobic digestion have been widely published. Both life cycle assessment and cost benefit analysis have found anaerobic digestion to be the best method of dealing with household waste, (Edelmann, Baier et al. 2005; Hogg, Gibbs et al. 2007), and it is also an optimal technology for greenhouse gas flux (Frigon and Guiot 2005) and integrated treatment of both sewage and kitchen waste (Zeeman, Kujawa et al. 2008).

Incentives in the United Kingdom, such as the Landfill Directive, greenhouse gas credits and Renewable Obligation Credits for renewable energy improve the prospects of AD, but the economics behind the current rush to install digesters around the UK are still risky, depending on feedstock (Schwager 2008).

Economies of scale mean that in larger facilities operating costs can be reduced, per unit, to the point that, in the current economic framework, very large AD facilities can be profitable whereas small ones are not. If energy and transportation prices continue to rise and the demand for local waste treatment, energy, and fertilizer increases, this framework may change. Regardless, decentralized waste treatment and reuse has many advantages (van Lier and Lettinga 1999), is widely considered to be the most sustainable form of waste treatment, and can provide community self sufficiency and benefits to society far preferable to large scale, centralized treatment (Lettinga 2008).

This paper examines the prospects of AD on a small scale, for organizations such as the members of the UK Community Composting Network. Common AD projects are briefly presented, then several case studies of less common community scale systems in developed nations are analysed in detail. An economic assessment of small scale AD is presented, and, finally, the prospects for this technology in the non-profit sector are considered, including a survey of current interest.

## Basics of Design and Process

During anaerobic digestion carbon in the feedstock undergoes two transitions: from biomass to acids (acidogenisis) and from acids to gas (methanogenisis). Sometimes these processes are separated into two tanks, and the first stage can be used independently, to produce acids useful for compost. Further details on process kinetics can be obtained in your favourite textbook covering anaerobic digestion, such as (Metcalf & Eddy, Tchobanoglous et al. 2002). One important distinction is between very low solids (less than 2%) in a sludge blanket reactor, traditional wet digestion (solids content below 12%), and dry, high solids (25% or higher solids) digestion that is more complex and more recently exploited. Common designs include a floating lid or a balloon membrane to hold biogas, above a plug flow or completely mixed clay-brick, steel or concrete tank or a vertical cylinder where dilute water flows upwards and loses solids to a sludge blanket. Substrate may be pasteurized to reduce pathogens. A worldwide review of current process designs in the industrialized world has been published by Juniper Inc. (Schwager 2008) as well as various other publications covering units in developing countries (Buren 1998; Wellinger 1999; House 2006).

Biogas is roughly 60% methane and 39% carbon dioxide, with small amounts of water vapour, hydrogen sulphide, and ammonia gas. It may be burned as is, or purified to over 99% methane, at which point it becomes identical to natural gas, and can be used accordingly (to produce light, heat, electricity, plastics, chemicals, transport fuel, etc).

Digestate from wet digesters is a low solids, nutrient rich liquid. All nitrogen, phosphorous, potassium and trace nutrients from the feed stock are retained in the digestate, making it suitable as a fertilizer.

## Scales of Anaerobic Digesters

Anaerobic digestion (AD) can take place on any scale. Measurements of scale often refer to:

- Input of biomass, tonnes per annum (tpa) or per day
- Size of the tank, volume in cubic meters
- Energy produced, power in MW or kW

In an efficient, completely mixed digester, biomass remains in the reactor for between 17 and 50 days (retention time) or longer in less efficient systems, where efficiency depends largely on temperature and microbial aptness. All else being equal, tank size is directly proportional to the input of biomass. Energy production depends on the energy content of the feedstock, ranging from manure at 1700 kWh/ tonne total solids to fat at 9400 kWh/ tonne of total solids, and is also proportional to input of biomass.

Millions of very small (less than 50 tpa), wet, farm digesters exist in developing countries such as China, whereas thousands of much bigger (over 1000 tpa) digesters exist in developed countries. For context, most organizations engaged in community composting in the UK process less than 50 tpa.

Loading a digester with 50 tpa translates into around 130 kg of biomass per day, which would likely require considerable labour. In England, the annual production of food waste is around 250 kg per person per year (Chesshire 2008), and faecal production per person is approximately 250mL per person per day (Zeeman, Kujawa et al. 2008), or 90 kg per year. The volume needed for a single person's food waste and faeces in an efficient system can range from 50L to 1000L (Zeeman, Sanders et al. 2000).

**Common big projects in the industrialized world**

Biogas projects in the developed world are generally large. In Germany the average installed facility increased from 50 kW in 1999 to 330 kW in 2002 (Wellinger 2005). Most European digesters are either On-Farm, digesting manure and/or agricultural biomass, or Centralized Digestion of sewage, food, industrial, and/or municipal waste (Nichols 2004).

In the UK, common scales are estimated below (Chesshire 2008; Scurlock 2008), costing hundreds of thousands, or millions of euros.

| | Annual input, m3 | Power production, MW |
|---|---|---|
| On Farm | 1000-2000 | 0.10-1.0 |
| Centralized | 10,000 | 0.50-10.0 |

On Farm systems usually involve treating large quantities of manure, and require less planning and regulation but are also less likely to make money from gate fees and large scale power generation. In Scotland a number of On Farm digesters have been financed by government in order to reduce nitrate pollution from manure, however, despite large farm size, farmers often do not have the capital to build such large digesters.

Centralized systems involve treating a combination of industrial waste, sewage sludge and municipal food waste. A review of Municipal Solid Waste (MSW) digestion (RISE-AT 1998) provides a number of examples and finds very large scale digestion (100,000 tpa) to be most economical. Germany and Denmark continue to lead the world in this field, while England now has just seven municipal food waste digester sites that have passed regulations for food waste treatment (listed below), while many others are planned around the country and more than ten UK based companies advertise engineering expertise in such technology in a recent Compost Association AD Report, 2005. A recent review of anaerobic facility providers rates hundreds of processes and services worldwide, indicating a wide range of expertise and track records (Schwager 2008).

Municipal Food Waste Digester Sites Approved by ABPR in the UK, downloaded from Defra's Website, August 2008:

**EU Requirement Approved Plants Report - SECTION VI Biogas Plants**

| Approval Number | Plant Name | Town | Postcode | ABP Category | Activity | Product | Associated Activity |
|---|---|---|---|---|---|---|---|
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | |
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The trend in biogas usage in most of the industrialized world is towards pipeline quality methane or vehicle fuel whereas in the UK it is towards electricity generation due to new government incentives (Schwager 2008).

Regulatory requirements for biogas projects in the UK include attaining a Waste Management License, clearance from Animal By-Products Regulations, and local county approval. Standards are currently being developed for agricultural use of digestate in the UK, that allow for classification of the digestate as a quality product rather than waste. Other legislation such as the EU Waste Prevention and Recycling Thematic Strategy, The Landfill Directive and the UK Energy White Paper provide concrete support to biogas projects (Holliday 2005).

**Common small projects in the developing world**

The biogas industry in the developing world is much less centralized and regulated than in the industrialized world. The most common facilities are small farm digesters running primarily on manure, which provide local cooking energy, particularly in China and India (Wellinger 2005). Small scale anaerobic digestion has resulted in a reduction of ecological stress in India's remote villages (Agoramoorthy and Hsu 2008), as well as clean cooking fuel and safe waste treatment and fertilizer production for the population.

Outlines of the design and operation of small digesters have been published widely, for example (Fry and Merrill 1973; Buren 1998; Wellinger 1999; Matthews 2004; House 2006). Micro-scale digester designs include the common underground clay and brick pit, the oil barrel with a floating or sealed lid and the ditch or tunnel with a rubber membrane to capture methane.

Government programs have had widespread success installing small farm digesters, as well as contributory efforts by local movements (Feliciano dos Santos 2008) and western aid (PACE 2008), LeAF, WSUP, GTZ.

In some parts of rural India, the government may subsidize 80% of the capital costs of building a digester, as long as a contract is made which forces the owner to use the digester for at least twelve years (Agoramoorthy and Hsu 2008). Construction and use of small digesters has been common for several decades in India and the benefits are better understood than in most industrialized countries.

## Uncommon small projects in the industrialized world

In some instances, small scale digestion results from the mainstream large scale digesters shrinking in size or from companies testing substrates for large scale application. In others instances, small biogas reactors have appeared as independent projects by communities or farms. Various scales of sewage sludge digesters such as septic tanks are already widespread, and could be integrated with community projects digesting food or other biomass waste.

In addition, digesters designed for particular industry effluents are already operating in the industrialized world, and these projects have lead the way in decentralized treatment. Combining industrial waste with agricultural and domestic waste may lead to improved treatment for all parties, for example in Wisconsin, USA, dairy farm manure is mixed with truckloads of waste ice cream, creating a locally produced, easily digested, high energy substrate.

### *Dry Fermentation*

Dry fermentation has been used since the 1940s and due to recent advancements in Germany and The Netherlands (ten Brummeler 2000), has become more widespread on both the large and small scale and perhaps attractive for ecological sanitation, as reviewed by (Köttner 2002). Garage-box type digesters can be loaded by dumping feed stock on the ground and closing a sealing door. They require no mixing and very little liquid, but require careful gas handling to avoid explosion. Variations including plastic membranes or steel containers which process less than 2000 tpa, often below 300 tpa on farms. These systems are becoming more common in France and Germany (Lukehurst 2008).

### *Farm Digesters*

Decentralized composting and biogas production has increased recently in Austria, with 93% of plants processing under 5,000 tpa and producing electricity at under 100 kW; over 202 plants process under 500 tpa, versus 10 plants that process over 10,000 tpa (Amlinger 2005). This decentralization has been partly a result of local farms providing organic waste treatment for local authorities, and higher government premiums for electricity produced by small biogas plants than large ones. The Austrian government has also interpreted the EU Animal By-Products Regulations in such a way that restrictions on farms are much less severe than in other EU countries.

Bioplex, a UK company has developed a small, mobile digester called the Portagester. It is commercially available to a minimum size of 50-150 tonnes per year for around £10,000. This model is not designed to produce methane, rather to process material through the first stage of anaerobic digestion, fermenting biomass into solids for composting and liquor, and pasteurising material to pass UK animal by-products regulations. Bioplex also offers a second stage digester for the liquor, which does produce biogas.

At Growing Power Inc. in Milwaukee, USA, a high solids food waste digester has been built within an urban community food production project, in collaboration with Wisconsin State University. It produces acids for composting from various imported waste food and on-site farm waste. The facility was financed by a research grant; however the digester is in use as part of a non-profit, community operation, integrated with the heating greenhouses and other operations on an urban farm.

*Residential and Household*

Two successful decentralized projects in Germany have been used as best practice examples by Ecosan GTZ. Both projects involve the digestion of sewage on site, one on a farm in Bessenbach, where the substrate is 5110 m3 per year of cattle manure and sewage from 14 full time people, 280 full time cattle as well as up to 260 people served in the restaurant (GTZ 2005a). The total investment for the digester system was around 200,000 euros, while annual operational income and savings from energy and fertilizer production add up to 50,000 per year. The other GTZ best practice example was installed in a housing development in Lubeck, where approximately 4.8 L/day of black water and food waste are produced, per capita, by approximately 360 people in 117 apartments. This project cost 600,000 euros for the ecological sanitation whereas the entire eco-housing complex cost 2 million euros (GTZ 2005b).

Otter Rotters, a member of CCN in the UK, has created an AD project in Southern England for several hundred households. The facility was approved by the Animal By-Product Regulations and secured funding for capital costs, however the operations are not economical and have, for the moment ceased. A planned local government food waste collection project in the same region has proposed to take the food waste elsewhere. The facility at Otter Rotters was originally designed by the British company Bioplex but was changed and redesigned significantly by the Otter Rotters team. The facility did not produce biogas, rather it pasteurized food waste under anaerobic conditions. The solids from digestate, which still contained in-tact solids was then composted and used in horticulture, on site, and the digestate liquids were kept in anaerobic chamber where biogas was recovered, and water was reused in the process. Bioplex is currently installing a similar design at a prison in the UK.

Three Japanese systems classified as "infrastructure free," treating 20 households' wastewater and organic wastes are argued to be cost effective. The bottom-up, decentralization approach of involving citizens and municipalities in city planning suits the current trends in demographics in Japan. An assessment was made of 30-year life-cycle cost performance of three current systems for wastewater treatment for a small community in Japan (Anilir, Nelson et al. 2008). Quoting from Anilir, "These systems are; wastewater gardens with biogas production, an anaerobic digester gas system integrated with fuel cell technology and a heat and power unit (CHP) combined with a biogas-producing reed bed system, all of which treat wastewater and result in useful end products, closing the life cycle with low maintenance, a lower environmental load, and two to four times smaller development cost than centralized options in both rural and urban communities."

A Dutch system for the on-site digestion of food waste and black water for 32 houses in Sneek, the Netherlands uses a more complex treatment method to produce biogas. An Upflow Anaerobic Sludge Blanket Reactor (UASB) is used to concentrate the organic fraction of wastewater and produce biogas at much lower temperatures, with lower concentrations of carbon, in smaller reactors with better removal efficiency than is possible otherwise. Magnesium is added to the effluent from the UASB to precipitate Struvite and recover valuable phosphorous, and finally a nitrogen removal process is employed to release nitrogen gas straight from ammonia through a new process known as Anoxic ammonium oxidation (Anammox) or Completely Autotrophic Nitrogen removal Over Nitrite (CANON) reviewed by (Sliekers, Third et al. 2003). An overall energy balance including consumption from vacuum transport from toilet and kitchen waste grinders as well as savings from sewer, sewage treatment plants and drinking water yields a 200 MJ per person per year advantage over centralized treatment systems. This includes the realistic 131 MJ per person per year of *electricity* produced by biogas but does not include the total 374 MJ/person /year energy value of the biogas that may be recovered up to 90% efficiency in the form of heat. It was noted that food waste approximately doubles biogas yield from wastewater digesters (Zeeman, Kujawa et al. 2008).

In Berching, Germany, the Huber Headquarters also employs a small biogas digester and complete reuse system for water, nutrients and organic matter produced by its several hundred employees on site. Huber is a company producing various products and engineering for wastewater treatment, and often uses membranes in its systems. It offers a very small, on site treatment unit for industrialized countries and also builds systems for developing countries (Huber 2008).

An small residential AD system has been demonstrated on a large household in the mountains of Italy in collaboration with the University of Padova, Italy. The reactor is a mesophillic completely mixed, two cubic meter digester, heated with hot water from a wood burning stove and a solar heater, eventually will be heated with biogas. The system has worked well, except that heat energy input is not recovered as biogas energy. A weeper system irrigates a small area of native plant species, which successfully phytoremediate grey water, separated urine, and the effluent from the digester, originally black water and food waste.

Two tanks of 1.5 m3 were used in food waste digestion trials which led to the development of a 5,000 tpa facility treating food and garden waste in England. One of the reactors was maintained at 56 C and the other at 36 C. The performance of the warmer (thermo-phillic) digester was slightly better, although both digesters produced approximately 0.4m3 methane per kilogram of volatile solids and averaged at 3.1m3 per day but reached a maximum of 30m3 per day??? (Banks, Chesshire et al. 2008)!

*Past projects*

In the 1990's, three household scale (1.2m3) Up-flow Anaerobic Sludge Blanket (UASB) reactors were operated for two years in various different, rural areas in the Netherlands. These reactors treated grey water and black water or only black water, and achieved the production of 300L of biogas per day with 60 to 70% methane content and an average efficiency of removal of 60-72% COD and BOD removal respectively (Bogte, Breure et al. 1993). Temperature was found to be a very important factor, with significant increase in treatment efficiency above 12 C.

In the 1970's, Jean Pain of France built himself a large, household digester, which was heated by situating the digester tank inside of a large pile of compost, in a batch type reaction. Chipped brush wood was used to produce humus for on site horticulture as well as biogas to produce electricity, heat and vehicle fuel. The reactor was a 30 ft pile of brush and wood chips, layered with pipes to heat water for his home. He left behind an institute in Belgium and a book, available on-line.

Living Machine Projects such as Ocean Arcs in Vermont, USA often operate anaerobic digesters as the first stage of treatment in the living machine wastewater treatment process. Another living machine was built north of Doncaster, but released the methane without flaring it for aesthetic reasons. Unfortunately both of these operations are no longer in operation, due to financial problems.

John Fry was a pioneer of small scale biogas in South Africa, England, and the USA. He welded oil drums together and wrote a book on small systems for producing biogas (Fry and Merrill 1973). During World War Two, biogas use in Europe, particularly England and Germany blossomed, due to the shortage of oil. Huge biogas balloons were strapped to the top of busses to store fuel.

*Planned projects*

- Bradford Organics Composting Service (CCN members) currently developing plans for food waste AD
- London CRN, (CCN member) is developing a small anaerobic digester under a parking lot in the London area.
- WyeCycle (CCN member) is considering introducing small scale 1m3 plastic tank digesters from India, from a company called Sintex.
- Fairfields Waste Management (CCN member) is developing an AD program for 20,000 tonnes/ year
- Low Impact Living Project, UK (CCN member) has hosted a course on how to run cookers on small scale biogas. They do not operate one regularly but do plan to in the future.
- Llanidloes, Wales, feasibility study for a community project showed economics to be very unfavourable (Holliday 2005)
- Several other small, on site are operating around the UK, at CCN member sites and farms, but the author is waiting for details.

- There is emerging interest from greenhouse hydroponics operators, as there is a significant amount of green waste (often landfilled), which could be digested on site to provide heat and boost $CO_2$ levels in the greenhouse.

*Research and Pilot Projects*
There is also experimentation and research on small scale AD through various institutions.

Pilot projects for big AD installations are designed to be just the same as their full size counterparts, only smaller. Greenfinch, a UK company, has built many small fibreglass digesters to test various substrates, some integrated with aquaculture, and some may be rented to test substrate, however generally these plants are not operated or distributed outside research and pilot projects. As a novelty, Greenfinch manager Michael Chesshire operates a digester run on whey and grass at his home, where the biogas is used for cooking. North American projects include two large mobile digesters to demonstrate the technology in Colorado (Schellenbach, Turnacliff et al. 1977) and Quebec (Electrigaz 2006).

Researchers are finding decentralized, anaerobic solutions to wastewater (Elmitwalli, Sayed et al. 2003; Abegglen, Ospelt et al. 2008) as well as combined wastewater and kitchen waste (Zeeman, Sanders et al. 2000; Han, Shin et al. 2002; Zeeman, Kujawa et al. 2008).

**Completeness of Projects**

****please comment on completeness****
*One relevant project in Wales, one in England, and one in Italy have been discovered since last writing.*

## Economics of small projects in industrialized and developing countries

### Traditional economic assessment

This section considers the traditional monetary analysis of a four cubic meter biogas digester for a rural community in an industrialized country versus in a developing country.

It is clearly economical for the rural Indian family, as demonstrated by the millions of installations each year, whereas it is not financially economical in England, as demonstrated by the lack of projects. An assessment of Capital Costs follows the Operating Costs and Benefits.

### Operating Costs and Benefits of a four cubic meter digester

| | United Kingdom (Estimated by Author) | India (Agoramoorthy and Hsu 2008) |
|---|---|---|
| Waste treatment<br><br>- all human and animal faecal matter and food scraps for several people and animals | None directly to user<br><br>Waste is disposed of through existing sewer/ septic tank and landfill infrastructures, often provided without fees by government. | Significant benefits<br><br>Carries worth of avoiding health problems and other disposal costs - reduces clinic visits by ½. Small herds of livestock horticulture provide a consistent feedstock |
| Energy production<br><br>- 400 to 3200 Litres of biogas per day | Benefit<br><br>Biogas produced may provide up to 12kWh (£1.20) per day, £438 per year and makes small contribution to community energy consumption.<br>Not as clean or convenient as natural gas, requires compression, equipment, etc | Significant benefit<br><br>4 hours of cooking fuel per day (enough for cooking) and savings of:<br>£ 30.0/ year on wood + less deforestation<br>£ 18.0/ year on kerosene in rural India<br>Biogas is cleaner than firewood fuel and associated labour, and provides enough energy for cooking |
| Fertilizer production<br><br>- 40 to 160 Litres per day of NPK rich liquid | Small benefit<br><br>Nutrient rich effluent water most often has a negative value. For fertilization, cheaper, more convenient petroleum derived nutrient rich liquid is produced | Significant benefit<br><br>Better (more nutritious, safer, easier to handle) than fresh manure for horticultural cropping.<br>£11.3/ year saved on fertilizer purchase |
| Environmental health | Not significant | Benefit |

| | | |
|---|---|---|
| - avoidance of pollution such as water contamination and resource depletion through a closed loop human life support system | Environmental health does not directly impact the public. Local water and soil quality are trivial to quality of life. Soon, GHG emissions may command a price. | Crucial for those who depend directly on their local environment for food, water, shelter and materials. |
| Maintenance and Operational Labour<br><br>-starting, loading, and operating the digester<br><br><br><br><br><br>Operator Salary | Very significant cost<br><br>Training and time required for loading, monitoring process and health and safety, etc. Difficult to justify in neo-classical economics<br><br><br>1/4 time: £4,000 per year<br><br>£16,492/ year poverty line in England (13 million below poverty line in England) | Cost<br><br>Digester requires valuable buckets of water and human labour; however these are well worth the benefits. Training also required<br><br>1/4 time: £10 per year<br><br>£41/ year poverty line in India (300 million below poverty line in India) |
| Annual Net Income<br><br>Benefit /Cost Ratio | Negative £5562<br><br>0.11<br>Benefits: £438,<br>Costs: £4000 | Positive £49<br><br>5.9<br>Benefits: £59,<br>Costs: £10 |

****Is the cost of labour accurate???****

At a larger scale, in the industrialized world, various other benefits may be reaped, such as the sale of heat and electricity and gate fees for imported waste materials. Still, on the scale of 250 tonnes per year (considered small scale in UK) a recent feasibility study in Wales highlighted the many benefits of community, proximity and environmental health but also the high cost in conventional economic terms. The following two tables were taken directly from this report reproduced without permission from (Holliday 2005).

| Scenario 1 | Tonnes per year |
|---|---|
| Household kitchen waste | 190 |
| School catering waste | 10 |
| Commercial catering waste | 10 |
| Grass verge cuttings | 42 |
| Total | 252 |

| | |
|---|---|
| Capital Cost | £278,400 |
| Income | £14,203 |
| Operating Cost | £29,097 |
| Net Income | £-14,894 |
| Annual Discount Rate | 7% |
| Lifetime of Plant | 15 years |
| Present Value of Net Income | £-135,654 |
| Less Capital Cost | £-278,400 |
| Net Present Value | £-414,054 |

**Capital Costs for a one cubic meter digester**

| | United Kingdom (Estimates by Author) | Rural India (Agoramoorthy and Hsu 2008) |
|---|---|---|
| Digester Tank | £300 for plastic or steel tank with insulation, and 3" plumbing, fittings, valves | £125 total construction costs. Government subsidies may cover 80% of this for some households, given agreement of long term use (becomes £25 for user) |
| Mixer, Heater, Pasteurizer, Automated Controls | £1000 predicted, after design, experimentation and development | £0. None needed, low efficiency system with manual mixing and warm climate, included in labour |
| Input tank, Effluent tank, Gas storage | £500 for membrane or floating lid and two other tanks | £0. Built into ground, gas storage on digester, included in digester tank cost |
| Integration into existing infrastructure | £3000 Re-plumbing and replacement of toilets, or solids separation from blackwater, system for collection and short distance transportation of solid and liquid food wastes (20 households) £500 Safe biogas handling and burning equipment for cooking indoors | £0. No existing sewage or garbage infrastructure,<br><br>£2? Pipe and primitive cooking element to burn biogas, may be included with government subsidized system |

The one cubic meter digester in the UK would require a more complex reactor system, due to the colder climate and the higher public and regulatory expectations from facilities.

**Non-traditional economic assessment**

This includes benefits and costs incurred by wider society and includes non-financial benefits for the community.

**Operating Costs and Benefits of a one cubic meter digester**

| | United Kingdom/ Industrialized Country |
|---|---|
| Waste treatment | Avoids point source pollution from landfill and sewage effluent |

| | |
|---|---|
| - all human and animal faecal matter and food scraps for several people and animals | Avoids cost of sewage infrastructure, 6.34 GWh/year (1% of national energy expense) to treat sewage in England and Wales (WaterUK 2006).<br>Energy producing instead of energy consuming<br>Minerals and organic material are re-used<br>Avoidance of huge costs of centralized infrastructure |
| Energy production<br><br>- 400 to 3200 Litres of biogas per day | 12kWh per day provides enough energy for cooking, or some heating and hot water<br>Overall energy balance of decentralized anaerobic treatment brings benefits of 200MJ/person/year compared to conventional system<br>Energy is completely carbon neutral, requires no transportation or complex external infrastructure for production (compared to hydro, wind, solar)<br>Energy production is not vulnerable to external factors and will not be sensitive to price volatility |
| Fertilizer production<br><br>- 40 to 160 Litres per day of NPK rich liquid | Very useful for local horticulture, requires no transportation or external infrastructure for food, fuel and fibre production on site<br>Nutrient overloading in surface water is a major threat to ecosystems worldwide (MEA 2005), that digestate use can minimize |
| Environmental health<br><br>- avoidance of pollution such as water contamination and resource depletion through a closed loop human life support system | As we move to a more locally based and sustainable society, environmental health will directly impact the public<br>With locally produced fertilizers and energy, city farms and community gardens can drastically improve the quality of community spaces.<br>GHG emissions are minimized with this option of organic waste management.<br>Widespread adoption will lead to overall reduction of resource depletion and therefore an improved future |
| Maintenance and Operational Labour<br><br>-starting, loading, and operating the digester | Training and time required for loading, monitoring process and health and safety, etc.<br>No odour or strenuous physical work, as with home composting.<br>Creates an opportunity for familiarity with process engineering – which can be educational and useful.<br>Creates an opportunity for community participation partnership, and resilience through re-use of resources<br>Creates usefully trained personnel |

## Potential for the community sector

### Barriers to wider adoption of small scale AD

“Generally the short-term economic interests of well-established structures comprise the major bottleneck for making progress on the route to sustainable and robust public sanitation. However, regarding the enormous social and economic benefits of the decentralized sanitation and resource recovery-concept, natural mineralization-based treatment systems irrevocably will be substitute, for the nowadays applied, highly centralised sanitation concepts with their complex and expensive treatment methods." (Lettinga 2008)

The traditional, financial economics of AD facilities are by far the biggest barrier to development. Nobody can make money by operating small AD units. Even with subsidies and renewable energy incentives, the cost benefit or net present value of even large digesters are often unfavourable (Schwager 2008).
Other risks and challenges include potential health hazards from pathogens, biogas explosions, and odour. Regulations, policy and licensing fees can also be barriers to community systems and in 2008, the lack of commercially available products and the extent of technological design and development required is another barrier.

To date, the author has not found commercial distributors of small scale, residential or community on-site biogas and fertilizer producing digesters in the industrialized world. Perhaps if a simple, affordable miniature digester were commercially available, home-owners and community projects, especially those engaged in gardening and farming would consider installation of such a unit, instead of a traditional septic tank or compost heap, for example.
??Please comment on this! Do replicable, commercially available units exist on the market?

A final, and related barrier is to adapt the infrastructure in the industrialized world to take advantage of small scale AD technology. In addition to low flush toilets and food waste grinders, in order to recover a value from the biogas energy and nutrient rich liquid, the unit must be well integrated. For example, if the heating of the AD reactor, pasteurizing of the substrate, and heating of hot water in a well insulated building or greenhouse were combined, more value could be recovered than isolating the reactor in its own building. Various uses of heat must be considered, including local industry, food production, heating, drying, cooking, etc. Also, irrigation of on site horticulture, aquaculture or some form of plant production or phytoremediation may recover a value from the effluent liquid and further reduce the polluting effect of liquid discharge into the environment.

## Opportunities for adoption of small scale AD

Because of the current financial environment, adoption of decentralized AD units depends on citizens and groups having a strong desire for their services, and/or an understanding of their wider benefits to society. In this context, the third (non-profit) sector has a major advantage. The third sector is based on providing benefits to society and is comprised of groups and projects not designed to make money, rather to act in the public interest.

Similarly to community composting, small and decentralized AD can be an attractive solution to meet landfill, sewage and greenhouse gas reductions, and provide numerous other benefits to society.

The Community Composting Network is situated ideally to disseminate information on suitable decentralized AD for the UK, for the sector to realize the benefits. The next steps to follow from this report are to create a commercially available product guide, an operational manual, and plans for a pilot scheme and a training program. Given the lack of commercial products, the product guide may need to include many individual components and design specifications.

With publicly available information and commercially available equipment, an individual may create a small anaerobic digestion unit.

**The current level of interest from communities in the UK**

CCN surveyed membership for their level of interest and knowledge in decentralized AD in August 2008, and all results were very positive, four members indicating they would like to form a steering committee for CCN's work in this field and would like to run pilot projects, if possible.

**Conclusion**

Although decentralized anaerobic digestion is not widespread in the industrialized world, diverse examples indicate that it can bring significant benefits to society. Like many other third sector activities, small and community AD units will not bring financial profits to the owner, according to traditional economic assessment, mainly due to the cost of labour for operation. However, if the goal of a community is to be self sufficient, create fertilizer and energy and avoid pollution, a small AD unit can be very profitable.

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