MODIFICATION OF UK MUNICIPAL ACTIVATED SLUDGE PLANT TO INCORPORATE ONSITE SLUDGE DIGESTION

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Abstract

A pocket ASP in Warwickshire County, United Kingdom, treats combined wastewater for 10,500 PE; with current discharge consent of 25/45/5 (BOD/SS/NH_3). Sludge produced is presently trucked fortnightly to another treatment facility. There are 15 nearby sewage works with no sludge processing facilities, with combined capacity of 200,000 PE. A proposed petrochemical plant and university sewer are to channel their effluents to the ASP. Techno- economic evaluation of two options, plant upgrade for onsite sludge processing and biogas generation as against maintaining the status quo, forms the basis of this paper. The most appropriate design solution to retrofit the current plant, justification for design options selected, efficiency considerations, as well as the project delivery plan are presented. It was found that constructing anaerobic digesters within the retrofitted facility would be more economical than transporting the massive load of anticipated surplus activated sludge to the third party owned facility, as sludge mass balance and cost estimations indicate. Successful negotiations with the surrounding sewage works would also enable the operator achieve a shorter payback period for the project, while the produced biogas would power the entire facility and the excess sold to the national grid. Lessons learnt would be useful for operators, contractors and consultants involved with similar projects in various parts of the world.

Keywords

Anaerobic digestion, ASP, biogas generation, onsite power generation, population upsurge, plant retrofit, process optimisation, sludge dewatering, sludge thickening.

Introduction

Larger volumes of wastewater sludge are generated by the day as a result of the increase in wastewater treatment plants, occasioned by global growth in urban population. Sewage sludge, which industry players now euphemistically term ‘biosolids’, is mainly a by-product of primary, secondary and tertiary wastewater treatment. It constitutes the largest volume of solid waste produced by municipal sewage works. Its processing, utilisation and disposal are easily the most difficult and expensive operations of city councils today (Yan et al. 2014). Being 95% water, sludge must undergo several treatment processes before its final reuse or disposal. Most of the sludge generated was traditionally disposed of in incinerators, landfills or ocean dumping, leaving very little for agricultural reuse. However, with stricter environmental legislation and monitoring, more elaborate sewage treatment became inevitable and the volume of sludge to be treated or disposed increased. Subsequent regulatory concerns about air and water quality as well as technological advances in recent years have seen the evolution of thermal sludge processing technologies that turn the waste into wealth (FRM 2013, Veenstra 1997).

BIOSAS Wastewater Treatment Plant (BWWTP) is a pocket activated sludge plant (ASP) commissioned in 2005, following conversion from a trickling filter plant that was built in 1980. BWWTP is located in a market town within the service area of Warwickshire County, Southern England, United Kingdom (see figure 1). The plant ensures that local residents can rely on a safe supply of water while living, working or engaging in recreation. To achieve these goals, it manages groundwater levels, treats combined wastewater (i.e. both sewage and runoff) and makes sure the water in streams, ditches and rivers is clean.

Figure 1: Map showing the study area (Google Imagery 2016)

With the ongoing construction of a petrochemical plant in the area and a university sewer whose effluents it has been mandated to handle, new phosphorus and oil & grease removal consents to be introduced by the Environment Agency (EA) on the quality of discharge effluents from wastewater treatment facilities in the UK, increased and new waste streams in its influent; BWWTP needs an immediate modification in order to remain relevant. The sewage works operator therefore decided to upgrade the plant to ensure its efficient and reliable operation in the next fifteen years to continuously meet up with ever-tightening regulatory requirements on discharged effluents, impending industrialisation of the area and the attendant population upsurge.

Figure 2: Pictorial View of BIOSAS Wastewater Treatment Plant

The following targets were thus set for the proposed plant retrofit:

- 1mg/l of total phosphorus in wastewater discharged from the ASP into surface waters
- Reduction of oil and grease content in petrochemical plant effluent wastewater (4ml/day, COD 860mg/l) from 300 mg/l to 5 mg/l in the preliminary process
- Reduced BOD loading (2.5Ml/day, BOD 250mg/l) of the additional municipal wastewater from the newly established university's sewer system to the existing BOD/SS/NH_3 limits (25/45/5 on a 95 percentile basis).
- Possible onsite sludge processing for resource recovery, energy efficiency and carbon footprint reduction (Bassey & Odigie 2016:2).

This paper, the third part in a series, complements two earlier publications (Bassey & Odigie 2016 and Bassey et al. 2016) that had exhaustively addressed the first two and the third targets, respectively. This study explores the options for meeting the fourth requirement through both qualitative and quantitative evaluation of key technical and economic parameters inherent in the associated plant retrofit designs. The data used are as supplied by the plant operator, while the missing gaps were supplemented from design manuals, past similar projects and the literature.

Sludge processing and biogas technologies

Anatomy of Sewage Sludge

Sludge is one of the largest by products of wastewater treatment plants and its disposal is the most challenging environmental problem in such facilities. Before the sludge or its components can be disposed into surface waters, in the air or on land, considerable treatment to yield environmentally benign products is required by statutory regulations, violation of which results in criminal prosecution and huge liabilities. In some extreme cases, sewage operators had been compelled to excavate farmlands contaminated with their sludge, which was used as compost manure, for remediation of the top soil!

Organic matter being biologically oxidized with the help of certain microorganisms without the presence of atmospheric oxygen could lead to the process of anaerobic degradation and generation of biogas (containing 55 – 70% CH_4 and CO_2). From an environmental point of view, anaerobic digestion (AD) is a waste treatment strategy reported as very attractive and beneficial to the society since it continuously uses renewable feedstocks to provide clean fuel (Mudhoo 2012 & Subramanian *et al.* 2014). However, the changes in the floc size distribution (FSD) are affected by anaerobic digestion process selected, which subsequently influences the dewaterability. Dewaterability of sludge worsens with a reduction in floc size in highly loaded reactors, although no sufficient and significant data have been found on the sludge dewatering activities once the reactor is being operated at low loading rate (Subramanian *et al*. 2014 & Lawler *et al.* 1986). Odour removal, mass reduction, less energy use and pathogen reduction are a few advantages of the technology behind anaerobic digestion (Mudhoo 2012).

Anaerobic digestion conditions are believed to have reasonable influence on sludge physical characteristics and behaviour. However, primary sludge settling characteristics have been found to be affected by the digestion process slightly; though, in practice, it is minimal and negligible (Mahmoud *et al.* 2006).

Sludge Treatment Processes

The sludge will be treated by various processes such as outlined below.

Blending: The primary sludge consist of settled solids which is been carried in raw waste water. Were as secondary sludge consist of biological solids and as well as additional settled solids. Therefore the sludge is been blended so as to produce a uniform mixture to downstream operations. (Garg 2009)

Sludge stabilization: The sludge is been stabilized to remove pathogens, to remove offensive odours and so as to eliminate potential for putrefaction. The number of technologies are been used in this process such as lime stabilization, anaerobic digestion, aerobic digestion and composting. (Garg 2009). Wastewater sludge has different characteristics, such as its physical, chemical and biological component by which it appears into the treatment plant. The treatment of waste water is highly focused in the reduction of conventional pollutant such as organics, oil and grease. The treatment process of waste water sludge has different steps such as thickening, dewatering, side treatment technology, phosphorous recovery and digestion.

Thickening: This is the first step used in waste water sludge process. It is the movement of sludge from primary to the secondary clarifier which is also include in a stirring mechanism. Thus the thickening sludge with less than 10% solid can also receive additional sludge treatment and the thickness returned to the sewage treatment process.

Dewatering: This aspect is the reduction of water content by the process of centrifugation or filtration which also helps to reduce the transportation cost of its disposal. The filtrate and centrate are returned to the sewage treatment process after the dewatering sludge is been handled as a solid containing 50-70 % of water of which a dewatered sludge that has higher moisture content are often said to be liquid.

Side stream treatment: When sludge is dewatered two products are formed: thickening dewatered sludge & treatment liquid. The liquid requires further treatment as it contains high level of nitrogen and phosphorous. This process can take place in sewage treatment plant itself and they will be separated from nitrogen and phosphorous.

Digestion: The waste water sludge are treated with the use of different digestion techniques and it has huge purpose of reducing the amount of organic matter, which also decrease the number of disease- causing microorganism that are present in the solids. The major treatment options are anaerobic digestion, aerobic digestion and composting.

The treatment of waste water sludge is totally subjected to the local, federal & state regulations which aims to produce an effluent that will do little or no harm as possible when it is discharged into the surrounding environment and also the prevention of pollution. Unlike the releasing of untreated water to the environment and all this are involved in three stages such as primary, secondary & territory treatment.

As grit and phosphorus removal would have been effectively done during the preliminary stages of the retrofitted ASP, the two units are not designed for the sludge treatment process, thus lowering capital and operating costs.

Biogas Production

Biogas is typically composed of 30-60%vol carbon dioxide and 45-70%vol of high calorific value methane (the main component of natural gas). Trace gases such as hydrogen sulphide (1-2%), oxygen (0-2%), ammonia, halogenated hydrocarbons and dust particles (all <1%) are also present. It is generated through a natural biological process that occurs when a wide range of wet organic matter undergoes anaerobic digestion. In AD process, a large fraction of the organic matter in sludge is broken down into CO_2 and methane CH_4 in the absence of oxygen. About half of the amount is then converted into gases, while the remainder is dried and becomes a residual soil-like material.

Biogas produced from AD can be utilised in power and heat generation through a Combined Heat and Power (CHP) unit or, after upgrading and purifying, injected to gas grid or used as biomethane transport fuel. The biogas upgrading process is often expensive and an undeveloped UK infrastructure can make it difficult to realise benefits. The most accessible and cost-effective benefits to many AD operators is therefore through power and heat generation. Electricity and heat can be utilised by operators leading to significant reductions in energy costs. Excess electricity could also be sold to the national grid (Marches Biogas Ltd 2016). The biomethane sector is expanding in response to emerging policy and economic drivers (e.g. feed-in tariffs, renewable heat incentives, fuel tax exemptions and renewable transport fuel obligations).

AD Process Selection

Dry digestion: Dry digestion is a process where the substrate contains 20-35 % TS (total solids). It is mainly used for stackable substrates such as organic waste, solid manure and crop residues. In a continuous process the material is fed into the digestion chamber, little by little, throughout the process. A batch process means that for every round of digestion all the material is loaded in and out at the same time. Sequential batch digestion means that multiple substrate chambers are linked in series and can be filled up and emptied at various times to get a steady gas production (Nordberg & Nordberg 2007).

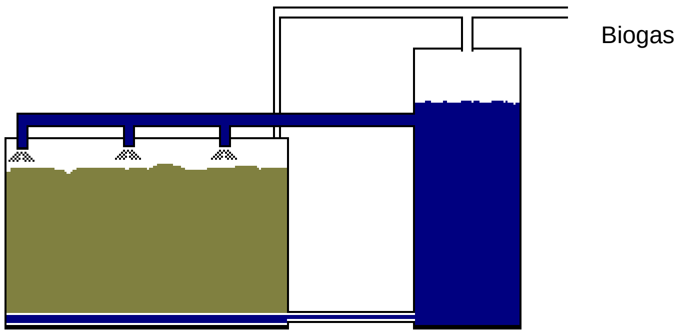

Figure 3: A simplified schematic diagram of a dry digesting facility with batch loading of substrate and circulating percolation liquid (Nordberg & Nordberg 2007).

A batch process can be designed as a percolation bed or a soaked bed. One can also imagine a combination between these two techniques. In a percolation bed liquid is sprayed over the material and allowed to flow down to the bottom of the chamber. The liquid is then passed on for recycling (figure 3). Multiple beds can be linked in series within the same fluid system. The circulating liquid has an inoculating effect to new beds. One problem that can occur is channel formation. This means that all the material will not be filtered through and methane production is lessened. A soaked bed means that the entire bed is soaked in liquid during substrate degradation. The liquid is drained off before the material is loaded out. The advantage of an evenly distributed liquid in the substrate is that a steady temperature and a good contact with all the material are achieved. The liquid is reused for the next round of substrate to be digested, providing a good inoculating effect.

Wet Digestion: Wet digestion means a process where the substrate contains less than 12 % TS and is possible to pump (Björnsson, verbally 2010). Wet digestion facilities are almost exclusively continuous plants (figure 4). Digestion takes place in a stirred tank. Stirring is required to maintain an even temperature and prevent foaming and sedimentation. To avoid problems with mixing, the material needs to be fine. In drier substrates liquid might need to be added in order to obtain a pumpable consistency (Christensson et al. 2009). Various types of stirring in the digestion tank occur. The most common method is the propeller stirring (mechanical). In the past gas stirring, where biogas is compressed and fed into the bottom of the tank again, was common but is increasingly being replaced by propeller stirring (Starberg et al., 2005).

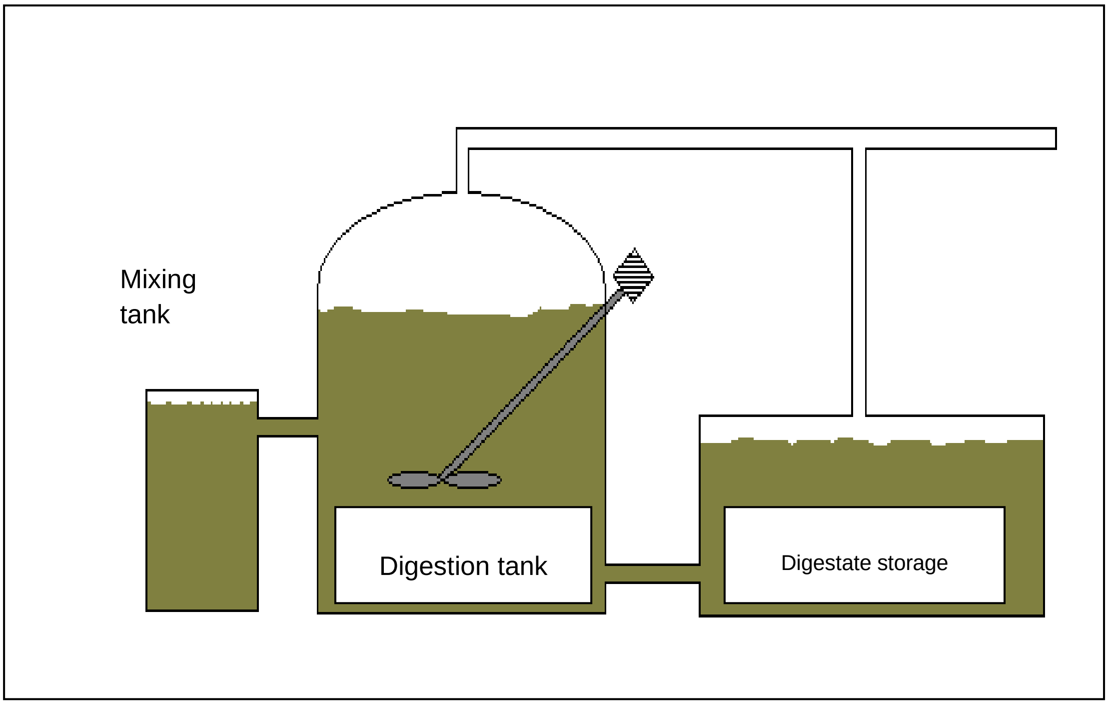

Figure 4: Concept of a wet digestion facility with propeller agitation and continuous operation.

The continuous process can be designed as a single-step or a two-step digestion. At two-step digestion there are two reactors connected in succession (Starberg et al. 2005). Another variation is to have an initial step with hydrolysis at higher temperatures. This may increase the degree of digestion and methane yield (Persson et al. 2010). For wet digestion in continuous operation, it is important to have a steady supply of raw material in terms of both quantity and type. It is also important that the residence time (time the substrate is in the digester) is long enough, at least 15 days. If the material passes too quickly a hydraulic overload is obtained and methanogens do not have time to grow but is washed out with the material leaving the digestion tank. This means that methane production is absent and undigested material leaves the tank. If the substrate has a high concentration of organic matter or the material is fed into the digester at high rate, you can get an organic overload. The process can handle a maximum of 1-4 kg of organic matter per m^3 tank and day. At higher loads the methanogens can not keep up with methane production and intermediates accumulates. Lower loads and longer dwell time gives a higher methane yield. This must be weighed against the construction cost (Björnsson, verbally 2010).

For this retrofit project, wet digestion was selected as the AD method as it is most suitable to the kind of sludge to be handled; wastewater sludge, pumpable and 6% dry solids concentration (less than 12%).

Plant retrofit design calculations

Influent Wastewater

Table 1: Summary of settled sewage load data (June 2008 to September 2014)

	BOD (kg/d)	COD (kg/d)	SS (kg/d)	NH_3 (kg/d)
Maximum	1467.53	3809.04	1298.09	187.18
95 percentile	1184.79	2340.94	1009.64	168.19
85 percentile	895.23	2013.25	650.78	150.15
Average	667.73	1585.01	472.91	117.91
Minimum	220.22	560.88	175.49	49.20
No. samples	95	90	92	94

Assume 50% removal of load in the PSTs.

Sludge Treatment Sizing

BOD removal contribution (Assume 50 % removal from PST) = 2713.79 Kg/d

BOD load contribution from PST (Population 10,500) = 0.14 kg BOD/hd/d

Assuming the average BOD contribution of load from surrounding 15 towns = 0.08 kg/BOD/hd/d

The average total BOD from PST (PST is negligible) = 0.08 kg/BOD/hd/d

Assuming the contribution of BOD load from the primary tank = 0.08 kg BOD/hd/d

Total Population Equivalent = Existing population + University Environment + Petrochemical plant

= 10,500 + 14,250 + 6,380 = 31,130 PE.

Total population equivalent + surrounding population = 31,130 + 200,000 = 231,130

Assuming the BOD load contribution from SAS = 0.04 kg BOD/hd/d

Assuming Sludge growth index = 0.9 Kg ss/kg/ BOD

Daily feed volume to thickened digester to 6% DS

Calculating the volume of sludge from primary, SAS & the surrounding towns at 6 % DS

Daily volume of primary sludge = PE x BOD loading = 31,130 x 0.08kg/d = 2490.4 kg/d

Volume of primary sludge at 6% = 41.51m^3/d

Mass of SAS/day = 31,130 x 0.04 x 0.9 = 1,120.68kg/d

Volume of SAS/day at 6% = 18.68m3/d

Volume of sludge from surrounding (STW)

Volume = 200,000 x 0.08 kg/d = 16,000kg/d

Volume of surrounding sludge @ 6% = 266.67m3/d

The total volume of sludge given to the digester/day = (41.51 + 18.68 + 266.67) = 326.86 m^3/d

Total number of Digesters required:

Retention time in anaerobic digester = 15 days

Daily sludge feed = Retention time x volume of digester = 15 x 327 = 4,905 m^3

Consider a tank of size 1000 m^3, 75 % of effective volume

75% of effective volume = 75% x 1000 = 750

Number of digesters required = 5

Therefore the working volume of digesters = 75% x volume of digester = 75% x 4902.9 = 3677m^3.

Table 2: Dimensions for Proposed BIOSAS ASP Modifications

Process Unit	Side Water depth (m)	Length (m)	Width (m)	Volume (m^3)	Status
Anaerobic tank	5.0	8.37	8.37	350	Construct
Anoxic Tank Cell 1	5.0	9.4	9.4	441.5	Retrofit
Anoxic Tank Cell 2	5.0	9.4	9.4	441.5	Construct
Aerobic Cell 1	5.0	10.23	10.23	523.4	Retrofit

Aerobic Cell 2	5.0	10.23	10.23	523.4	Retrofit
Aerobic Cell 3	5.0	10.23	10.23	523.4	Retrofit
Aerobic Cell 4	5.0	10.23	10.23	523.4	Retrofit
Aerobic Cell 4	5.0	10.23	10.23	523.4	Construct
Anaerobic Digesters 1	5.0			2000	Construct
Anaerobic Digesters 2	5.0			2000	Construct
Anaerobic Digesters 3	5.0			2000	Construct
Anaerobic Digesters 4	5.0			2000	Construct
Anaerobic Digesters 5	5.0			2000	Construct

Explanation of Equations for Qw and Qr

Most of the equations used above are rather straightforward application of a loading factor, calculation of retention time as volume divided by flow rate, or the equation follows directly from the units. The sources of the equations for Qw and Q_r aren't quite as obvious, however, so they are discussed briefly here.

Waste Activated Sludge Flow Rate: The equation for waste activated sludge flow rate, Q_w, is based on the principle that the average length of time activated sludge solids stay in the aeration tank [the sludge retention time (SRT) or sludge age] is equal to the mass of solids in the aeration tank divided by the rate at which solids are being wasted from the system. In equation form:

SRT = lb activated sludge in aeration tank/(lb act. sludge leaving system/day)

SRT = (8.34*X*VMG)/(8.34*Xw*Qw)

(Note that the factor 8.34 converts mg/L to lb/MG.)

Units in above equation are: [(lb/MG)*MG]/[(lb/MG)*MG/day] = lb/(lb/day) = days

Solving for Qw gives the equation in the list above:

$$\mathbf{Q_w} = (\mathbf{VMG}*\mathbf{X})/(\mathbf{SRT}*\mathbf{X_w})$$

Recycle Activated Sludge Flow Rate: An equation for the recycle activated flow rate can be determined by a material balance around the aeration tank.

The inflows to the aeration tank are Q_o with suspended solids concentration of X_o and Q_r with suspended solids concentration of X_w. The outflow from the aeration tank is $Q_o + Q_r$ with suspended solids concentration of X (equal to that in the aeration tank).

A material balance over the aeration tank must take into account the fact that there is a net growth of activated sludge solids in the aeration tank. The material balance is thus:

Rate of solids outflow – Rate of solids inflow = Growth rate of solids

The growth of activated sludge is typically hydraulically controlled with the activated sludge wasting rate and is equal to Q_wX_w. The material balance equation thus becomes:

$$(Q_o + Q_r)X - (Q_oX_o + Q_rX_w) = Q_wX_w \text{ (kg/day in S.I. units or lb/day in U.S. units)}$$

Solving the equation for Qr, the 8.34 in each term will 'cancel out.'

Through a bit of algebraic manipulation, the equation can be solved for Qr to give:

$$\mathbf{Q_r = [Q_o(X - Xo) - Q_wX_w]/(X_w - X)}$$

The activated sludge wasting rate, Q_w, is typically much less than the influent flow rate, Q_o, so the term Q_wX_w is sometimes dropped out to simplify the equation to:

$$Q_r = Q_o(X - X_o) / (X_w - X).$$

Financial Incentives for AD Plant Operation

A range of government financial incentives are in place to assist uptake of green energy generation projects in the UK in a bid to reduce carbon emissions associated with conventional fossil fuel use (Brockett 2016). The Office for Renewable Energy Development of the Department of Energy and Climate Change (DECC) had put in place and annually reviews the incentives in line with varying economic realities to ensure the desired outcomes are achieved. This could be seen in figure 5, which indicates biogas outstripping other renewable energy sources in the energy mix and competing closely with nuclear power.

1. Feed in Tariff (FiT): This is a government index-linked incentive that offers guaranteed payments for each kWh of electricity generated. Table 3 illustrates this further.

- Plants up to 250kW currently receive 11.21p/kWh
- Plants 250kW - 500kW receive 10.37p/kWhr
- Plants above 500kW receive 9.02p/kWhr

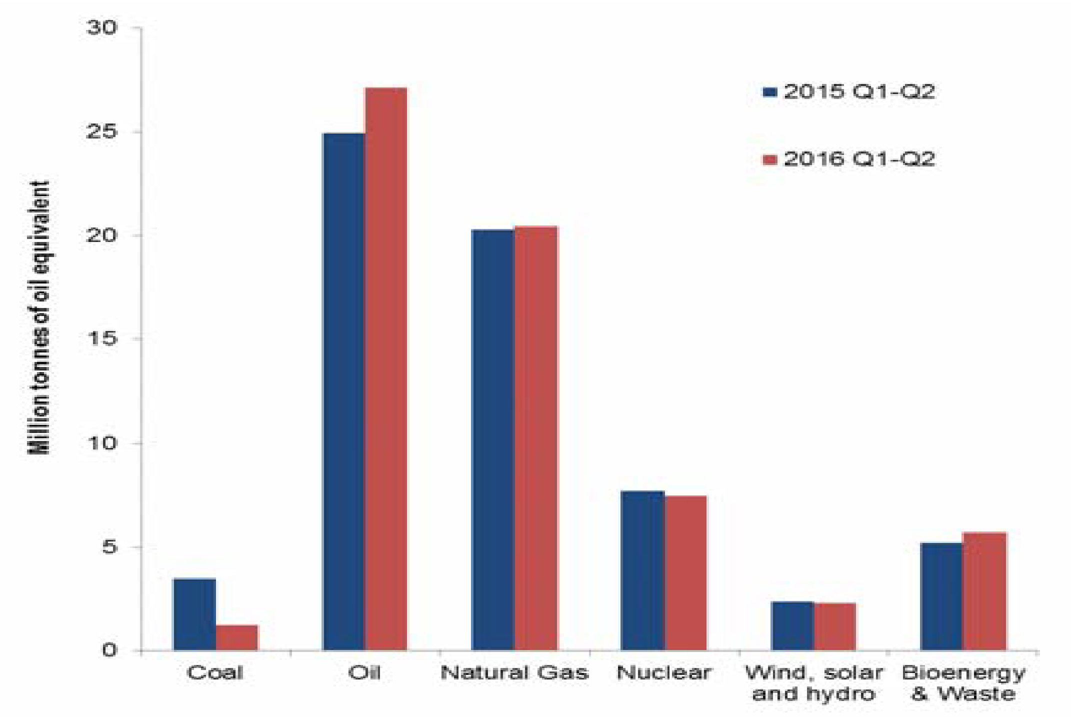

Figure 5: **Production of indigenous primary fuels (BEIS 2016)**

Table 3: **Overall Feed-in Tariff statistics from 1st April 2010 to 17th December 2015 (*FIT 2016*)**

Technology	Quantity	MW	Quantity	MW	Quantity	MW
AD biogas	1	0.004	224	158.638	225	158.643
Hydro	303	4.243	365	85.142	668	89.385
Solar PV	674,144	2,330.298	22,130	980.815	696,274	3,311.113
Wind	3,947	42.434	2,392	418.452	6,339	460.886
Micro-CHP	491	0.504	11	0.014	502	0.518
Total	**678,886**	**2,377.483**	**25,122**	**1,643.062**	**704,008**	**4,020.545**

2. FiT 'Degression': The FiT incentive is reducing in line with installed capacity of AD in the UK. The 0-500kW and 500kW+ bands are subject to separate degression calculations. A 10% degression is envisaged from the above 0-500kW tariffs from April 2015 - effectively 1st January 2015 for pre-accredited projects. We expect the 500kW+ tariff to degress by 5-10%.

3. Electricity Export to Grid: Generated electricity exported to the grid receives a payment from the energy supplier, currently set at a minimum 4.5p/kWhr. Exporters can negotiate higher payments with energy companies, with 6p/kWhr currently achievable.

4. Renewable Heat Incentive (RHI): The RHI provides a fixed income (per kWh) to generators of eligible renewable heat and biomethane. The lifetime of the tariff is 20 years. The current RHI for renewable heat is displayed on table 4 below, reporting a 3-tier structure being implemented from 2015.

Table 4: New Tariff levels (DECC 2014)

Tier	Tariff, p/kWh[1] (FY 2014/15)	Tier Break – MWh per annum (Output at which tariff changes)	Approximate Biogas plant capacity that produces an annual output equivalent to Tier Break - MW
Tier 1	7.5	40,000	6
Tier 2	4.4	40,000 to 80,000	12
Tier 3	3.4	> 80,000	> 12

[1]*The tariff will be paid up to the maximum volume of biomethane the producer is entitled to inject under the Network Entry Agreement (NEA).*

5. Renewables Obligation Certificates (ROCS): These are green certificates issued to accredited generators for eligible renewable electricity generated within the United Kingdom and supplied to customers within the United Kingdom by a licensed electricity supplier. An anaerobic digester will receive 2 ROCs/ MWh until April 2015. This makes ROCS a viable option for larger scale AD plants, particularly after potential FiT degression in 2014. Unlike FiTs, the value of ROCs is not fixed but could either reduce or increase.

Project management

Every wastewater utility's engineering department is primarily tasked with delivering projects to its stakeholders on schedule, within budget, fit-for-purpose and that can be operated and maintained. Commissioning is critical to attaining these goals. Just as any construction industry, the wastewater sector has been challenged with executing one of the most critical stages of a construction project; commissioning. This is common at the end of most projects when the risk of budget deficits is very high and considerable pressure exists for the contractor's work to be completed. Another challenge is that the facility is operating during commissioning, when the contractor must have completed all the specified testing, as owners usually start operations and maintenance the very next day (Birdsell and Puccio 2011). Careful planning and control throughout the design, construction and commissioning phases is thus indispensable towards paving a clear road to project success.

For this paper, commissioning is defined as testing and start-up of a project as well as works related to preparing the project to be turned over to the operators and maintainers including:

- Equipment Testing
- Piping, Tank and Structural Basin Testing
- Utility System Testing
- Control System Testing
- Process Testing
- Vendor Equipment Manuals
- Vendor Equipment Training
- Operations Manual (designer prepared)
- Operations Training
- As-Built Drawings.

Project Implementation Activities

The estimated timeline to deliver the AD retrofit project timeline is captured in table 5. The entire activity was broadly grouped into four:

- Construction of 190 million gallons per day (MGD) headworks facility
- Construction of co-thickening and dewatering centrifuge facility
- Construction of primary sludge distribution pump station
- Construction of digesters and central generation facility.

Table 5: Project Timeline for BIOSAS WWTP Onsite Sludge Processing

PROJECT ACTIVITY	DURATION
Pre-design Planning	6 months
Environmental Review and Permitting	4 months
Design	5 months
Bidding, evaluation of bids and award of contracts	4 months
Construction	10 months
Testing, Commissioning and Modifications	1 month
Total Duration	**30 months**

Implementation activities for any project include some or all of the following, with required time as noted:

Pre-design Planning: This activity typically would take three to six months but could extend to 18 months if a project requires pilot testing or full-scale demonstration. Some smaller projects may not require any pre-design activities, with detailed project definition occurring during the design. Six months was selected for this case and it took just about that duration.

Design: For smaller projects the design time could be as short as three months. Typical design time would be five months for this study.

Bidding and Award: The bidding and award time will vary depending on project size and district requirements. Bidding typically requires one to two months, as does awarding, depending on operator and regulator schedules. Thus, this activity's overall time frame was four months.

Construction: Construction duration reflects construction complexity and lead time required for key equipment. Typical durations range from six months or less for smaller projects without specialty equipment to up to 20 months for a major project, possibly with complicated tie-ins to existing facilities. The AD retrofit is projected to last for ten months.

Commissioning: Commissioning times vary widely from several weeks to several months. For example, commissioning often includes substantial time for staff training; however, none of the recommended projects defined through master planning include completely new processes for which field personnel would need such training.

Environmental Review and Permitting: In summary, the EA and Warwickshire County Council could implement smaller projects in as little as nine months, while the most complex projects could take almost four years if there is need for a detailed environmental review. It is expected that this project will be completed onsite with little or no offsite impact, so little is expected for environmental review and permitting. Most projects will require a negative declaration determination by the County Council, which may require a public comment period of one month and adoption at a subsequent meeting. Permitting will be minimal, though it should be noted that expanding the recycled water system may require updating the Engineer's Report for the EA, which may require two to three months to review. Four months was therefore allowed for this activity.

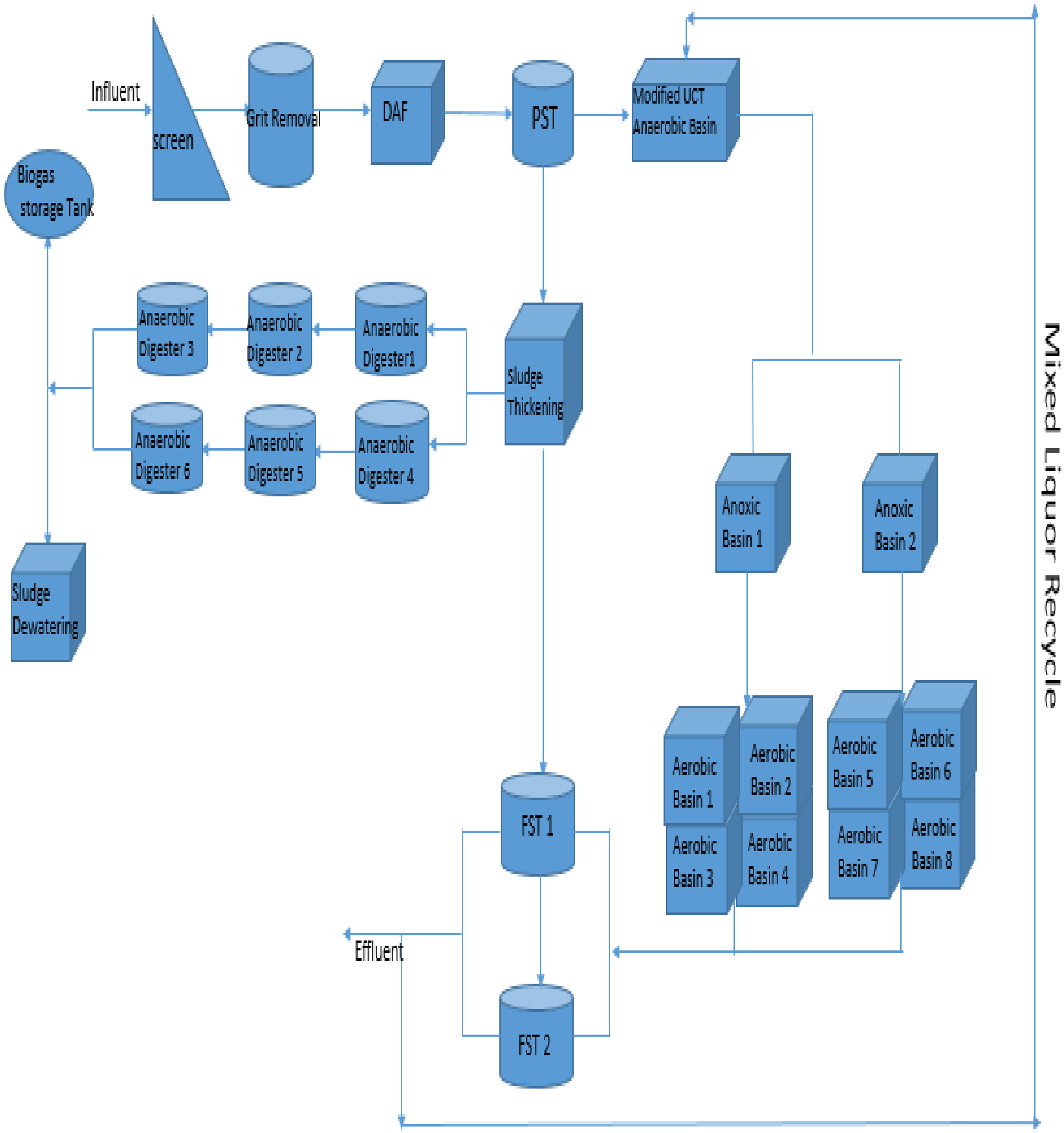

Figure 6: **Simplified flow diagram for the retrofitted BWWTP (Bassey & Odigie 2016)**

Table 6: BIOSAS Modification Capital Expenditure

ITEM DESCRIPTION	COST ($)
Site excavation	516,300
Dissolved air flotation (DAF) for O&G removal in PST	4,505,000
Anaerobic Tank for Phosphorus Removal	648,500
Anoxic tank 2	490,000
Aerobic tank 5	363,000
Aerobic tank 6	363,000
Aerobic tank 7	363,000
Aerobic tank 8	363,000
Anaerobic Digester 1	1,002,000
Anaerobic Digester 2	1,002,000
Anaerobic Digester 3	1,002,000
Anaerobic Digester 4	1,002,000
Anaerobic Digester 5	1,002,000
Anaerobic Digester 6	1,002,000
Sludge Pre-treatment Processes	4,180,000
Biogas storage tank	500,000
Head works – Pumps, fine screens, primary sludge tanks, etc.	28,001,000
Contractors' Fees	4,000,000
Approvals and permits	72,700
Miscellaneous/Overhead	2,000,000
TOTAL COST	**52,377,500**

Conclusion

- This paper summarised the recommended project imperatives for upgrading the BIOSAS WWTP to prevent impending redundancy, expand capacity and ultimately boost returns on investment. Proposed improvements would accommodate growth and both existing and possible future, more stringent discharge requirements. The modifications would also deliver more recycled water when needed to accommodate increased demand from domestic, commercial and industrial clients.

- Process optimisation is key to both biological and financial productivity of the AD unit proposed for BWWTP. With 50% BOD removed in the preliminary and primary treatment stages of the activated sludge process, mixed liquor recycle and continuous sampling for effluent quality assurance, the feedstock to the AD unit is kept at required quality. The large sewage load anticipated due to plant expansion to meet population growth, industrial waste streams and third party sludge handling would definitely provide enough sludge feed to keep the plant continually busy, thereby creating a favourable economics of scale.

- Rigorous condition monitoring, data mining, performance measurement and process modifications are however required from start-up through operations and maintenance to address any hydraulic or other 'teething' problems that may arise using proven best available and sustainable technology (BAST). To enhance this, computational fluid dynamics (CFD), economic and project risk management models are currently being developed for activation during the testing and commissioning phases of the project.

Recommended Best Practices for Hitch-Free Commissioning

- Develop a separate commissioning phase for each project with a budget and schedule.
- Develop a commissioning team for the program and commissioning teams for each project.
- Establish tasks for design engineers to include on the plans and specification to facilitate commissioning.
- Develop a specification to define the contractor's responsibility in commissioning.
- Develop specification to define the contractor's responsibility for vendor training and vendor equipment manuals.
- Establish requirements for detailed testing procedures with pass/fail criteria.
- Provide procedures, training and assistance to construction managers and inspectors to enforce contract requirements during construction.
- Develop post construction process acceptance testing requirements.
- Develop lessons learnt process.

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