FROM SEWAGE TO ENERGY

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Abstract: *The Drainage Services Department (DSD) undertakes the responsibility for sewage collection, treatment and disposal in Hong Kong. On average, 2.74 million m^3 of sewage was collected and transferred by 224 sewage pumping stations and treated by 68 sewage treatment facilities of various scales every day in 2012 – 2013*[1]*. High electricity demand in DSD sewage facilities has always been an issue needed to be addressed as sewage treatment is an intensive energy consumption process. With a vision "To provide world-class wastewater and stormwater drainage services enabling the sustainable development of Hong Kong", the department has been, in the course of operation, utilizing various energy saving technologies and forms of renewable energy such as wind and solar wherever practicable in the past years. To make use of the energy-rich biogas, a by-product of secondary sewage treatment process, Combined Heat and Power (CHP) technology has been introduced since 2006 in some Sewage Treatment Works (STWs) and has achieved a great success in reduction of energy consumption and carbon footprint. Furthermore, hydropower technology is being planned to be applied in the Stonecutters Island Sewage Treatment Works (SCISTW) as a trial to capture the potential energy from sewage flow in the Works. This paper highlights the recent development of CHP and hydropower technologies in DSD.*

INTRODUCTION

Over the years, DSD has addressed the energy issues by a two-pronged approach, namely conducting energy audits and implementing energy saving initiatives. Energy audits help identify energy management opportunities from which saving of energy can be realised. Through exploring advanced technologies worldwide, several energy efficient initiatives have been implemented, for instance, variable speed drives for pumping, low pressure high intensity UV lamps for disinfection of effluent (i.e. treated sewage), solar panels and air blowers with dissolved oxygen control for biological treatment of sewage, etc. Riding on the successful experience of our first CHP plant put into operation in Shek Wu Hui STW in 2006, the number of CHP plants has remarkably grown to 6 units by now. The overall biogas production in 2013 was about 9.4 million m^3. The equivalent electricity saved was higher than 14 million kWh, which is equivalent to the annual electricity consumption of 1,560 four-member families.

ENERGY FROM SEWAGE TREATMENT

It is a human nature to get rid of waste. Sewage, which is normally regarded as waste, is generated in large volume in the course of people's daily activities in densely populated cities like Hong Kong. In the old days, sewage would only receive very preliminary treatment or not be treated at all before disposing back to our mother nature without noticing that the large amount of energy contained in sewage was being thrown away at the same time. With the

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[1] Data from DSD Sustainability Report 2012 – 2013.

advent of advanced energy recovery technologies, we can turn sewage to energy effectively and efficiently through the application of suitable sewage treatment processes.

Sludge is produced during a secondary sewage treatment process. Prior to delivery to landfill sites, stabilization process is required to remove the harmful substances. Anaerobic digestion is a traditional process commonly used for the stabilization of biosolids and widely employed in the secondary sewage treatment works worldwide. Its basic principle is by biological decomposition of organic materials in the absence of molecular oxygen which involves a complex microbial process with different groups of bacteria and methanogens. Organic materials of the sludge are broken down into less harmful inorganic products and various kinds of gases are produced as a result of biodegradation of the organic materials. These gases are collectively named as biogas.

Typically, composition of biogas from the anaerobic sludge digestion contains about 60 - 65% methane by volume, 35 - 40% carbon dioxide, and small amounts of nitrogen, hydrogen, hydrogen sulphide (H_2S), water vapour and other gases. The following table shows the volume of sewage treated and the associated production of biogas annually at the four major STWs with secondary sewage treatment, which employ anaerobic digestion process in sludge treatment.

Table 1: Production of biogas at four secondary sewage treatment works in 2013

Parameters	**Shatin STW**	**Tai Po STW**	**Shek Wu Hui STW**	**Yuen Long STW**
Treated Sewage (million m^3)	85	36	31	10
Biogas produced (million m^3)	5.6	2.0	1.2	0.6

The heating value (i.e. the heat released when a known quantity of fuel is burned) of biogas is generally above 22.4 MJ/m^3. In general, the gas composition at the four STWs is generally in line with the normal ranges except the relatively high content of H_2S at Tai Po STW and Shatin STW. It is because seawater flushing contributes much to the higher sulphate content in the sludge and this resulted in a higher H_2S concentration in biogas. H_2S is notorious for its corrosive nature which can cause severe dilapidated damages to E&M equipment and building structures if not properly handled. Suppression of H_2S formation or removal of H_2S to a lower concentration level after the sludge digestion process is therefore required prior to its being fed to a power generator.

Before 2006, only a small proportion of biogas was used as fuel for hot water boilers and electricity generation by internal-combustion engines which in turn drive pumps, air blowers. Hot water from boilers or from engine jackets and exhaust of boilers were used for maintaining the sludge in the required temperature in the digestion process and for space heating in buildings. A large portion of remaining biogas was often burned and flared to the atmosphere.

COMBINED HEAT AND POWERTECHNOLOGIES

Combined Heat and Power (CHP), also known as "Cogeneration", is a technology to increase the overall efficiency of an energy recovery system through simultaneous generation of heat and power from a single energy source. It encompasses a range of equipment, but will always include an electricity generator and a heat recovery system. Taking into account the recovery of thermal energy, the overall efficiency of CHP plant can reach 90% or more in some Europe's experience[2].

Except for the micro-turbine CHP in Yuen Long STW, the CHPs installed in DSD's STWs are all running on reciprocating engines. From an engineering point of view, this kind of engines has the merits of quick starting and good part-load efficiencies.

The following flow diagram indicates the normal operating process of a CHP system.

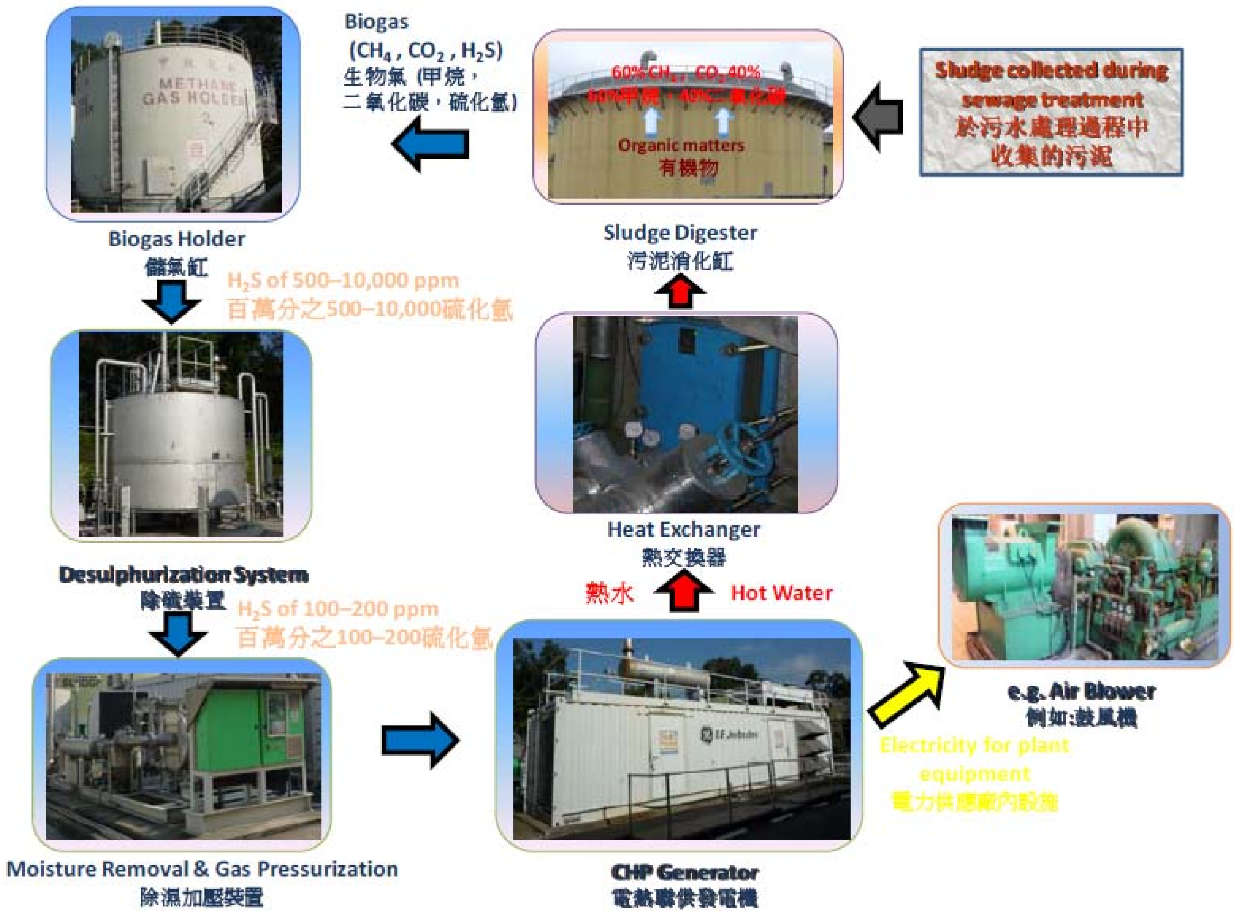

Figure 1: CHP system flow diagram

Biogas collected from digesters is first stored in a gas holder. It is then compressed and purified by desulphurization and moisture removal. The biogas is fed at a constant pressure into the CHP plant. Energy stored in the biogas is then converted into thermal energy and mechanical energy which drives a synchronous generator for producing electricity to meet part of the power demand for the sewage treatment process. With a total capacity of 3,650 kW, all CHP plants in DSD are now operating in on-grid configuration (i.e. connected to operate in parallel with the power supply grid). The CHP plant in Shatin STW, with a capacity of 1.4 MW, is the largest HV grid connected generating unit operating in Hong Kong.

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[2] Page 3 of "A guide to cogeneration" by COGEN Europe, Ed. March 2001

Figure 2: CHP installed in Shatin Sewage Treatment Works

Micro-turbine

A micro-turbine is similar to a typical turbine but it is smaller in size. Its operating principle involves the combustion of biogas to create a high pressure air flow. The air flow moves the turbine impellers and the shaft of the turbine in turn drives the generator to produce electricity. Thedesign usually consists of a single stage radial compressor, a single stage radial turbine and recuperators. Design and manufacturing of recuperators are required to meet stringent requirements because they need to be operated under high pressure and extreme temperature differentials. Exhaust heat can be used for water heating, space heating, drying processes or absorption chilling, which makes use of heat energy instead to provide cooling. Typical electrical efficiencies of micro-turbines are 25 to 35%. When it operates in a combined heat and power cogeneration system, efficiencies higher than 80% can be achieved.

Turbine systems have many advantages over reciprocating engine generators, such as higher power density (with respect to footprint and weight), extremely low emissions and few moving parts. Turbines also have the advantage of having majority of waste heat contained in relatively high temperature exhaust, whereas the waste heat of reciprocating engines is split between its exhaust and engine cooling system. However, reciprocating engine generators are quicker to respond to changes in output power requirement, and are usually slightly more efficient. Nevertheless, the efficiency of micro-turbines is increasing with the progressive advance in technology. Also, the efficiency of micro-turbines is generally lower than that of reciprocating engines at low power output levels. A comparison between the two CHP technologies is shown as follows:

Table 2: Comparison of Micro-turbine and reciprocating CHPs

Facilities	Pros	Cons
Micro-turbine CHP	Compact size. Accept biogas with high H_2S concentration. Power generation capacity down to 30 kW. Low maintenance cost. Suitable for use in sewage treatment facilities with less biogas generation. Waste heat contained in its high temperature exhaust.	Higher biogas intake pressure requiring higher energy input for compressor unit. Lower heat recovery rate. Higher installation cost per unit power.

Reciprocating CHP	Higher heat recovery rate. Lower installation cost per unit power. Suitable for use in major sewage treatment facilities with high biogas generation rate.	Require pre-treatment of H_2S. Larger footprint. High maintenance cost for pre-treatment system of H_2S removal system.

The photo below shows the micro-turbine generator system installed in Yuen Long Sewage Treatment Works.

Figure 3: Micro-turbine generator system

In designing a CHP plant, considerations have to be given to the load profile of major E&M equipment in STWs, the configuration of existing electric network and proximity of the heat load installations to the CHP plant. For example, mixing of thickened sludge in the sludge digestion tank in Tai Po STW is accomplished by circulating the biogas back to the digestion tank. There were two biogas hot water boilers, one electric hot water boiler and one dual fuel water boiler for maintaining the re-circulating water at an optimal temperature of around 35^{o}C inside the sludge digestion tanks. The rating of the CHP generator installed is 625 kW. Power generated is connected to the main switchboard of the new thickening house while the heat generated is used to provide an alternative heat source for digesters.

Recent development of CHPs in DSD

The first large-scale 330 kW combined heat and power (CHP) generator was commissioned in 2006 at Shek Wu Hui Sewage Treatment Works and was subsequently connected with CLP Power's distribution network two years later. The electricity generated is supplied to the existing E&M facilities while the recovered thermal energy is used for pre-heating the recirculation water for maintaining the required temperature for the sludge digestion process.

Figure 4: CHP installed in Tai Po Sewage Treatment Works

Between 2006 and early 2013, two more CHP generators were installed, which were at Shek Wu Hui STW and Tai Po STW (see Figure 4 above). The total installed power generating capacity from the utilization of biogas then reached 1,590 kW and the generators had converted 9.32 million m^3 of biogas to some 20.2 million kWh of electricity, which is equivalent to the annual electricity consumption of over 2,240 4-member households. In monetary term, it represents a saving of about HK$17.5 million in electricity cost. The reduction of greenhouse gas emission, after installing these CHP generators, is equivalent to 14,140 tonnes of CO_2. In end 2013 and early 2014, two further CHPs were commissioned in Shatin STW and Tai Po STW, with capacity of 1,400 kW and 630 kW respectively. The graph in Figure 5 below indicates the timeline for the installation of CHPs and micro-turbine in STWs in DSD.

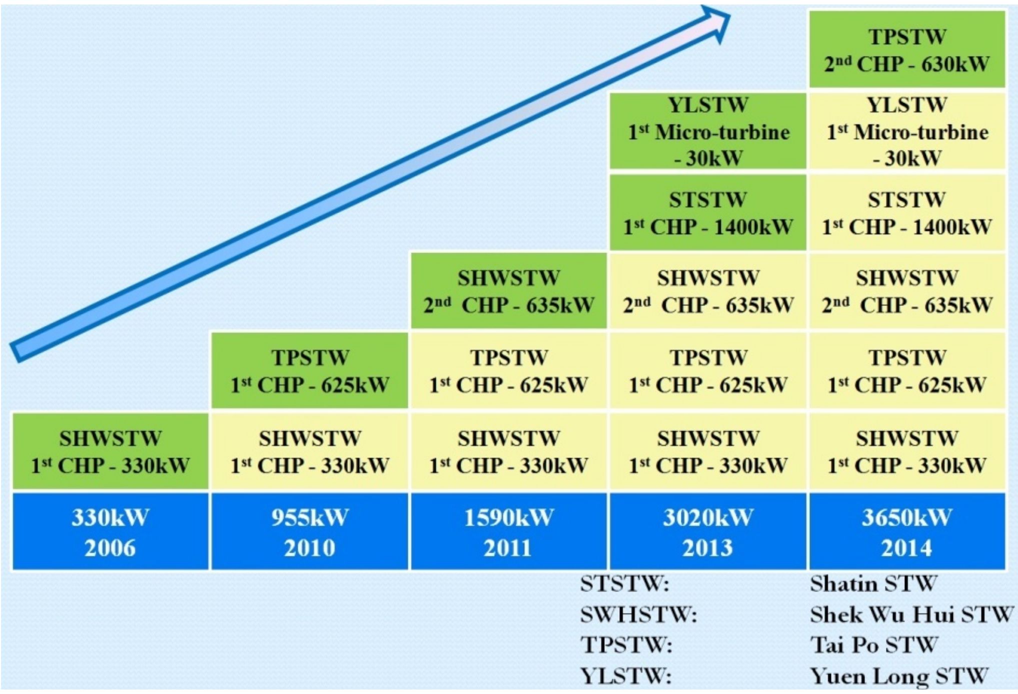

Figure 5: Timeline for installation of CHP plants and micro-turbine generator in STWs

Yuen Long STW is the first sewage treatment works in DSD with an installed micro-turbine generator. The installation works commenced in mid-2012 and was completed in mid-July 2013. Its operation mechanism is similar to that of a typical aircraft engine but in a smaller scale. The micro-turbine generator at the Yuen Long STW uses biogas as fuel. Housed in an area of about 20 m^2, the generator system comprises of four major pieces of equipment (see Figure 3), a compressor, a gas dryer, a receiver, and a micro-turbine generator.

The design capacity of this system is 30 kW and its output voltage is compatible with the local power supply systems in Hong Kong (i.e. 380volt/ 3 phase/ 50 Hz). The operational speed of the micro-turbine generator at the Yuen Long STW is 96,000rpm. Its operating noise is about 65 dBA which is generally the same as reciprocating CHPs in other STWs. The biogas consumption rate is about 15 m^3 per hour.

The average biogas production rate of Yuen Long STW is about 146,000 m^3per annum. The micro-turbine generator can consume more than 60% of the biogas produced while the remaining 40% will be supplied to the existing gas-fuelled water heaters to provide hot water for the sludge digester tanks.

On energy saving aspect, the micro-turbine generator can generate 108,000 kWh electricity per annum, which is equivalent to the annual consumption by 12 four-member families and a saving of annual electricity cost of $100,000. For greenhouse gas emissions, over 75 tonnes of CO_2 emission, which is equivalent to the carbon absorption by over 3,600 trees in a year, can be reduced.

Outlook of CHPs and micro-turbines in DSD

DSD will continue to explore the feasibility of additional CHPs or micro-turbines in various sewage treatments works to cater for the increasing demand in sewage treatment capacity and to keep abreast of the latest development in CHP development with a view to further enhancing energy saving in our operation.

HYDROPOWER TECHNOLOGY

Hydropower technology refers to the power derived from the energy of falling or flowing fluid. Back in 2008, DSD started to look into the feasibility of utilizing hydropower in DSD's plants, involving falling/flowing water, and a R&D study was then carried out in the Stonecutters Island STW. The study concluded that, for utilitization of hydropower to be economically viable, two basic conditions had to be met, namely adequate surplus head and stable water flow. With the Harbour Area Treatment Scheme Stage 2A project to be completed soon, the opportunity of utilizing hydropower could be realized.

The Harbour Area Treatment Scheme (HATS) is the biggest sewerage infrastructure in Hong Kong. Above 60% of the sewage of the city is currently treated at The Stonecutters Island STW, which is a core element of the scheme and capable of handling 1.7 M m^3/day, currently handles the treatment of over 60% of sewage of the city. After the commissioning of HATS Stage 2A, it will provide treatment to the remaining sewage from the northern and south western parts of Hong Kong Island. The treatment capacity of Stonecutters Island STW will increase from the existing 1.7 M m^3/day to 2.45 M m^3/day.

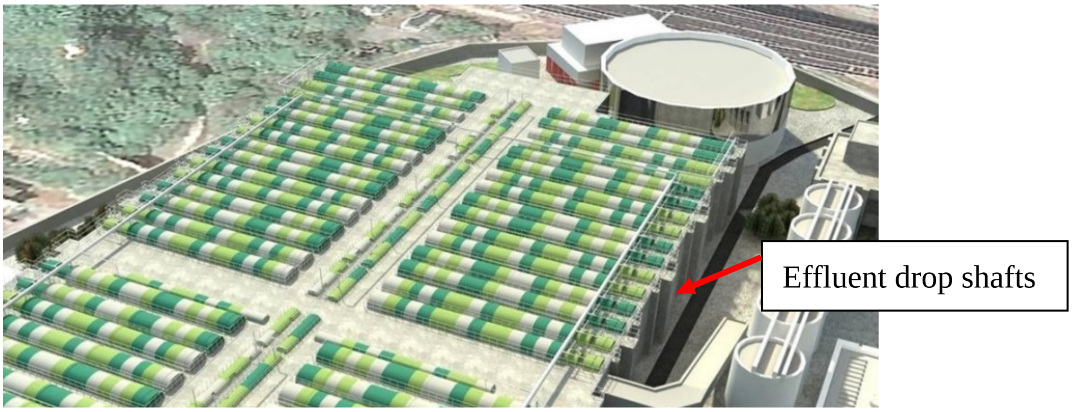

Figure 6: Aerial view of Stonecutters Island STW(HAT2A)

Under the scheme, there are 46 sedimentation tanks. In every two tanks, there is one effluent drop shaft (see Figure 6 above). After the chemically enhanced primary treatment, treated sewage will drop through the shafts for chemical dosing before discharging to the sea. Surplus head and steady flow in these shafts make it a good choice for applying hydropower technology. Figure 7 below illustrates sectional view of a drop shaft. It is estimated that the maximum head available for hydro-turbine installation through these shafts is approximately 4.9 metres.

Based on preliminary design calculations, it brings an opportunity for trial to install in one of the effluent drop shafts a fixed flow propeller type 55 kW hydro-turbine at 4.9m rated head and 1.3 m^3/s rated flow to capture the energy from falling water. Subject to the result of this trial, the turbine could be extended to be installed in other drop shafts. If fully implemented, a total hydro-power generation capacity of around 1,265 kW (55 kW x 23) could be achieved, which amounts to about 7.6 million kWh electricity and is equivalent to the electricity of annual consumption of 840 four-member families. Propeller machines are often preferred for low head small hydro schemes due to the lower cost and simpler construction. As a propeller type hydro-turbine has no means of flow adjustment whilst in operation, a modulating bypass control valve is required to control the flow rate of effluent entering the turbine through to the underground effluent culvert.

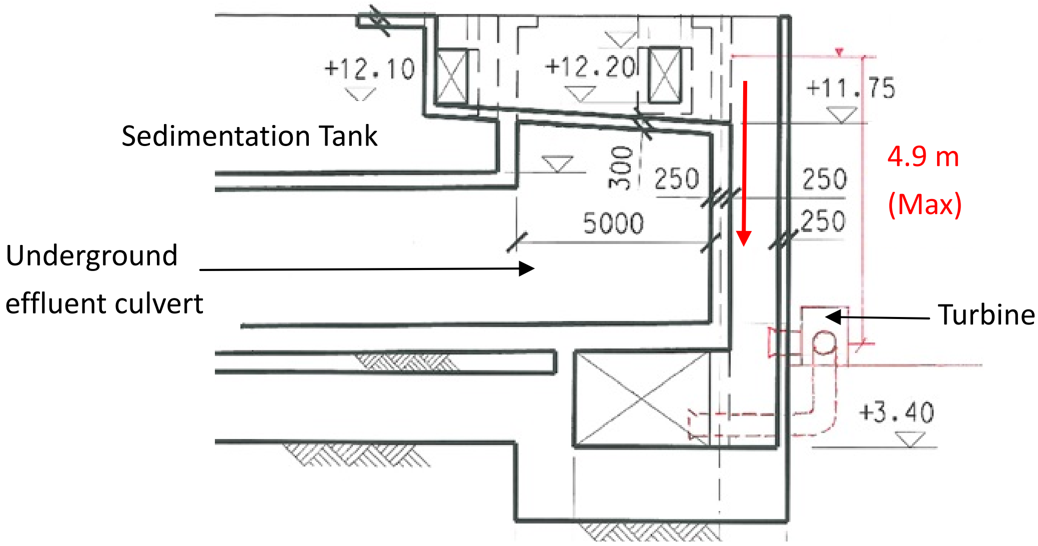

Figure 7: Sectional diagram of Effluent drop shaft at Stonecutters Island STW

Figure 8: Effluent drop shaft at Stonecutters Island STW

To take forward the installation, civil works provisions for future installation of 2 hydro-turbines have been reserved in the 4 new sedimentation tanks under the current on-going HATS 2A contract as additional works. The installation of the first trial hydro-turbine is planned for completion upon the commissioning of the facilities.

The trial will enable DSD to evaluate the operability, maintainability and performance of hydro-turbine equipment under effluent condition of high salinity up to chloride content of 10,000 mg/L.

CONCLUSION

Population growth, rising public aspiration for better quality of life as well as economic development increase the demand for sustainable development of the sewage treatment system in Hong Kong. While it may not be practical to design a STW requiring no resource input, the design of sewage treatment process should aim to (i) minimize the resource input to the process and (ii) prevent wasting of surplus energy by energy recovery from the system.

CHP, being one of the fast-growing installations in DSD, is considered to be one of the practical ways for turning waste to resource by recovering the chemical energy in biogas from sewage sludge. Further studies will be carried out for installing additional new CHPs in sewage treatment works to achieve optimum biogas utilization.

Along the line, a hydropower generator will be installed in SCISTW as a trial to capture surplus energy from the sedimentation tank effluent drop shaft.

DSD will continue to strive reduce energy consumption and greenhouse gas emission. It is envisaged that new technologies and management tools like carbon audit will emerge in the not too far distant future which help further enhance the performance of sewage treatment processes in terms of energy saving, whereby providing even more contribution to the sustainable development.

REFERENCE

1. Environmental Protection Department and the Electrical and Mechanical Services Department (2010), Guidelines to Account for and Report on Greenhouse Gas Emissions and Removals for Buildings (Commercial, Residential or Institutional Purposes) in Hong Kong.