ENERGY EFFICIENCY IN THE WATER INDUSTRY: A COMPENDIUM OF BEST PRACTICES AND CASE STUDIES

GLOBAL REPORT

Report Ref. No. 10/CL/11/3

Global Water Research Coalition

Programme Area & Reference	**Climate Change: Mitigating Measures CL/11**
Report Title	**Energy Efficiency in the Water Industry: A Compendium of Best Practices and Case Studies - Global Report**
Project Management	**Gordon Wheale, on behalf of UKWIR**
Collaborator	**GWRC**
Contractor	**Black & Veatch**
Authors of Report	**M J Brandt** **R A Middleton** **S Wang**
Report Type	**Final**
Period Covered	**2009 - 2010**

UK Water Industry Research Limited provides a framework for a common research programme to undertake projects, which are considered to be fundamental to water operators on 'one voice' issues. Its contributors are the water and sewerage companies and the water supply companies of England and Wales, Scottish Water and Northern Ireland Water.

Global Water Research Coalition

Global cooperation for the generation and exchange of water knowledge

GWRC is a non-profit organisation that serves as a collaborative mechanism for water research. The benefits that the GWRC offers its members are water research information and knowledge. The Coalition focuses on water supply and wastewater issues and renewable water resources: the urban water cycle.

The members of the GWRC are: KWR – Watercycle Research Institute (Netherlands), PUB (Singapore), Suez Environment- CIRSEE (France), Stowa - Foundation for Applied Water Research (Netherlands), DVGW – TZW Water Technology Center (Germany), UK Water Industry Research (UK), Veolia- Anjou Recherché (France), Water Environment Research Foundation (US), Water Quality Research Australia, Water Research Commission (South Africa), Water Research Foundation (US), and the Water Services Association of Australia.

These organisations have national research programmes addressing different parts of the water cycle. They provide the impetus, credibility, and funding for the GWRC. Each member brings a unique set of skills and knowledge to the Coalition. Through its member organisations GWRC represents the interests and needs of 500 million consumers.

GWRC was officially formed in April 2002. A partnership agreement was signed with the U.S. Environmental Protection Agency in July 2003. GWRC is affiliated with the International Water Association (IWA).

Disclaimer

Acknowledgement

This GWRC study was funded by KWR – Watercycle Research Institute (Netherlands), PUB (Singapore), Suez Environment- CIRSEE (France), Stowa - Foundation for Applied Water Research (Netherlands), UK Water Industry Research (UK), Veolia- Anjou Recherché (France), Water Environment Research Foundation (US), Water Research Commission (South Africa), Water Research Foundation (US), the Water Services Association of Australia and EAWAG-the Swiss Federal Institute for Environmental Science and Technology (Switzerland).

On behalf of the GWRC members, UKWIR served as the lead agent of the study and managed the project. Black & Veatch (B&V) were the contractors responsible for bringing the project to a successful conclusion.

The project could not have been completed without the commitment of B&V and in particular of the 'continental co-ordinators' who were responsible for collection and analysis of information from the four continents. These were:

- North America, led by the Water Research Foundation and Water Environment Research Foundation
- Europe led by KWR and STOWA
- Australasia led by WSAA and PUB
- South Africa led by WRC.

The efforts of all the utilities and other organisations who provided the detailed information regarding the case studies are also gratefully acknowledged.

Published by UK Water Industry Research Limited
1 Queen Anne's Gate, London SW1H 9BT

First published 2010

ISBN 1 84057 571 9

Printed by Webree.com Ltd.

ENERGY EFFICIENCY IN THE WATER INDUSTRY:
A COMPENDIUM OF BEST PRACTICES AND CASE STUDIES
GLOBAL REPORT

Foreword

Over the last decade, energy consumption by the water sector has increased considerably as a consequence of the implementation of new technologies to meet new potable water and effluent quality standards. The price of energy has also substantially increased and these increases will be compounded by the need for additional energy intensive processes to achieve more exacting regulatory requirements.

The objective of this research study was to develop a Compendium of best practice in the energy efficient design and operation of water industry assets. It is built on recent successful case studies, with the expectation that the Compendium will enable GWRC's members to transfer some of those successes to their associated utilities.

The case studies – all based on results of full scale operations - show that different companies have historically adopted widely varying approaches to energy management. For those just starting to look in depth at efficiency, the savings quoted will probably be achievable; conversely, those who have been intensively investigating and acting on the issues for some time will be closer to the optimum and therefore less able to make further significant gains.

We cannot assume that all the efficiencies gained from the case studies will be applicable to the thousands of works around the world, or even where they are relevant, that they will achieve the same savings. However, it is hoped that as water utilities evolve and changes are made they will follow and improve on some of the best practices described here.

In some cases, operators may find that the changes required to secure operational efficiencies do not justify the capital expenditure required or are uneconomic to achieve. Nevertheless, it is hoped that whatever the maturity of energy saving initiatives in GWRC's membership, each member will be able to identify at least one case study that has transferrable benefits.

UK WATER INDUSTRY RESEARCH LIMITED

GLOBAL WATER RESEARCH COALITION

**ENERGY EFFICIENCY IN THE WATER INDUSTRY:
A COMPENDIUM OF BEST PRACTICES AND CASE STUDIES**

GLOBAL REPORT

Executive Summary

Objectives

The objective of this research study is to develop a Compendium of best practice in the energy efficient design and operation of water industry assets. Through detailed examination of current best practice and technologies, the study has identified the promising developments and future opportunities to help deliver:

- Incremental improvements in energy efficiency through optimisation of existing assets and operations.
- More substantial improvements in energy efficiency from the adoption of novel (but proven at full scale) technologies.

Background

After manpower, energy is the highest operating cost item for most water and wastewater companies. Over the last decade, energy consumption by the sector has increased considerably as a result of the implementation of new technologies to meet new potable water and effluent quality standards. The price of energy has also substantially increased.

Future changes to regulations and standards will require additional energy intensive processes to achieve more exacting requirements. High energy consumption will affect the water industry world-wide and is inextricably linked to the issue of carbon emissions. It is therefore important to minimise the use of energy by optimising efficiency across the water cycle. There are also opportunities for energy generation from waste and sludge through CHP technology and for hydraulic energy recovery from turbines.

The members of the Global Water Research Coalition have included Water and Energy as a priority area of their joint research agenda. The project ‘Energy Efficiency in the Water Industry: a Compendium of Best Practices and Case Studies’ is one of the projects of the Water and Energy research project portfolio. On behalf of the GWRC members UKWIR has acted as the lead agent for the project and the project is supported by the GWRC members world-wide as represented by the four Continental Coordinators in Australasia (Australia and Singapore), Europe, South Africa and the USA.

Each continental group and the UK has drafted a report of best examples submitted by individual utilities in their region. This report compiles the findings from those reports. The Global Compendium is therefore a collection of best practice case studies and a review of the best technologies for energy efficiency in the world-wide water and wastewater industry.

The authors wish to acknowledge and thank the many contributors for the detailed and varied collection of case studies submitted.

Methodology

An initial desk study and literature review focused attention on key areas of the industry with most potential for energy efficiency improvements. This was followed by contact and meetings with the four Continental Coordinators and water utilities in the UK to identify case studies of cost effective energy reduction projects that validated, conflicted with and extended the initial study conclusions.

Outcomes and Benefits

This report summarizes the findings from data collected throughout the global water industry and contains information on current energy usage across the water cycle, highlighting where energy saving actions could be focused.

Generally the case studies are focused within components of the water cycle identified as priority areas in the Water Cycle Matrix (Table ES.1).

The matrix shows the areas where potential savings are expected, together with the case studies received from water and sewerage companies. When the report is being read in its electronic format, a factsheet on a subject will be opened in a new window by clicking on the subject title.

Each case study is also identified by a colour for the continent and a case study code. As for the factsheets, by clicking on the case study code, the full case study will be opened in a new window. The best case study in each subject group has been chosen to be presented against the relevant subject area in the Compendium (Section 3, Result). All factsheets and cases studies are included in Appendix 3.

Some improvements, such as conservation, can have a wider impact on the water cycle than within a single component or part of the process. There are some examples where data are not formally recorded but anecdotal information is incorporated into the text. These examples may represent opportunities for the future.

Incremental improvements have not been separated from the more substantial gains to preserve continuity through water cycle matrix.

The benefits of the Compendium to the water industry will be more comprehensive guidance on energy efficiency, reduced energy use and cost and a reduction in carbon footprint. There may also be benefits in communication of status and expectations of the industry's contribution to national and global energy and carbon reduction targets.

Conclusions – Current Energy Use

The rising demand for drinking water and sanitation is increasing the industry's energy demand as source waters become more difficult to treat and the safe disposal of wastewater becomes more problematic. Climate change is also affecting the water cycle, but as demonstrated in Australia, some of its impacts can be partly managed through technical developments together with major social, environmental and economic responses.

There is direct correlation between energy demand and the location, availability and quality of natural resources and treatment and disposal of sewage and sludge disposal. The key energy demand areas are: pumping from distant or deep water sources; distributing potable water over wide areas, asset condition and pipe leakage; treatment of sewage by aeration and pumping raw and treated effluents. A customer's utility bill may be further impacted by where he is living: the real costs of services in areas of high population concentration with severe resource and disposal constraints will be increasingly higher.

Table ES.1 Water Cycle Matrix and Global Case Study Summary

Africa – Yellow **Australia & Singapore – Pink** **Europe – Red**
North America – Blue **UK – Black**

WATER CYCLE ENERGY SAVING MATRIX		Drinking Water			Waste Water		
		Raw Water	Treatment	Distribution	Sewerage	Treatment	Disposal
Energy Estimate (% of whole)		25	10	65	25	60	15
Demand Manage-ment	Conservation (Water & Energy)	BW1, AW1, AWU2, CRWD1, CWW1		BW1, SESW1, MC1, AW1, AWU2, CRWD1, CWW1			
	Leakage Reduction	SESW2, EM1	SESW2, EM1	SESW2, EM1, SW5			
	Infiltration/Inflow Reduction				HW2, HW3	HW2, HW3	HW2, HW3
Pumping	Optimise Gravity Flow	KWR1					
	Pumping and pumps	UU3, ScW5, SSW2, AW1, TVW1, TVW2 SEW1, SWW3, NM1, HW1, SAW1, MW1 AWU1, ND1, KF1		SSW1, TVW3, TVW4, UU1, AW2, ScW6, KWR2, PUB1, SAW1, WC1, WC2 MCW1, OWD1	ScW2, UU4, UU5 SAW1		AW6, SAW1, MW2
	Catchment Transfer	KWR1					
Treatment	Clarification / Primary		YW4, ScW4			ST4, ESP1	
	Aeration					AW4, AW5, AW7, DCWW1, ScW3, SnW1, WW1, YW3, YW5, UU6, UU7, ST6, ST7, BW1, SW1	
	Mixing / Coagulation		KWR3,			PC1	
	Nutrient Removal					WW3, NW2, PUB2 ST1, ST3, VE2	
	RAS Pumping					NW1,	
	Membrane Treatment					ST2, PUB3	
	Disinfection / UV		KWR4			WW2	
	Ozonation		KWR5				
Sludge	Thickening / Dewatering					ST8, ST9	
	Digestion / Co-digestion					YW2, ST5, VE4, EAW3, PUB4, PUB6 BCC1, SEW2 CM1	
	Sludge Drying					PUB5, SE1	
	Building Services		AW3, SW2			SW2	
Generation	Mini Hydro-Turbines	ScW1, SWW2		VE1, MW3, SAW2, SEW1	YW1, CSD1		VE3
	Wind Turbines			CWD1			ACUA1
	Solar Power		NJAW1			IEUA2	
	Biogas / CHP					UU2, SWW1, SE2, EAW1, EAW2, MW4, SAW3, SW3, SW4, CWW2, IEUA1, CB1, CC1, KC1, LAC1	

There is limited energy demand information of the split between clean and waste water cycles. Comparisons are made more problematic because of the need to reflect common areas for drinking water supply and sewerage. However the perception is that the split is probably 45% to 55% drinking water to sewage cycles, but with a potentially wide variability depending on site specific and catchment area characteristics.

There is strong evidence that up to about 15% of wastewater energy demand can be offset by biogas generation and CHP and this may be higher where existing levels of take-up are low.

Pumping represents upwards of 70% of water supply energy demand and at least 30% for waste water. For sewage services the major single energy demand is for aeration; up to 60% or more of the usage for the service. Clearly the best opportunities for reducing energy demand are linked to these high usage components.

Energy Savings

Case studies indicate that energy savings from pumping vary widely depending on the circumstances, but overall savings of between 5 and 30% of current energy demand appear achievable. The larger savings will be mainly due to improving maintenance and closer matching of pumps to their duties. Energy efficiency gains from new pumping technology will probably be less than 5% since the technology is generally mature. However, more significant improvements should be feasible in submersible and borehole pumps where hydraulic and electrical configurations are more challenging. The case studies and examples tend to focus on these two areas but there is a broad range of activities across the globe from leakage reduction to renewable energy.

Table ES.2: Energy savings from pumping interventions

Means of saving	VSDs	Duty Point	Intrinsic Pump	Duty Change	Waste Water	Duty Range
Saving (%)	12 to 30	3 to 63	6 to 11	10	8 to 4	3

In wastewater, up to 50% energy savings have been demonstrated by case studies on aeration. Simple changes in control methods and set points have frequently shown substantial quick wins and checks on plant, control methods, operational routines and maintenance have proven worthwhile.

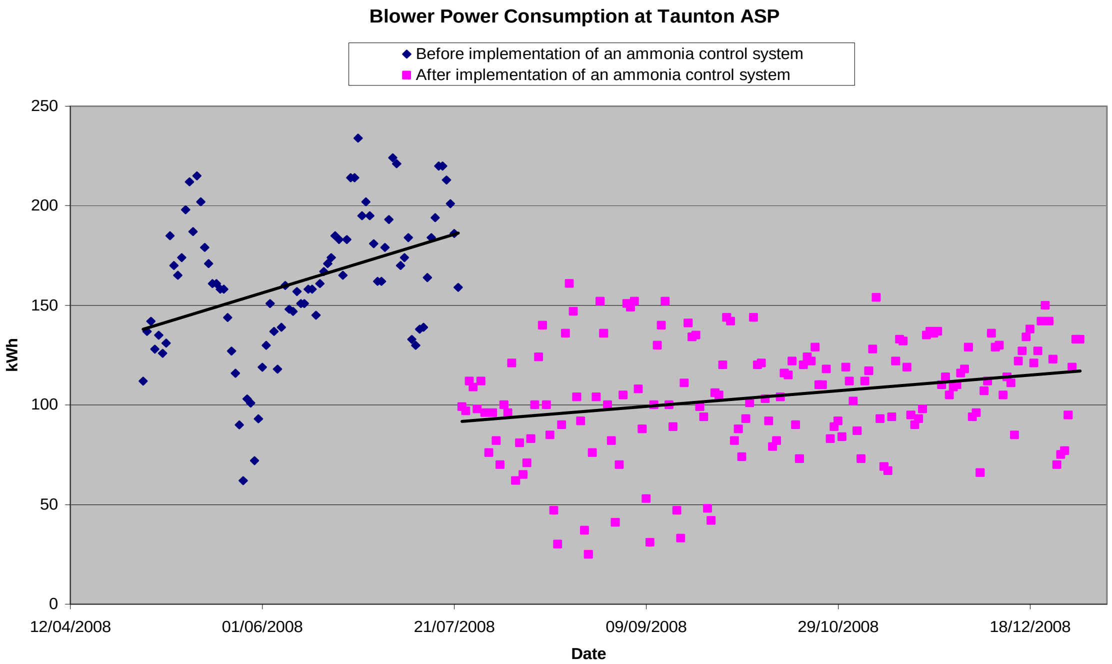


Figure ES.1 Example of aeration energy reduction following process changes

The above savings relate specifically to a single component of the water cycle. However improved water efficiency (leakage reduction and demand conservation) represents a significant opportunity for improved energy efficiency across the whole water cycle in that reducing the demand for water reduces the volume to be abstracted, treated and distributed with a corresponding reduction in sewage to be collected and treated and effluent and sludge disposal; for example a 5% reduction in consumer demand will be mirrored by energy reductions through all components of the water cycle. Interventions include consumer education, installation of water saving devices and maintenance, and replacement of the infrastructure.

Water companies have offered a few case studies of drinking water process improvement through process optimisation. There is potential in areas such as dissolved air flotation (DAF) and there may be opportunities to investigate membrane technology, Ultra-Violet (U/V) systems and ozone packages at older plants. However, apart from membranes which have significant pumping costs, the relatively low energy use in these processes may account for the low potential for savings and hence lack of case studies. No new technology has been highlighted for drinking water but a hierarchy of alternative interventions is given in Table ES.3 for current processes based on their energy efficiency.

Table ES.3: Hierarchy of Water Treatment Processes by Potential Energy Efficiency

← Low energy use					High energy use →
Clarifiers	Hydraulic Mixers	Media back wash	Chemical dosing	UV Disinfection	Dissolved Air Flotation

Table ES.4 lists the hierarchy for sewage treatment processes. By optimising current processes it is feasible to increase primary sludge production which reduces load on aeration blowers and increases digester biogas production. Net energy efficiency is thereby increased particularly with sludge digestion and CHP on site.

Table ES.4: Hierarchy of Sewage Treatment Processes by Potential Energy Efficiency

← Low energy use					High energy use →
Biological (percolating) filters	Anaerobic membrane bioreactor	Bio-aerated flooded filter	Step fed activated sludge(ASP)	Nutrient removal ASP	Conventional membrane bioreactor

There is also the possibility of using anaerobic effluent treatment. This needs to be confirmed, but promises similar effluent quality with the bonus of greater yields of biogas than would come from digesting sludge from aerobic treatment. The net energy saving is therefore significant.

Table ES.5: Hierarchy of Sludge Treatment Processes by Potential Energy Efficiency

← Low energy use				High energy use →
Picket fence thickeners	Drum thickeners	Belt thickeners	Belt presses	Centrifuges

For sludge handling, suggestions are given for energy efficient mixing, pumping and thickening with a hierarchy of thickening processes, as shown in Table ES.5. Increased uptake of advanced sludge treatment is expected to enhance quality and increase biogas yields with the various proprietary sludge treatment processes available. Combined heat and power (CHP) from sludge biogas is mature technology but more uptakes will increase the net energy efficiency of waste water utilities.

For building services the trend towards the use of air conditioning should be challenged as plant specific cooling is more efficient and targeted ventilation uses far less energy. Reductions in lighting loads are feasible although marginal when replacing fluorescent tubes but better with LEDs, and all schemes should include health and safety issues.

Opportunities for other renewable energy sources are usually site specific geographically and financially. Large wind turbines have been used and some applications exist for small solar and wind packages combined with battery storage, usually for remote instruments. However the reader should not confuse the construction of a renewable energy resource for energy cost and 'environmental sustainability' reasons with the implementation of energy use reduction measures and energy generation from water industry 'waste' resources, be they biogas from sludge or energy from surplus hydraulic head. The prime objective of this compendium is the reduction of energy use within the water cycle.

Hydro-turbines are expected to be increasingly exploited, and while this technology is mature, there may be transient control issues. Adoption of CHP technology for digester biogas has not been universal, so there is still potential for significant net energy saving as is evidenced by reported net energy exports to the grid by several utilities. With current energy prices the payback times may be long but local financial incentives and feed-in tariffs can make a significant difference.

For all innovations aimed at energy efficiency it is evident that cost/benefit analyses should use future energy prices projected to about half the design life of the proposed plant.

Key Points

Overall energy efficiency gains of between 5 and 25% seem realistic across the water cycle. However this conclusion must be taken in context. Where energy price rises have already had a significant impact the potential for further energy savings may be only 5 to 15%.

The case studies demonstrate that, historically, different companies and regions have adopted widely varying approaches to energy management. For those companies just starting to look in depth at energy efficiency, the savings quoted will probably be achievable; conversely, those who have been intensively investigating and implementing energy efficiency for some time will be closer to the optimum and therefore less able to make further significant gains.

Users of the Compendium cannot assume, therefore, that all the efficiencies gained from the case studies will be applicable to the thousands of works around the world, or even where they are relevant, that they will achieve the same savings. However, it is hoped that as water utilities evolve and changes are made they will follow and improve on some of the best practices described herein.

There are two areas with most potential; pumps of most types and functions, and aerobic wastewater treatment systems. Potential energy savings include:-

1 Pumps and pumping:
- 5% to 10% from existing pumps,
- 3% to 7% through improvement to pump technology,
- Simple gains are possible in some pumping situations where the operational set up has been changed from the design condition. Gains of between 5% and 30% may be realised
- More complex and large scale pumping energy savings are feasible but frequently show marginal payback using current financial analyses.

2 Aerobic sewage treatment
- Simple gains of up to 50% are possible on some aerobic wastewater systems by aligning control parameters with the discharge consent.
- Up to 25% in ASP wastewater plant,

Lesser gains can be derived from:
- Up to 20% from drinking water processes, but the energy use in this category is low,
- Up to 15% improvement in building services,

‘Drinking water only’ companies have limited opportunities for net energy gains.

In order to optimize efficiency gains, we recommend that companies consider:

1 Where incremental improvements or technologies are relevant in the local or regional context and follow the advice and examples where applicable.

2 Use future electricity prices in financial analyses, projected to about half the design life of the proposed facility; say ten years.

3 The unrealised potential in drinking water processes opportunities associated with older DAF, membrane packages, U/V systems and ozone plants and implement current optimum performance and energy demand.

4 The potential for optimising waste water processes towards increasing primary sludge production, reducing secondary treatment loads and increasing gas yields to CHP plant with minimal investment. Pursue treatment improvements for waste water bio-filter technology

5 Discharge consent standards, both absolute and varying seasonally, in relation to the end use of the water or the quality of the receiving water. A balance may also be struck between the energy demand for higher treatment standards and the pollution caused by generating and transmitting that energy. The common metric is the holistic system carbon footprint as this allows objective discussions between generators, regulators, water industry innovators and environmentalists.

6 Review energy demand for sludge mixing regimes and sludge thickening plant.

7 Reassess comparative energy demand of various enhanced sludge treatment processes.

8 Renewable energy, mainly in the form of CHP from sludge gas, could contribute significantly to the net energy demand of the water industry.

9 Obtain more case studies relating to operational management, and maintenance, research, finance and regulation, all of which are inextricably linked to the process.

10 Undertake a more in-depth statistical analysis of water industry data to validate or correct energy usage and potential savings.

11 Update this compendium bi-annually with current case studies/industry best practice. Include more contact with academia for research on new processes etc.

The study has not identified any major imminent technological developments to reduce demand for energy in the water cycle or to increase efficiencies substantially.

This report has set no timescale for realising potential energy gains, but if the right financial conditions are put in place, incremental improvements should be achievable with two to three years. More substantial changes will depend on infrastructure development and asset maintenance business plans which typically identify projects in 5 or 10 year programmes of work.

**For further information please contact UK Water Industry Research Limited,
1 Queen Anne's Gate, London SW1H 9BT quoting the report reference number**

Contents **Page Number**

1 Introduction

This report is a Compendium of energy efficiency best practice in the water industry. It contains information on current energy usage and prospective areas for efficiency improvements and savings in the form of a matrix based on the water cycle and the various processes involved. The Compendium comprises energy efficiency factsheets and technical guidance illustrated by case studies and examples gathered from the water and wastewater companies.

The Compendium is a compilation of reports from four Continental Coordinators representing the Global Water Research Coalition (GWRC) members, representing Australasia (Australia and Singapore), Europe, the USA and South Africa.

UK Water Industry Research (UKWIR) managed the project on behalf of the GWRC.

2 Methodology

2.1 Global project

The methodology used to prepare this report was developed for the UK study and subsequently adopted by GWRC members for their individual reports and the global report.

A **Priority Short List** report was prepared from an initial desk study and literature review to highlight the parts of the water cycle matrix which had most potential for making energy savings from incremental and more significant efficiency improvements.

Case Study Guidelines were prepared to explain the objectives and to ensure consistent quality of data from world-wide sources. The guidelines include a table of data required for each study, a set of energy usage matrices and some explanations for the priority areas from which case studies were expected. It was stressed that these were guidelines only as it was thought important to gather anecdotal as well as scientific, peer-reviewed data and case studies due to the wide spectrum of global cultures and activities.

The above documents are attached as appendices to the Compendium.

2.2 Project

Data gathering documents and guidance notes were accepted and issued in March 2009 and meetings or phone calls arranged with Continental Coordinators. Support was offered for data gathering and provisional case study selection and draft reports were reviewed.

The case studies presented are an attempt at auditable, quality data gathered from a wide variety of people and cultures. A truly rigorous, scientific approach to making energy efficiency improvements in the water industry is restricted by the practical necessity of providing a high standard of potable water and treating whatever quality of sewage arrives at the works. Good quality data is presented in the format of the Case Study Information table. Data that are less than ideal or even anecdotal are described in the text. All sources of case study information and examples are credited.

The programme allowed about six months for the data gathering phase and progress has reflected the local circumstances.

2.3 Scope

It was agreed at early UKWIR and GWRC meetings to exclude two areas from the study;

- Energy savings and efficiency are the prime objective so measures which only save costs, such as tariff management, are not included. Some examples show that energy consumption has increased as a result of tariff management, where off-peak pumping does not coincide with optimum hydraulic conditions.

- The water cycle as depicted in the matrix stops at drinking water distribution and starts again at collection of sewage. Any activity within the consumers' premises is generally not covered although water conservation measures, such as reduced flow appliances, are reported.

3 Results

The results are the core of the report and their presentation is structured on the sequence of the water cycle starting with abstraction of drinking water, its treatment and distribution, and followed by sewage collection, treatment and disposal. The results are presented in matrix format to illustrate the overall picture.

At the top of the matrix are issues which affect the complete cycle such as water conservation, leakage reduction and sewage infiltration. Actions in these areas affect the whole of the matrix. These are followed by main processes such as pumping, sedimentation, aeration, and other treatment stages.

Below the main processes but key to the industry are sludge treatment, building services associated directly with the industry and opportunities for reducing demand through generating renewable energy. Wind or solar energy examples are usually contracted out of the water industry, but CHP and hydro-turbines are covered in detail.

Each subject or process area is introduced by a factsheet. This explains the technology at various levels and establishes an objective appraisal of the engineering issues involved derived from the peer-reviewed outputs of experienced engineers. The potential savings shown in the factsheets are generic, and are illustrated by savings shown in the relevant case studies. Local conditions, climate, corporate policy, finance and regulation all vary significantly around the world so these issues must be taken into account when considering how energy savings should best be executed. Some of these variations are covered in Section 4, Discussions.

Generally one case study or example has been selected for each subject or process area. It is appreciated that one example will not cover all the issues so other case studies and examples are referred to and all are included in the Appendices.

Factsheets, case studies and examples include only the key points to illustrate and explain a balance of understanding and concise presentation. All raw data, derived data, calculations and methods, full explanations, references and background are included in appendices.

The project brief requires the report to illustrate the two approaches of:-

- Incremental improvements with immediate effect and minimum investment,

- More significant improvements over medium timescales with more substantial investment, including new technologies.

Where there are incremental improvements or “quick wins” available these are highlighted in the text. Frequently these can pave the way for more substantial improvements, for example by improving the data available on a process or item of plant to enable operational improvements, thereby allowing the development of an investment model to establish the payback for an energy efficiency project proposal.

New processes, plant types and systems, realising more substantial gains but requiring more significant investment are also highlighted in the text, with provisos that:-

- Only technologies that are proven at full scale are recommended,
- Technologies at pilot scale development are noted for future investigation,
- Areas where new technical development is required are also highlighted.

Pilot scale technologies are seen as promising potential developments possible for future investment but are not yet proven at full scale. Although pilot scale technologies are outside of the remit of this study, the more significant trials and developments are recorded as an *aide memoire* for possible inclusion in future updates of the Compendium.

3.1 Water Transfer and Distribution

Supply and demand optimization

Supply and demand is managed by balancing storage to match diurnal and seasonal demand variations with the more steady production supply flow rate from one or more sources. Operational production decisions rely on current and historic demand data and experience to predict production needs over the next 24 hours, week or month. However daily or weekly production plans need to be flexible to be able respond to both diurnal variation and abnormal or unforeseen demand changes. Increased availability of on-line telemetry monitoring downstream of the treatment works allows utilities to analyse supply and demand in near real time and thereby plan for and respond to the variations as they develop.

An example of holistic management of water and energy is Bristol Water in the UK.

Bristol Water Management Strategy

Monthly Resources Meetings consider high, medium and low risk approaches to resource management looking forward. The assessment includes chemical and carbon costs (via the shadow price) and is informed by a model based on more than 100 years’ worth of data.

Inhibitions to moving towards lower costs are reviewed and means of their removal considered.

Medium term priorities include demand, the weather and soil moisture deficit which is currently very high so a lot of rain is needed before it gets to the aquifers.

Anticipated events such as potential drought are also considered along with personnel availability to plan ahead for any actions required.

Bulk supplies are delivered to Wessex Water at Bath, at a typical rate of 9 Ml/day Historically the focus was on one pumping station on the Gloucester to Sharpness canal, where 35 to 40% of BW's energy was used.

Over the last three years rainfall has been higher than the long-term average. As a result, a more flexible approach has been possible, with water sourced from the Mendips including a number of reservoirs, which are lower carbon and low treatment options.

There is also a small groundwater source in the Cotswolds but this is a deep aquifer so the pumping costs are high.

When an abnormal event such as a drought is forecast, management take actions to position their water resources for cost- and energy-effective deployment. This makes best use of energy and helps to avoid surprises.

Such approaches are typical of the water industry. It is important to recognise that a technology improvement such as a SCADA system will not produce gains on its own, and much will depend on the analysis of data and the culture of decision making and actions.

3.1.1 Leakage Reduction and Conservation

Water leakage reduction and conservation benefit all aspects of the water cycle through reduced abstraction, treatment, distribution, collection, wastewater treatment, and disposal. Leakage in the abstraction stages wastes abstraction pumping energy, but the further across the water cycle the leakage occurs the more energy is lost. Infiltration into sewer mains increases flows to be treated throughout the effluent treatment and disposal processes. The amount of energy wasted is directly proportional to the amount of water lost on the clean side of the matrix, or infiltration on the waste water side.

Leakage is a high profile aspect of water conservation and is therefore treated separately.

Water Supply – Leakage Reduction

Any reduction in leakage from a system which includes pumping within the cycle will have a proportional reduction in energy consumption.

Description of Process *Loss of water from any part of the water cycle represents an inefficient use of energy (abstraction, transmission, treatment, distribution). Therefore any reduction in leakage will impact all the processes in the water cycle up to the location of the leak. However some amount of leakage is unavoidable.*

The (Sustainable or Environmental) Economic Level of Leakage (ELL), typically a target volume, is used to quantify in economic terms the level of effort and thereby resources necessary to minimize leakage for a defined set of conditions. The ELL is the level at which the cost per m^3 of constructing, treating and delivering additional water resources equals the operational and capital cost per m^3 of leak detection and repair to reduce loss. The ELL will be unique for each system.

Potential Interventions *Interventions are designed to reduce the volume of water lost and thereby save energy. The intervention options include:*

1. ***Reactive or Passive Leakage Control****: reacting to reported bursts, consumer complaints or unexpected changes in flow or pressure. Leaks are detected, located and repaired only when the utility becomes aware that there is a supply problem in the network. However undetected leaks and the underlying system losses will gradually rise and network assets will deteriorate.*
2. ***Active (proactive) strategy*** *for reducing water losses (to a target) comprising:*
   - *Asset renewal to maintain and replace mains and service connections*
   - *Pressure management to minimize supply pressures and leakage. It will also extend the asset life.*
   - *District metering to monitor system flows and for water losses*
   - *Active Leakage Control for targeted detection and location of unreported leaks*
   - *Minimizing repair times for visible and detected leaks.*

Range of Potential Savings ***Up to 38% from case studies.***

Reported leakage (including non-revenue water) can range from 5 to 10% of the distribution input (quantity of water supplied) for well managed systems up to 40% and 60% or more for systems in poor conditions, where there is a history of long term under investment. (Twort's Water Supply, 2009)

Potential savings will be unique to a system depending on the starting position and the utility's loss reduction strategy, reactive or active. However it is a complex analysis to attempt to relate any energy saving to a single specific action. The above interventions represent both step changes with "one off" impacts as well as ongoing actions needed to manage recurrence.

Case Studies **AU-SW5; UK-SESW2; SA-EM1**

Leakage Reduction Case Study: AU-SW5 ***Sydney Water, AU***

Leakage reduction through pressure management programme, combining with water main renewal and flowmeter upgrade – Active Leakage Control.

Ref	Enquiry Item	Response information, description and remarks
1	**Location:** Country, urban or rural:	Australia, urban. Temperate Zone
2	**Sector:** clean, waste or sludge:	Drinking water
3	**Works Owner or Operator:**	Sydney Water, regulated
4	**Size:** flows and loads or population equivalent:	Estimated water leak in 02/03 was 188 ML/day, following the ongoing water leak reduction program the water leakage per day went down to 117ML/day 07/08 and 105ML/d in 08/09.
5	**Energy Provider:**	-
6	**Process:** physical, chemical, or biological description:	Implement pressure management, water main renewal and meter renovation.
7	**Component:**	Distribution system.
8	**Specific energy problem:** including quality or consent details:	Reducing leakage has direct (proportional) reduction in pumping and treatment energy usage.
9	**Process/Plant changes:**	None.
10	**Civil/Physical Changes:** to water / effluent quality, civil works, or process:	Pressure Management Program to reduce and control pressures Water main renewal Flowmeter upgrade program to improve flow monitoring
11	**Operational Changes:** skill levels, procedures and maintenance routines:	Active water leak detection on reticulation pipes and customer service pipes. 21,000kms of pipes surveyed per year. Improved response times to customer reported water leaks
12	**Risks and Dependencies:**.	-
13	**Implementation:**	Operational – All implemented. Capital – Pressure management and main renewal.
14	**Energy Efficiency gains:** kWh & kWh/m^3	An estimated 6,617 mWh has been saved across the 5-year water leak reduction maintenance program (02/03 – 07/08).
15	**Cost / Benefit analysis:** financial appraisal or payback time.	Active water leak detection is justified on a break even basis (Economic Level of Leakage) Pressure Management is justified on a NPV basis with benefits of water leakage reduction, reduction in main breaks and asset life extension.
16	**Project review:** could it be improved or developed?	Adaptive management applied with annual reviews of program
17	**Confidence grade:**	High

Observations:

Improved flow metering has identified issues with open valves that are supposed to be kept closed. When these valves are inadvertently left open water can leak through, this results in energy being wasted as water often needs to be re-pumped. Energy benefits estimated above do not include this side benefit of leakage management.

Water Supply – Conservation

Any reduction in the demand for water from a system which includes pumping within the cycle will have a proportional reduction in energy consumption.

Description of Process *With the increasing awareness of the scarcity of fresh water and need for water conservation, government agencies and water utilities are increasingly promoting campaigns and schemes to encourage water conservation including waste reduction. Successful campaigns will have significant impact on reducing the demand for water.*

Utilities or government agencies generally promote an intervention initiative, but ultimately, it is the consumers who implement the measure and not all consumers will necessarily be willing to install water saving devices or change their water use habits.

Any reduction in demand will impact all the processes in the water cycle, both water and waste water; reducing the volume and thereby energy demand.

Potential Interventions *Effective water conservation measures include:*

- *100% domestic and non-domestic metering. Can reduce domestic demand by up to 10%.*
- *Increase tariff or revise structure to penalize excessive usage. However water is generally considered to be price inelastic (ie. 25% cost increase results in a 5% reduction in demand.)*
- *Promote use of low water use fittings. Smaller capacity cisterns for toilet flushing (and dual flushing) deliver the greatest benefit - 30% to 50%.*
- *System pressure management improves the reliability of network control valves, thereby reducing wastage through valve malfunctioning.*
- *Set operational pressures at minimum necessary to maintain levels of service reduces water taken unnecessarily.*
- *Flow limiters and throttles on service pipes to curb consumption. They are not always effective.*

Short term measures can include:

- *Use publicity (public awareness campaigns) to achieve a temporary and short term reduction in demand, perhaps as much as 10 percent.*
- *Impose temporary bans on the use of water for non essential activities.*

Range of Potential Savings ***Up to 31% from case studies.***

See Potential Interventions above for broad estimates of potential savings

Potential savings will be unique to a system depending on local water fitting regulations and standards, availability of the fittings, PR campaigns and consumer acceptance of conservation arguments.

There must be a significant consumer response for there to be discernable reduction in demand and thereby energy saving.

Case Studies **SA-MC1; UK-SESW1; UK-BW1**

NA-AW1; NA-AWU2; NA-CRWD1; NA-CWW1

Retrofitting and replacement of plumbing fixture like cisterns, taps and pipes on private properties to control leakage.

Ref	Enquiry Item	Response information, description and remarks
1	**Location:**	South Africa, Mogale City.
2	**Sector:** clean, waste or sludge:	Drinking water
3	**Works Owner or Operator:** with financial set-up, regulatory or not.	Owner: Mogale City Implementing agent: Alliance to Save Energy with financial aid from USAID
4	**Size:**	Approx Flow= 1.024 m^3 x 1371 = 1404 m^3 per day
5	**Energy Provider:** with costs, incentives, taxes and conditions:	Energy provider is Eskom – no incentives were available at the time of the case study
6	**Process:** physical, chemical, or biological description:	Physical – Retrofitting and replacement of plumbing fixtures like cisterns, taps, pipes, etc.
7	**Component:** all or part of the works:	Leakage control of centralized water supply pipelines on properties.
8	**Specific energy problem:** including quality or consent details:	Energy powered (pumped & treated) drinking water is wasted through leakage, therefore associated energy is wasted.
9	**Process/Plant changes:**	None
10	**Civil/Physical Changes:** to water / effluent quality, civil works, or process:	Repair and replacement of cisterns, taps and pipes. Valve refurbishment and/or replacement Pipeline connection
11	**Operational Changes:** skill levels, procedures and maintenance routines:	Municipality staff trained for billing and monitoring accounts. Staff trained to maintain connections
12	**Risks and Dependencies:**	Failure of residents to adopt metering and adapt to a culture of payment
13	**Implementation:** design, build, procurement, installation and commissioning:	Establish water demand management programme which includes: Establishing metering systems to monitor existing water connections and water consumption Installing conventional / pre-payment meters and fixing pressured yard connections Conducting leak repairs for households Improve staff capabilities Community awareness and education
14	**Energy Efficiency gains:** kWh&kWh/m^3 or %	Energy savings = **15.4 million kWh** per year **2.57kWh/m^3** **31%** based on one year of operation
15	**Cost / Benefit analysis:** financial appraisal or payback time.	Payback time is 2.32 years (calculated on water price not energy price) <u>Based on 1 year of operation</u> Total cost savings = USD 3.5 million per year
16	**Project review:** could it be improved or developed?	Complete buy-in from community required. In the case of South Africa, some communities see pre-payment as unfair as it is not uniformly applied across the country
17	**Confidence grade:** on data provided.	Good - been repeated in other areas in South Africa eg Buffalo city and Johannesburg.

3.1.2 Infiltration/Inflow Reduction

For any reduction in Infiltration/Inflow (I/I) to a sewer system there will be a proportional reduction in energy demand resulting from reduced volumes to be pumped and treated.

Sewerage Systems – Infiltration/Inflow Reduction

Description of Process *Infiltration water enters the sewerage system by percolation through the ground and is characterised by being either continuous or having a slow response to rainfall. Inflow, rainwater runoff entering sewers through direct connections, is characterised by having a rapid response to rainfall. Localised infiltration can be the result of leakage from nearby water supply pipes. Identifying infiltration hot-spots can highlight a water pipe leakage issue. (See also Water supply - Leakage reduction).*

I/I is quantified in terms of "l/s/mm-km", where mm-km is the calculated sum of all sewers in the sub-catchment; mm is the sewer diameter and km the sewer length. The sub-catchment with a high I/I in l/s/mm-km is one with a high density of problems, and therefore one likely to benefit from intervention.

I/I reduction interventions will result in reduced continuous and peak flow and thereby pumping and treatment volume reduction. Leakage from pumping mains reduces downstream pumping and treatment volumes.

Potential Interventions *Interventions are designed to reduce the volume of flow entering the sewer from non-sanitary sources. The intervention options include:*

- *Sewer and manhole sealing. Various lining techniques have been developed for insertion in sewers with structural or leakage problems, many of which will successfully limit existing infiltration through structural defects. They often have limited effect, however, if the manholes are not also sealed or lined.*
- *Sewer replacement. For very poor condition sewers, replacement may be the best option to resolve infiltration problems.*
- *Runoff source control. Reduction of inflow through source control is the most sustainable method, as it removes the flow from the sewer and does not add flow to any other drainage system. Suitability of this approach may be dependent on local ground conditions.*
- *Surface water disconnections. Where there is an existing surface water drainage system, transfer drainage connections from the sewer to the drainage system. However, the outcome is uncertain because it is difficult to predict the impact of disconnections and transfers before the work is commenced.*

Range of Potential Savings ***Up to 68% from case studies.***

Infiltration ranges from 35 to 40% of sanitary flow for systems in good/average condition up to 100% + in old systems in poor condition. Inflow volumes and reduction potential are system, area and building regulations specific and therefore more difficult to quantify. However any reduction in inflow will result in reduced volumes for pumping, treatment and disposal.

Case Studies **AU-HW3, AU-HW2,**

Infiltration/Inflow Reduction Case Study: AU-HW3 ***Hunter Water, AU***

Hunter Water Corporation has been running an ongoing audit of its wastewater pumping stations' constructed overflows. The audit aims to provide a comprehensive and up to date database of constructed overflows, most of which have not been inspected since their construction. In a few instances the inspections have revealed that the overflow structure is a substantial source of infiltration into the sewer network. The overflow for Windale 2 Wastewater Pumping Station (WWPS) is one such example.

Ref	Enquiry Item	Response information, description and remarks
1	**Location:** Country, urban or rural:	Australia, urban
2	**Sector:** clean, waste or sludge:	Waste Water
3	**Works Owner or Operator:** with financial set-up, regulatory or not.	Hunter Water Corporation, State Owned Corporation, regulated
4	**Size:** flows and loads or population equivalent:	Average daily flows out of the station are estimated to have dropped by 2.8 ML/day since a flap valve was installed (based on pump run hours)
5	**Energy Provider:**	Country Energy
6	**Process:**	Wastewater network – constructed overflows
7	**Component:**	-
8	**Specific energy problem:** including quality or consent details:	Substantial infiltration from creek into the pumping station after modest levels of rainfall because the overflow did not have a flap valve.
9	**Process/Plant changes:**	Mechanical – retrofitting a flap valve
10	**Civil/Physical Changes:**	-
11	**Operational Changes:**	Development of a preventative maintenance strategy for future inspections.
12	**Risks and Dependencies:** risk assessment of project and changes.	Risk of flap valve getting stuck and staying open. (Medium). Risk could be reduced by undertaking more frequent inspections and monitoring of WWPS pump run times.
13	**Implementation:** design, build, procurement, installation and commissioning:	The scope of the preventative maintenance strategy was to inspect all 394 constructed overflows within the sewerage network by CCTV and record the findings. The flap was designed by Hunter Water and constructed by a local metal working firm.
14	**Energy Efficiency gains:** kWh & kWh/m^3	The average pump run hours per day went from 7.26 hours/day to 2.27 hours per day after the flap valve was installed. Pumping consumes 82 kW. Total energy saving is estimated to be **281 GWh p.a**, including 149 GWh p.a. at the pump station plus secondary power savings from downstream pumping. Electricity billing data has been muddied as a pump with particularly poor efficiency has been installed in the short term due to breakdowns, but best efforts to allow for this change at the station confirm the magnitude of the saving.
15	**Cost / Benefit analysis:** financial appraisal or payback time.	The cost to inspect all constructed sewer overflows within the network was $200k over three years. The example described at Windale 2 WWPS is just one of several problems found within the network by undertaking an inspection of all overflows. It is impossible to determine a true Benefit to cost ratio but we can calculate that the leak need only have remained undetected for a further 5 years in order to have accumulated a present day net present value of $200k in electricity costs.

16	**Project review:** could it be improved or developed?	Cost effectiveness of constructing and installing the flap is easily proven, however the cost effectiveness of inspecting all overflow structures needs to be determined continuing with the existing strategy into the future.
17	**Confidence grade:**	Highly transportable and adaptable

Observations:

3.1.3 Optimise Gravity Flow

Water abstraction and distribution systems evolve into complex assemblies of pipework over time as the networks are extended and modified to meet changing supply and demand conditions. Any opportunity to review and assess opportunities for rationalising the network should be taken, including marginal pumping situations. Recent energy cost increases may now validate projects which may not have been cost-effective a few years ago.

Water Supply – Optimise Gravity Flow

Description of Process *The most energy efficient layout for both transmission mains and distribution networks is one that is gravity fed from the water source to the delivery point. However in practice the geographic and physical system characteristics often impose layout and operational constrains that are resolved by pumping. Pumping is also used to increase hydraulic capacity where gravity can deliver a lower flow. There are therefore opportunities to minimize pumping by optimizing gravity flow.*

If water is delivered to the top of storage, the system downstream is fed at all times by gravity from the storage; differences between inflows and outflows being balanced by the available storage.

Pumped systems with rise-and-fall mains and floating storage are common in distribution networks. The layout delivers higher pressures than can be maintained using elevated storage and a gravity supply alone.

Potential Interventions *If pumping is required, it is generally more energy efficient to pump at a relatively constant rate whereas tariff linked pumping may represent a lower OPEX cost.*

The energy used to pump though transmission mains and distribution networks is influenced by the following factors:-

- *Hydraulic layout and capacity of the facilities and their physical condition,*
- *The hydraulic gradient and elevation profile between the source and delivery points,*
- *Operational supply regime*
- *Valve maintenance regime, including line, air and pressure management valves,*
- *Mode of operation of facilities, including:*
    - *Level of Service – pressure, quantity and restrictions,*
    - *Storage – high or low level inlet, capacity in relation to demand/ pumping,*
    - *Pumping facilities – operational regime including diurnal and seasonal variations.*

For existing systems, monitor flow and plant performance, and understand the operating regime to quantify demand and thereby energy usage. Thereafter question the process and assumption in order to minimize the need for pumping.

For the designs of new systems and extension to existing systems, the characteristics listed above should be considered with the objective of minimising or eliminating the need for pumping.

Range of Potential Savings ***Up to 19% from case studies.***

Case Studies **NL-KWR1**

Gravity Flow Case Study: NL-KWR1 *Bergambacht, Netherlands*

Hydraulic connection of water pumping stations

Installation of a hydraulic connection between the water intake pumping station Brakel and the water transport pumping station Bergambacht, resulted in a substantial reduction of water spillage at Bergambacht. Together with the established harmonised control of water flow between the stations, this has resulted in more than 700,000 kWh/y energy gain.

Ref	Enquiry Item	Response information, description and remarks
1	**Location:**	Netherlands, Bergambacht.
2	**Sector:** clean, waste or sludge:	Clean. Pre-treated river water.
3	**Works Owner or Operator:**	Dunea. Water company. Shareholders: 19 municipalities. Regulators: Ministry of Environment and Province
4	**Size:**	75 million m^3 per year
5	**Energy Provider:** with costs, incentives, taxes and conditions:	Nuon electricity (private) Cost: ± 0.085 € / kWh
6	**Process:** physical, chemical, or biological description:	Water transport (intake) Physical (hydraulic junction) and control engineering.
7	**Component:** all or part of the works:	River water transport (transport from intake point of surface water to pumping station).
8	**Specific energy problem:** including quality or consent details:	Main incentive is from environmental objectives of the company and employees: prevention of wastage of water and energy.
9	**Process/Plant changes:** mechanical, electrical or controls:	Automation control. Control (for water transport from Brakel) linked to basin level (at Bergambacht).
10	**Civil/Physical Changes:** to water / effluent quality, civil works, or process:	Hydraulic junction of Brakel transport pipe to intake pipe of Bergambacht. Adjustment of intake work (valves).
11	**Operational Changes:**	Training in process automation. Harmonise procedures between Brakel and Bergambacht.
12	**Risks and Dependencies:**	Risk assessment was performed, especially in relation to high pressure in pipe versus dike stability.
13	**Implementation:** design, build, procurement, installation and commissioning:	Construction costs for hydraulic junction were part of a major dike renovation project. Limited costs for control engineering.
14	**Energy Efficiency gains:** kWh & kWh/m^3	Before: 13.4 million kWh/y. Transport of 86 million m^3 water of which 4.5 million m^3 spillage lost. Average: 0.16 kWh/m^3, thus potential gain: 700,000 kWh/y. After: 9.7-10.1 million kWh/y. Transport of 76 million m^3 water. Average: 0.13 kWh/m^3.
15	**Cost / Benefit analysis:** financial appraisal or payback time.	
16	**Project review:** could it be improved or developed?	Key was to take the opportunity of improving the linkage between the transport pipes in combination with planned dike renovation.
17	**Confidence grade:**	Low.

Observations:

Interview by Jos Frijns (KWR) with: Ruud Draak (technical processes) and Rob Noordhuizen (river water intake) at pumping station Bergambacht, Dunea.19 August 2009.

The above study shows that significant energy can be saved even if apparent gravity head differentials are low. There are no other case studies covering gravity flows but an example from Wales is of a reservoir which was located on utility owned land sufficiently above an existing works to maintain treatment pressure. A new DAF plant was located about 20m above the existing works to maintain head and avoid the need for inter-stage pumping, saving about £68,000/year.

3.2 Pumps

Pumps use between 80 and 90% of the total energy consumed by the water industry. Although many pumps are better than 85% efficient and motors better than 95%, their selection, engineering, operation and maintenance often do not make the best use of the asset.

Many of the parameters and problems concerning energy efficiency are generic so the subject is covered below from the principles governing the appropriate selection of a pump and its system, rather than by application. This should allow rapid diagnosis of problems and identification of solutions.

3.2.1 Selection

Assuming that the type of pump required is known the selection process starts with matching the required duty with the best available pump characteristic.

It is often difficult to ascertain the exact pumping requirements of a given system, frequently because many different conditions need to be satisfied. There is no easy short-cut to this process although involving pump suppliers will usually help.

It is usual to arrange for pumps to be directly driven at synchronous speed which is about 1480 or 2850rpm for four or two pole motors on 50Hz supplies and 1780 or 3460rpm on 60Hz supplies.

The pump characteristics can often be matched more closely to the system duty by using an indirect drive, usually through Vee belts to adjust the pump speed using a standard motor. However, Vee belts can slip and generate heat and introduce transmission efficiency and layout complications.

Some users have increased the transmission efficiency by using toothed belts similar to timing drives instead of Vee belts. These do not slip so are equivalent to a chain drive but do not need lubrication.

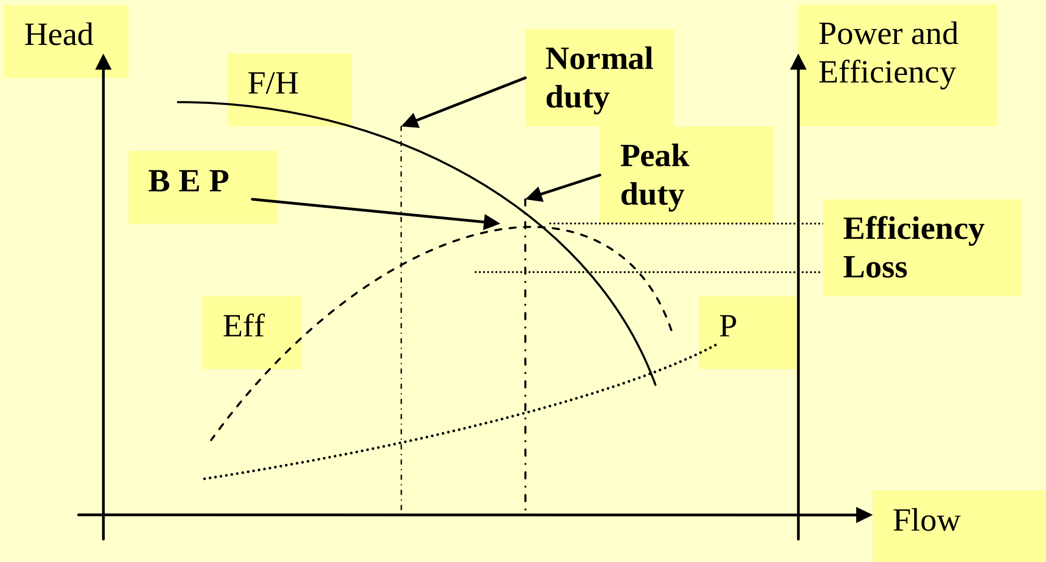
Pump Efficiency Factsheet 1 – Duty Point Selection

A pump's Capex is <10% of the wholelife cost

A pump should be selected to best match the expected duty:-

- *Maximum flow and head within the pump's range,*
- *Abnormal operating conditions safeguarded, e.g. non-overloading power curve,*
- *Normal operating point closest to the pump's best efficiency point.*

The third item is often neglected. Efficiency at peak flow of head may not be important if extremes are only occasional. It is more important to operate efficiently at the duty the pump will most usually be working at, as shown on the graph below.



The curves show a typical centrifugal pump with flow (F/H), power (P) and efficiency (Eff) curves and the location of the "best" duty point, i.e. the point on the duty curve giving best efficiency.

If the peak or maximum duty requirement is only occasional and the pump works for most of its life at the lower flow then it may be using 5 to 15% more power than necessary, depending on the shape of the efficiency curve. If the best efficiency point were at the lower flow, the efficiency loss at peak flow would be about the same, but perhaps only for a few hours a week.

Potential Interventions *Select pump with BEP closer to normal duty*

Range of Potential Savings ***Up to 11% from case studies.***

Case Studies **UK-TVW4; UK-TVW1; UK-SWW3; UK-AW1**

The original design of the ozone cooling circulation pumps was wrong, resulting in pumping to the right hand side of their pump curves. New cooling pumps were installed to replace the old ones.

Ref	Enquiry Item	Response information, description and remarks
1	**Location:** Country, urban or rural:	UK, Urban (90%)/ Rural (10 %)
2	**Sector:** clean, waste or sludge:	Drinking water
3	**Works Owner or Operator:** with financial set-up, regulatory or not.	Three Valleys Water Financial and Quality Regulators (UK Government)
4	**Size:** flows and loads or population equivalent:	Flow = 180ML/D into supply (ozone cooling flow at 9.1Ml/d).
5	**Energy Provider:**	EDF £6.6 p/kWh
6	**Process:**	Pumps were replaced.
7	**Component:** all or part of the works:	Part of the works – ozone cooling circulation pumps
8	**Specific energy problem:** including quality or consent details:	The original design of the ozone cooling circulation pumps was wrong, resulting in the pumps operating to the right hand side of their pump curves.
9	**Process/Plant changes:**	Changes associated with pump replacement
10	**Civil/Physical Changes:**	Changes associated with pump replacement
11	**Operational Changes:**	Less breakdown maintenance is expected, due to improved operating conditions for the pump sets.
12	**Risks and Dependencies:** risk assessment of project and changes.	Less failures are expected, due to improved operating conditions for the pump sets.
13	**Implementation:**	Changes associated with pump replacement
14	**Energy Efficiency gains:** kWh & kWh/m^3	Saving: **267K kWh/year** & **0.004 kWh/m^3** (to final water), **0.08 kWh/m^3** (within ozone cooling system).
15	**Cost / Benefit analysis:** financial appraisal or payback time.	Capital cost is £138K. Energy Saving per year is £17.7K. The payback time is **7.8 years**, based on £6.6p/kWh.
16	**Project review:**	None Planned.
17	**Confidence grade:** on data provided.	70%; design data used, without validation.

Observations:
The savings are calculated as two thirds of the maximum design duty (full flow from the works). This underestimates the expected flow rate by approximately 25%.

3.2.2 Covering a range of duties

If the range of conditions required for a pumping system is too wide it can be cost-effective to select more than one pump. A single pump may be a compromise which may cover the range but at the expense of operating efficiency as shown on Pumping Efficiency Factsheet 2. The justification is that the capital cost of a pump is usually less than 10% of the wholelife cost, whereas the energy costs are often over 80%.

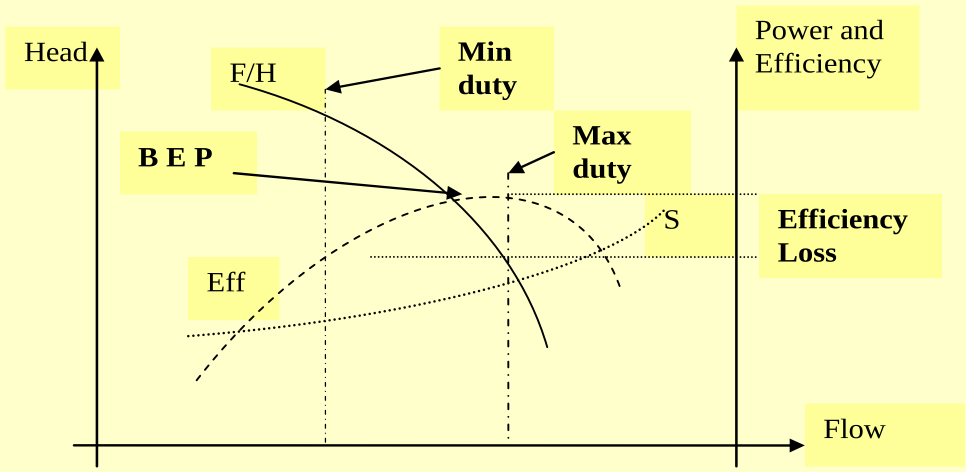
Where the range required is even wider, for example due to diurnal variations, three or more pumps are frequently used.

Where efficiency characteristics are flat, one pump may cover a range of operations and can also cope with changes to its duty point.

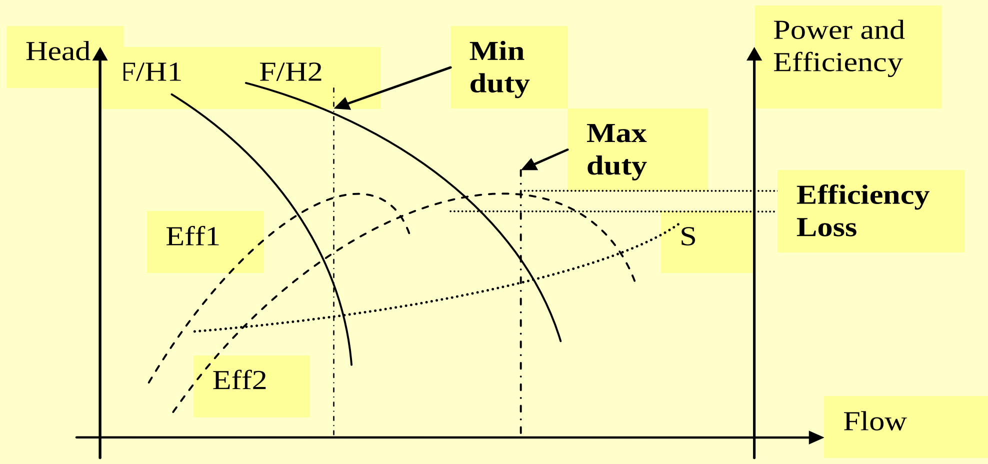
Pump Efficiency Factsheet 2 – Duty Range Selection

A pump's Capex is <10% of the whole life cost

Where the normal duty varies over a significant range, no single pump can be expected to cover all duties efficiently. It may be cost effective to accept the complications of using multiple pumps to avoid efficiency loss across the range, as shown on the graph below.



The smaller pump would cover the minimum flow and the larger pump the maximum duty thus covering the operating range more energy efficiently, as shown below.



F/H1 *and* F/H 2 *with* Eff1 *and* Eff2 *show the curves for 1 and 2 pumps working.*

Using two pumps also gives operational flexibility and eases standby provision.

Potential Interventions *Select multiple pumps for a wide duty range.*

Range of Potential Savings ***Up to 3% from case studies.***

Case Studies **UK-SSW1**

3.2.3 Change of duty

Operational changes affect pumps but it is not always cost effective to change the pumps.

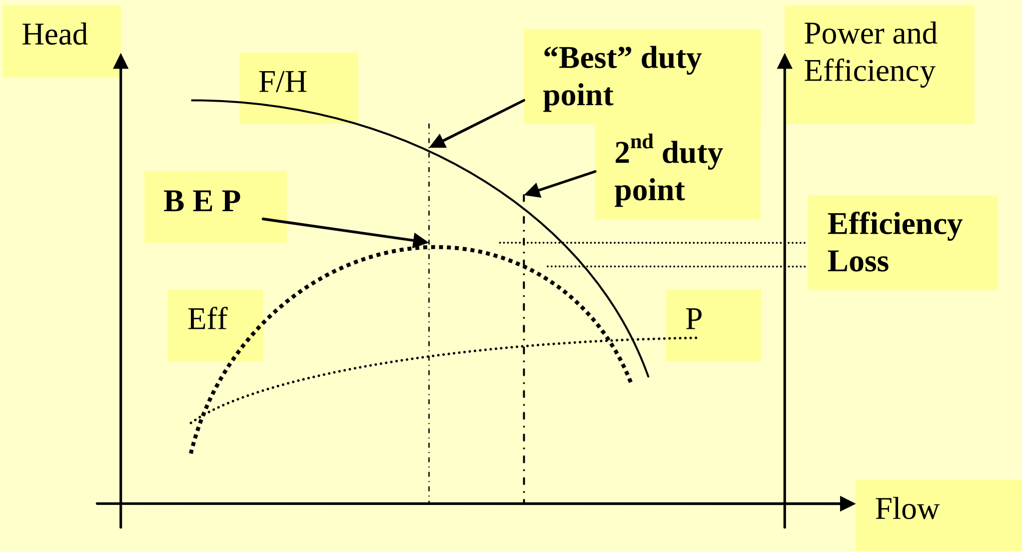
Pump Efficiency Factsheet 3 – Changes of Duty

A pump's Capex is <10% of the whole life cost

A pump characteristic should include at least three curves plotted against flowrate:-

- *A head or pressure curve to show fluid performance,*
- *A power demand curve to show what energy it takes,*
- *An efficiency curve to show where it works best.*

The peak of the efficiency curve is, logically, the Best Efficiency Point, BEP, and this is the optimum point for the pump's duty. If a duty changes, then a few % may not affect the efficiency as shown on the graph below.



The curves show a typical centrifugal pump with flow (F/H), power (P) and efficiency (Eff) curves and the location of the "best" duty point, i.e. the point on the duty curve giving best efficiency.

If the duty requirement changes then a "2nd duty" point may be significantly different in flow or head, but if the efficiency curve is flat the efficiency loss may be small.

If there are no other issues such as pipework headlosses, electrical overloads or vibration, it is the efficiency difference which will indicate potential energy savings.

It can be difficult to economically justify a new pump for small efficiency gains so refurbishment with perhaps a new impeller may be an option.

Potential Interventions *Check pump selection when duties change.*

Range of Potential Savings ***5 to 20% for single pumps from experience.***

Case Studies **UK-TVW3; SA-NM1**

Pump Efficiency 3 Case Study: UK-TVW3 *Three Valleys Water, UK*

When 2 pump wells operated together the interference caused the well level in both wells to drop by an additional 6 metres. To avoid the interference, the local control was changed on site to remove this duty from the automatic pump changeover software.

Ref	Enquiry Item	Response information, description and remarks
1	**Location:** Country, urban or rural:	UK, Urban (70%)/ Rural (30 %)
2	**Sector:** clean, waste or sludge:	Drinking water
3	**Works Owner or Operator:** with financial set-up, regulatory or not.	Three Valleys Water Financial and Quality Regulators (UK Government)
4	**Size:** flows and loads or population equivalent:	Flow = 20.8Ml/d
5	**Energy Provider:** with costs, incentives, taxes and conditions:	EDF £6.6 p/kWh
6	**Process:** physical, chemical, or biological description:	No change
7	**Component:** all or part of the works:	Part of the works – pump well
8	**Specific energy problem:** including quality or consent details:	When 2 pump wells operated together the interference caused the well level in both wells to drop by an additional 6 metres.
9	**Process/Plant changes:** mechanical, electrical or controls:	The control software of the pumps is re-programmed.
10	**Civil/Physical Changes:** to water / effluent quality, civil works, or process:	no
11	**Operational Changes:** skill levels, procedures and maintenance routines:	n/a
12	**Risks and Dependencies:** risk assessment of project and changes.	n/a
13	**Implementation:** design, build, procurement, installation and commissioning:	n/a
14	**Energy Efficiency gains:** kWh & kWh/m^3	**Saving: 91K kWh/year & 0.012 kWh/m^3**
15	**Cost / Benefit analysis:** financial appraisal or payback time.	Capital cost is £3K. Energy Saving per year is £6.01K. The payback time is 6 months, based on £6.6p/kWh.
16	**Project review:** could it be improved or developed?	Similar savings are being looked at for other sites.
17	**Confidence grade:** on data provided.	80%: Actual Half Hour data and calibrated flowmeter used for data collection.

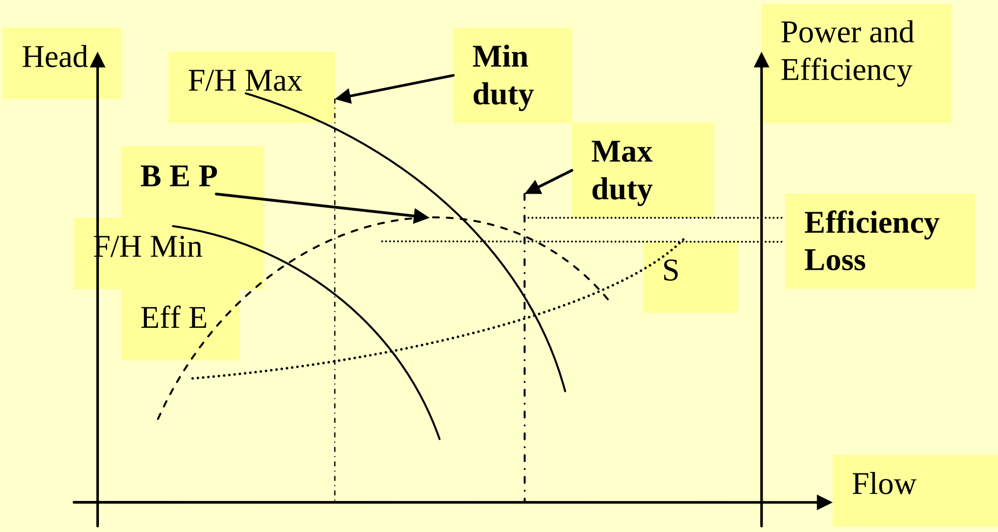
3.2.4 Variable Speed Drives

Pump duties which vary or change can be catered for by Variable Speed Drives (VSDs).

Pump Efficiency Factsheet 4 – Variable Duty Selection

An alternative solution for wide duty range

To cover a wide duty range with a single pump, a Variable Speed Drive can be used. This allows better efficiency envelope (Eff E) *over a wide operating range on the system curve S as shown on the graph below.*



The F/H Max *curve shows the flow/head at full speed; the* F/H Min *curve shows the same pump at slow speed; a family of almost parallel characteristics will exist for most pumps although anomalies can occur at low flows.*

The reduction of efficiency at slow speed is not as great as for a fixed speed pump at the lower duty.

Variable Speed Drives (VSDs) are also known as Variable Frequency Drives (VFDs) as they work by changing the voltage and frequency of the electricity to a normal pump motor.

A VSD with one pump may be cheaper and more compact than using two fixed speed pumps, but see the separate Fact Sheet on VSDs.

Where multiple pumps are available the potential for energy gains using VSDs will be reduced.

Potential Interventions Use VSDs for a wide duty range.

Range of Potential Savings ***Up to 12% from case studies.***

Case studies **UK-UU3; UK-SSW2; KWR2**

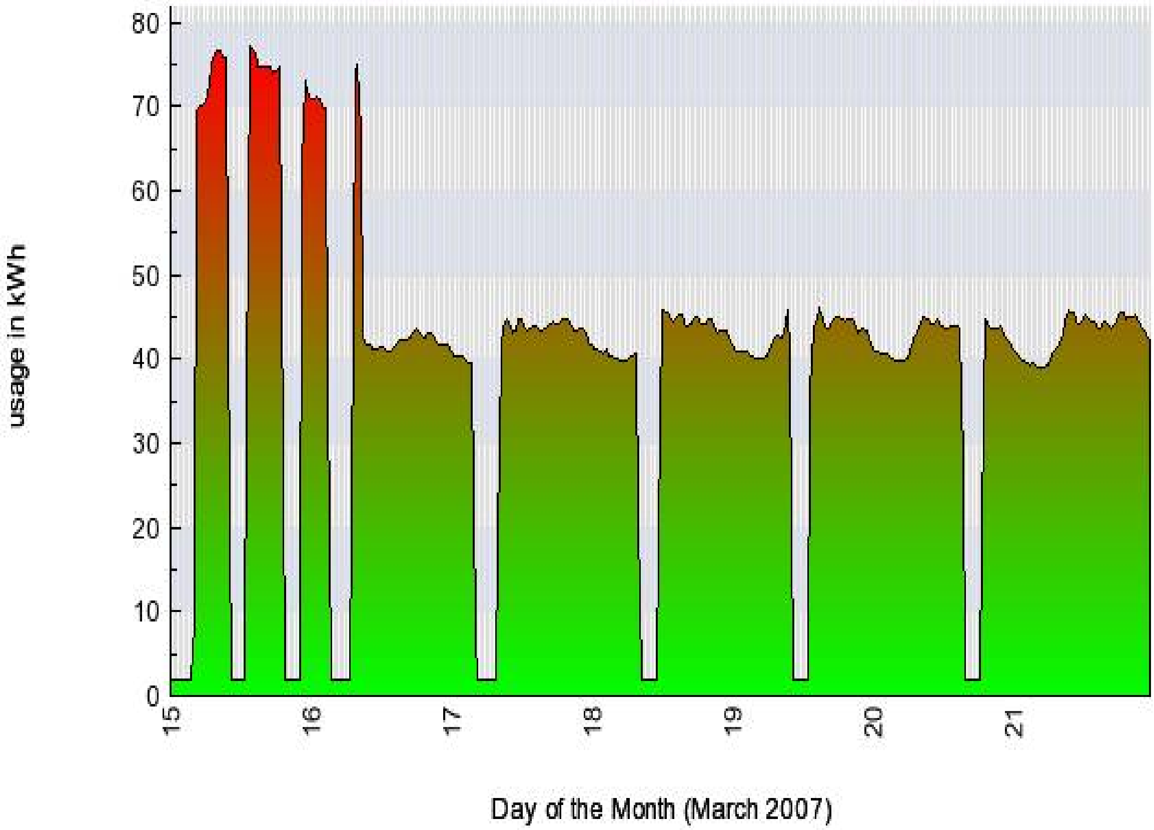
Pump Efficiency 4 Case Study: UK-UU3 ***United Utilities, UK***

Variable Speed Pump Control changes at Pilsworth PStn.

Ref	Enquiry Item	Response information, description and remarks
1	**Location:** Country, urban or rural:	North West UK Urban Water Network
2	**Sector:** clean, waste or sludge:	Drinking water network
3	**Works Owner or Operator:**	United Utilities - Regulated water business
4	**Size:**	Daily flows of 16 Ml/d feed to service reservoir
5	**Energy Provider:** with costs, incentives, taxes and conditions:	GDF, annual usage typically 0.9 GWhs, unit costs ave. 8.3p/kWh (total)
6	**Process:**	Physical pumping of treated water in network
7	**Component:** all or part of the works:	Major network pumping station
8	**Specific energy problem:**	High volume of water pumped on a daily basis
9	**Process/Plant changes:** mechanical, electrical or controls:	Control of pumps is by variable speed drive with normal operation close to maximum frequency. Operational change to reduce operational frequency on VSD by several Hz. Pumping rate reduced from 32 to 25 Ml/d increasing pump operating times but reducing friction head on system
10	**Civil/Physical Changes:**	No physical change to process
11	**Operational Changes:**	No change to maintenance routine etc
12	**Risks and Dependencies:**	*N/A*
13	**Implementation:**	Operational change to drive frequency only
14	**Energy Efficiency gains:** kWh & kWh/m^3	Average annual kWh usage reduced by approx **115,000 kWh per year** or **12%** **0.020kWh/m^3**
15	**Cost / Benefit analysis:**	Energy cost savings circa £8k per year.
16	**Project review:** could it be improved or developed?	Adjustment of VS drive frequency could lead to further improvement based on a detailed assessment of service reservoir operating levels and tolerance to lower level of storage
17	**Confidence grade:** on data provided.	No CAPEX costs but potentially significant OPEX savings

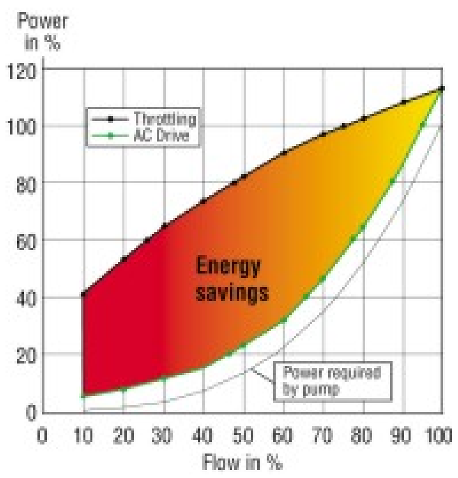
Observations:

Actual benefits have been delivered against energy bills for no capital costs with potential to further improve OPEX impact based on system review and service res control.



Graph of power usage changes from UUs empire database showing changes in energy usage trend after reduction in VS frequency. Energy saving equates to 115,000 kWh per annum.

Slowing a pump down by powering its motor with lower than mains frequency electricity is more efficient than throttling with a control valve. Flow does not vary linearly with speed so speed regulation is usually only between 80% and synchronous, i.e. 40 to 50Hz. Speeds should be agreed with the pump makers and tested on commissioning to ensure that the pump cannot run stalled, since this can result in overheating.



Source: ABB Website

Figure 3.2 Energy Saving Though Variable Speed Drives

Figure 3.2 shows in general how much energy a variable speed drive saves at different flows compared to traditional control methods.

The Case Study examples show a range of options that can be used for covering variable duties or a range of duties. Opportunities for energy saving can be approached in different ways.

Variable Speed Drives are alternately seen as either the answer to everything or the villains of the piece so the factsheet below attempts to balance the issues.

Pump Efficiency Factsheet 5 – Variable Speed Drives

>80% of a pump's cost is the energy it uses

Variable Speed Drives (VSDs) are electronic devices which alter the frequency and voltage of the electrical supply to a motor. They are also known as variable frequency drives (VFDs) and allow speed and torque control without wasting power. However:-

- *Pump efficiency usually falls at lower speeds,*
- *Pump characteristics sometimes change shape at lower speeds,*
- *Pumps may not have test data at lower speeds, calculated curves are risky,*
- *High head pump flows change significantly for small speed changes,*
- *VSDs take typically 5% of the motor power to drive themselves,*
- *Cables losses between VSDs and motors can be <1 to >10%,*
- *Special motors may need special VSD management software,*
- *Losses from VSDs and cables generate heat in MCCs and buildings.*

Cable losses vary with their length so plant layout is important, and the heat generated may require cooling or air conditioning in an MCC or building.

VSD advantages include:-

- *Closer matching of an existing pump to an existing or new duty,*
- *Operation of one pump over a variety of duties, saving separate pumps,*
- *Flexibility to respond to seasonal, emergency or peak tariff situations,*
- *Potential for automatic pump or pipeline management events,*
- *Ability to set limits on pump operation,*
- *Good apparent power factor as seen from the mains supply.*

Potential Interventions *Size pumps correctly first, Use VSDs for varying duties, Check energy savings balance. Check power factor correction.*

Range of Potential Savings ***Up to 37% from case studies.***

Case studies **BL-KWR2; AU-HW1; AU-WC1; UK-ScW2; UK-ScW5; UK-SEW1; UK-TVW2**

Pumping Efficiency 5 Cast Study: BL-KWR2 ***Pidpa, Belgium***

The application of variable frequency drivers at the pumps of the water collection well Grobbendonk resulted in about 15-20% energy saving; equivalent to about. 100.000 kWh/y.

Ref	Enquiry Item	Response information, description and remarks
1	**Location:** Country, urban or rural:	Belgium, Grobbendonk. Rural. Water Production Centre Grobbendonk delivers water to a large rural area South-East of Antwerp.
2	**Sector:** clean, waste or sludge:	Clean. Collection of groundwater in wells for production of drinking water.
3	**Works Owner or Operator:** with financial set-up, regulatory or not.	Pidpa is the drinking water company of the province of Antwerp. Pidpa is an intercommunity without private interests. Her partners are the Province of Antwerp and 67 communities in this province.
4	**Size:** flows and loads or population equivalent:	6.2 million m^3 per year. The water collection has 30 wells with a capacity of 20,000 m^3/d.
5	**Energy Provider:** with costs, incentives, taxes and conditions:	Electrabel (electricity, private) Cost: 0.085 € / kWh (due to continuous operation for water collection there is little room for peak discounts). Energy resembles about 1/3 of the variable costs.
6	**Process:** physical, chemical, or biological description:	Physical: ground water collection in wells equipped with pump. After collection the water is aerated, filtered, disinfected and distributed at Grobbendonk water production centre.
7	**Component:**	Ground water collection in wells.
8	**Specific energy problem:** including quality or consent details:	The water collection wells of Grobbendonk are sensible for clogging, increasing the pumping head with up to 10 meters over the years. Moreover, the groundwater level has a 2 meter seasonal variation, and mutual influence on collection between wells can have an effect on the level of about 5 meter. Thus, originally the wells were equipped with oversized pumps that had to be strangled, so that sufficient head would remain available. To overcome the related energy loss, variable frequency drivers have been installed at the low pressure pumps of 11 new wells (of the 30). Variable frequency drivers, or variable speed drivers (VSD) alter the frequency and voltage of the electrical supply to a motor, and allow speed and torque control without wasting power. Main incentive was cost saving from energy saving.
9	**Process/Plant changes:**	Electrical control: VSD. Electromagnetic flow meter and a PLC for flow control.
10	**Civil/Physical Changes:**	The cover of the water well was equipped with an opening for ventilation of the VSD.
11	**Operational Changes:**	No training or new maintenance procedures needed as VSD are common practice at Pidpa.
12	**Risks and Dependencies:**	As there are several wells in operation, the consequences of VSD failure are limited. VSD are proven technology.
13	**Implementation:** design, build, procurement, installation and commissioning:	The VSD was installed during renewal of the wells, operated by the contractor Smet GWT. The additional costs for equipping the wells with VSD were about 3,000 Euro per well. About 1,000 Euro of this was

		subsidized (energy conservation subsidy).
14	**Energy Efficiency gains:** kWh & kWh/m3	On average, about 5 m pumping head could be gained. The pumps discharge 50 m^3/h, 365 days per year, with an efficiency of 62.4%. Thus the energy gain is about 9,600 kWh per pump (or about 15%). This equals 0.022 kWh/m^3 energy gain. In total, for the 11 pumps, the energy gain is 105,000 kWh/y. The average energy use at the wells without VSD is about 0.11 kWh/m^3. Application of VSD thus has a 20% energy efficiency improvement.
15	**Cost / Benefit analysis:** financial appraisal or payback time.	The yearly cost saving for each pump is 815 Euro. The payback time is 2.5 years.
16	**Project review:** could it be improved or developed?	In the near future the other 19 water collection wells will also be equipped with VSD. When all 30 wells have VSD, the pumping control regime can be changed from an on-off mode into a continuous control. This will result in additional energy savings. Moreover, less operation switching might have a positive effect on the life span of the well.
17	**Confidence grade:** on data provided.	Average. No direct energy monitoring of individual pumps/VSD.

Observations:

Pidpa, the Provincial and Interurban Drinking Water Company in the province of Antwerp, provides water to 65 municipalities in the province of Antwerp. At Grobbendonk, drinking water is produced from 30 wells that collect groundwater. In the water distribution system, VSD have been installed at the high pressure pumps, resulting in energy saving from a steady flow control.

During renovations of 11 water collection wells, Pidpa decided to install VSD also at the low pressure pumps of the wells. This elimated the existing practice of strangling oversized pumps. On average 5 m pumping head was gained, or 9,600 kWh/y energy gain per pump, a 15-20% energy efficiency improvement. Total savings are about 100,000 kWh/y. Payback time is 2.5 years.

3.2.5 System impacts

The pump must be considered as part of the system including the pipework layout immediately around the pump and any impacts on the suction or delivery conditions.

Pump Efficiency Factsheet 6 – Pipework System Design

Match pipework to pump duties
Many pump installations are compromised by hydraulic restrictions in suction wells and local pipework. This is often due to duty or system changes, but awareness may help to avoid throttling pumps and wasting energy.

Pump designers size casings for efficient flows over the duty range but pump flow speeds are much higher than pipe velocities. Good practice to minimise headloss and ensure efficient flow in and out of pumps can be summarized as:-

- *design sumps and intakes according to best practice; CFD models can be useful but they should be calibrated against physical model experience,*
- *keep suction pipework short, the ideal length is zero,*
- *keep suction pipework speeds low; between 1 and 2.5m/s,*
- *avoid adjacent bends in perpendicular planes; this promotes swirl,*
- *site pumps low down relative to suction well levels to reduce NPSH losses and avoid cavitation,*
- *ensure flooded suctions to eliminate priming and air entrainment problems,*
- *sudden contractions on the suction side are not usually a problem provided that edges are rounded and vortices are avoided,*
- *locate the pump for easy access for maintenance,*
- *expand pipe size with a taper at the pump discharge flange if possible,*
- *avoid sudden expansions as they create instability,*
- *discharge velocities can be higher; between 1.5 and 3.5m/s,*
- *use swept bends if possible and avoid sharp edges with high velocities,*
- *use appropriate valves for check and isolation duties,*
- *incorporate facilities for flow and head measurement.*

The last item is important for performance monitoring. Permanent instrumentation may have a short life due to environment, local conditions or the pumped media. Strap-on flowmeters and plug-in pressure transducers may be more reliable, easy to calibrate and form a part of a regular monitoring routine to check efficiency and other trends.

Particularly where multiple pumps are used, pipework, manifolds and connection designs should be evaluated against wholelife costs to ensure hydraulics are not compromised by Capex savings.

Potential Interventions *Check hydraulic restrictions against duty*

Range of Potential Savings ***5 to 20% for single pumps from experience.***

Case studies **None.**

If a pump or impeller change cannot be justified on the basis of energy efficiency alone, it may be worth considering other factors as in the table below. Individual effects are small but the cumulative effect of all these factors could be significant.

Table 3.1 Potential Pumping Efficiency Gains

Factor	Potential Efficiency Gain
Age, over 30 years	5 to 10%
Obsolescence	5 to 10%
Heavy silt load	5 to 15%
Corrosive water chemistry	0 to 20%
Maintenance regime	0 to 20%
Change of system duty	1 to 10%
Modifications to pipework	1 to 5%
Cumulative potential gain	**up to 90%**

Performance against age usually depends on the environment and media being pumped. Obsolescence depends on continuity of manufacture and availability of spares. Other factors impose physical or chemical limits on efficiency and the effects of pipework are explained in Pump Efficiency Factsheet 6.

3.2.6 Applications – Drinking water

The above notes cover generic issues of pumping technology but in practise different types of pump are preferred for specific applications.

River abstraction requires robust pumps to deal with silt and possibly debris with good suction capabilities. To cope with water level variations it is often useful to have more than one pump or a variable speed capability to allow reduced flows to avoid excessive siltation. Split-case centrifugal pumps are often used since they are efficient, hydraulically balanced and allow easy replacement of wear rings, seals and bearings. These considerations will also apply to any pumps dealing with filter backwash water or other plant applications where dirt or filter media may be entrained. Easy maintenance and inspection means that a pump is more likely to be kept working at close to its as-built efficiency and wear or corrosion will be monitored. Wash-out facilities in the pipework could help to avoid sediment build-up and partial blockages.

One case study from Germany shows that in extreme instances of sedimentation in raw water pipework it is economic to make provision for regular pigging. This technique was developed in the oil industry and during a short pumping stoppage a piston (the pig) is inserted into the pipe. When pumping re-commences the pig is driven by pump pressure and pushes any sedimentation or partial blockages to a terminal point where the sediment and pig are automatically removed. This technique has also been used for sludge. It requires a constant diameter pipeline with only large radius bends and facilities for inserting and removing the sediment and pig.

Pumping Efficiency Case Study DE-KF1 ***Krefeld, Germany***

Pigging of a raw water pipe

Ref	Enquiry Item	Response information, description and remarks
1	**Location:**	Germany, Krefeld, Urban.

2	**Sector:** clean, waste or sludge:	Clean. Raw water pipe, collection of raw water from reduced groundwater.
3	**Works Owner or Operator:** with financial set-up, regulatory or not.	The municipal utility Krefeld provides the town of Krefeld with drinking water (approximately 14 Mio. M³/year, e.g. 38Mld).
4	**Size:** flows and loads or population equivalent:	approximately 14 million m³ per year in the considered pipe system approximately 3,6 million m³ per year as first stage.
5	**Energy Provider:**	From the market-
6	**Process:** physical, chemical, or biological description:	Physical: pumping, head loss in cause of friction depending on iron oxidation, sedimentation and clogging due to oxidation products.
7	**Component:**	Raw water Pumps and pipe system.
8	**Specific energy problem:**	Because of friction the specific energy consumption (kWh/m³) rises up.
9	**Process/Plant changes:**	No process related
10	**Civil/Physical Changes:**	No changes
11	**Operational Changes:**	New procedures of operation.
12	**Risks and Dependencies:**	No risks expected, better performance of operation.
13	**Implementation:**	Installed and operated.-
14	**Energy Efficiency gains:** kWh & kWh/m3	After pigging the head loss was approximately 3 bar lower. Calculation of the energy-saving is difficult, because after pigging the head loss increases continuously again.
15	**Cost / Benefit analysis:** financial appraisal or payback time.	The costs per pigging are 2200 Euro. The pigging costs were low, because the pipe was build with special controls and instruments (higher investment). Energy-saving not calculated.
16	**Project review:** could it be improved or developed?	The optimized intervals of pigging will be calculated, depending on development of head loss. .
17	**Confidence grade:**	High

Observations:
The municipal utility Krefeld provides the town of Krefeld with approximately 14 Mio. m³ drinking water per year. The supply consists of two waterworks. One of the waterworks is feed by two raw water pipes.
One of these pipes (DN 500) is approximately 4.5 km long. Because of friction depending on iron oxidation, sedimentation and clogging due to oxidation products, the head loss increases. After pigging the head loss was approximately 3 bar lower.
Head loss in pipes produces an additional power consumption by the pumps. The costs of pigging could be reduced significantly by the installation of watergates to place and replace the pig. For this reason it's possible to pig the pipe from an ecomonic point of view all 18 month.

Aquifer abstraction uses borehole pumps which are usually multi-stage mixed flow pumps with special submersible motors. The long, narrow configuration is not as efficient as a standard pump or motor and two pole motors running at 2800 or 3500 rpm are often required to generate sufficient head; so line-shaft pumps should be assessed for shallow applications. Having the motors at the surface would also reduce the length of cable from the starter so VSDs could become feasible. Against these features are the line-shaft bearings and their supports, possibly exposed to the flows, with the resultant mechanical and hydraulic friction.

Pump Efficiency Case Study: UK-AW1 ***Anglian Water, UK***

Replacement of a submersible borehole pump with vertical line shaft pump at a satellite raw water abstraction site supplying a treatment works.

Ref	Enquiry Item	Response information, description and remarks
1	**Location:** Country, urban or rural:	UK, rural
2	**Sector:** clean, waste or sludge:	Drinking water,
3	**Works Owner or Operator:** with financial set-up, regulatory or not.	Anglian Water, regulated
4	**Size:** flows and loads or population equivalent:	7 Ml/d
5	**Energy Provider:** with costs, incentives, taxes and conditions:	HHM, TRIAD
6	**Process:** physical, chemical, or biological description:	Raw water abstraction
7	**Component:** all or part of the works:	All
8	**Specific energy problem:** including quality or consent details:	Focus on increasing pump efficiency. Targeted as high unit cost site
9	**Process/Plant changes:** mechanical, electrical or controls:	Installation of new VLS pump and EFF1 motor
10	**Civil/Physical Changes:** to water / effluent quality, civil works, or process:	n/a
11	**Operational Changes:** skill levels, procedures and maintenance routines:	Use as base load duty pump
12	**Risks and Dependencies:** risk assessment of project and changes.	n/a
13	**Implementation:** design, build, procurement, installation and commissioning:	n/a
14	**Energy Efficiency gains:** kWh & kWh/m^3	**~ 430,000 kWh/yr.** **~ 0.168 kWh/m^3**
15	**Cost / Benefit analysis:** financial appraisal or payback time.	Payback within 5 years
16	**Project review:** could it be improved or developed?	n/a
17	**Confidence grade:**	Data checked and verified upon completion

Aquifers are frequently exploited by multiple abstraction boreholes and some techniques for energy savings have emanated from affected companies:-

- Prioritise the most efficient pump for the main duty,
- Monitor the aquifer drawdown and match against pump locations,
- Using multiple sources for a particular flow may result in reduced drawdown, thereby minimising suction head.

Aquifer recharge and aquifer storage and recovery (ASR) are specialised applications potentially requiring a reverse of normal flows to introduce water back into an aquifer. Suitable pumps may be split case or other centrifugal pumps but they should be selected on an individual basis for best efficiency at the normal duty.

Transfer pumping covers bulk transfer of water between facilities in a system such as river intakes, treatment works, pumping stations, service reservoirs and centres of demand. Bulk transfers include base loads, balancing reservoirs and for emergency situations. Since the volumes, distances and therefore power involved are often quite high, it is important to ensure such plant works at close to optimum efficiency.

As well as the plant and design issues, the Operational aspects include:-

- monitoring the requirements to avoid unnecessary working,
- working the pumps when the receiving system is best able to accept the transfer,
- ensuring that the delivering system is at high pressure to give the pumps the best suction conditions, although the receiving operator may not have any control over this.

Booster pumps are used in two general applications during drinking water treatment:-

- For boosting pressure or raising the level of the flows in the main,
- For boosting pressure of drinking water for mixing, dilution or inducing chemicals.

For large flows split case or other centrifugal pumps are used and for high lifts, two or three stage versions are available. Imparting high pressures to large flows will obviously involve high energy costs so the whole installation should warrant close attention.

For smaller flows multi-stage mixed flow pumps are common and although their motors are not subject to the physical constraints as the hydraulically similar borehole pumps, their overall efficiency is occasionally poor since they are aimed at a low Capex market. It is possible that water company pressure may drive efficiency improvements in this pump type.

Dissolved Air Flotation (DAF) recirculation is a specialised aspect of pressure booster pumping and is energy intensive because the pressures involved are quite high. It is usually more efficient to use direct air injection as the air handling losses are less than for water, but if the injection system is part of a package the supplier's advice should be sought, (See section 3.5).

Chemical Dosing pumps are generally low flow and relatively low head so are not major energy consumers. However, the principles of good pump and system design still apply although there are some specialised issues that are outside the remit of this Compendium, for example, loading valves and recirculation to prevent blockage. The potential energy savings are relatively small.

Mixing does not usually involve pumps in drinking water, but does involve energy input, (See section 3.4).

Filter Backwash pumps are used for rapid gravity or other types of filters and are usually conventional centrifugal pumps. With a simple system energy efficiency should be straightforward, but large filter banks can be complex and the pumps are frequently in almost continuous use.

In some situations it may be energy efficient to maintain a header tank for wash water which is topped up either by small dedicated pumps or by a bleed from the supply or high lift pumps. However, if any part of the system involves a control valve with large loss of head and high flow, this represents a loss of energy. A more direct means of backwash may then be more effective.

Water Treatment – Inter Stage Pumping

Inter stage pumping may be required: -
1 Depending on the site topography e.g. flat or site with depressions
2 When replacing an existing process stage with a new one.
3 When a new process stage is added to an existing works
4 When provisions are made to include new process stages in the future

Inter stage pumping usually involves high flow and low head. The types of pumps used are mixed flow or screw type, which are inefficient compared to types used for raw water pumping.

Potential Interventions *Interventions relate energy demand to design.*
1 Select sites to suit the hydraulic gradient of the treatment process or arrange the process units to suit the site topography.
2 On flat sites design for the hydraulic gradient by raising the inlet structure (subject to height limitations) with treated water reservoir located in the ground.
3 Select a new process stage to operate within the hydraulic profile when replacing an existing process with a new one. Where possible, any spare head should be utilised in the process.
4 When making provisions for including a new process stage in the future inter stage pumping should be considered instead of including the process in the initial hydraulic gradient.

Range of Potential Savings ***5 to 100% (when eliminated)***

Air Scour blowers are similar to wash water systems, in spite of the different medium, and the same principles of matching plant to system design apply, (See section 3.3).

Membrane Booster pumps are required for boosting treatment flows for Ultra-Filtration or Reverse Osmosis applications. Pressures can be up to 50 bar so the energy requirements are large. However, the pumps are usually part of a plant package so they may be sized for plant supplier's commercial reasons rather than for the whole life cost benefit. Operations and maintenance staff are often unwilling to investigate them or consider replacements.

It may be worth raising the energy efficiency issue with the original membrane package plant supplier as there could be some cost effective updates for incremental improvements, for example to the controls or the software on cleaning routines. These combined with improved data gathering could confirm the viability of a more fundamental change.

We have no case study to reinforce this but modern membranes are reported to require lower operating pressures, have lower flow reject rates and less onerous cleaning requirements. With energy costs increasing it may become economical to consider changing older membrane cartridges for more modern developments which may also increase reliability and avoid wasting energy due to failures. It could be worth enquiring of membrane suppliers for modern replacements for older plant on a pay to save basis. This is detailed further in Section 4 – Discussion.

Potable water distribution pumps are usually conventional centrifugal types although the range of flows to manage special applications may be justified by particular duties or circumstances. Selection problems include diurnal and seasonal demand variations and providing for emergencies. Energy and water saving technologies have been focused on this area as, combined with leakage rates, it is politically sensitive and in the public eye. Some of the techniques include:-

- Maximising pumping during low tariff periods,
- Adjusting delivery pressures to match diurnal demand variations,
- Changing distribution zones to match supply and demand more efficiently,
- Introducing local boosters and lowering the overall system pressure.

There are also proprietary software models, some operating in real time, to monitor and optimise the many variables in operating a complex distribution network. However, it should be noted that, these and the first item above can actually increase the energy demand even though the energy cost is reduced. This is due to minimum tariff periods not coinciding with the minimum headloss periods in the system diurnal variations. An example is a 'rise-and-fall' pumping main where the service reservoir is further away from the centre of demand than is the source of water. If the rate of output from the source is equal to the average daily supply, water flows out of the service reservoir whenever the demand rate exceeds the average and flows into the reservoir when demand is less than the average. The alternative of making the source output sufficiently large to fill the reservoir during part of a day may result in optimized use of electricity tariffs (by pumping only at night), but can be less energy efficient overall.

3.2.7 Applications - Wastewater and Sludge

Raw sewage pumping usually prioritises reliability above energy efficiency but with increasing distances between catchments and treatment works this balance is changing.

Screening flows in front of pumps helps to avoid some of the above issues but introduces a materials handling and disposal problem. In most cases the pumps and system must be designed and operated to cope with whatever the influent contains.

Facilities for portable instrumentation are more relevant here than for drinking water pumps since the environment is more severe and aggressive and the potential for blockage of capillaries is almost certain. Catchment characteristics change and flow estimates can be inaccurate making accurate pump selection difficult. An incremental energy efficiency saving could come from measuring flows and heads to optimise operation of existing pumps, and if these are no longer appropriate, a substantial benefit could come from investment in refurbishment, new impellers or new pumps.

Pump Efficiency Factsheet 7 – Wastewater Pumping

Pumping takes about 30% of wastewater energy demand

Wastewater pumps suffer a higher wear rate because of grit, rags, debris and other solids. Managing these issues saves energy by avoiding pumping against partial blockages and maintaining pumps and their systems close to best efficiency.

Wastewater pump systems have all the same design problems as drinking water systems (see PE Factsheet 6) with some extras:-

- *debris accumulation in sewers and inlet sumps,*
- *storm events wash down debris accumulations causing blockages,*
- *fats, oils and greases bind surface debris into scum rafts,*
- *silt, grit and gross solids build up at low flow velocity points,*
- *rags, paper and other solids bind round pump shafts and impeller vanes,*
- *valves and other hydraulic fittings are potential blockage points,*
- *maintenance risks include health and safety issues of gas and hypodermics.*

Good design practice for energy efficient wastewater pumping should cover the issues in PE Factsheet 6 and emphasise:-

- *steep benching in pump sumps and intakes to avoid sediment,*
- *access and means for removing scum, sediment and debris,*
- *short, simple and self-venting layout for pump station pipework,*
- *selection of pump and impeller type to suit worst case flow conditions,*
- *swept bends and tees and no valves if possible in delivery pipework,*
- *any unavoidable pipework constraints covered by rodding or flushing points,*
- *arrange for automatic back-flushing if possible.*

The last item refers to pumps with free discharge or where air valves can be incorporated in the discharge pipes so that when the pump is switched off the flow reverses for a short time. This flows back through the pump, clearing the vanes of any ragging, and into the sump which can clear the sump floor around the pump suction.

Operation of wastewater pump systems also involves extra measures over drinking water pumps. Regular routines can help to avoid some problems:-

- *regular "fill and draw" cycles to flush out sewers and pump sumps,*
- *regular drain down cycles to "snore" levels to avoid scum rafts,*
- *performance checks should be more frequent than drinking water pumps.*

The last item should include chipped or bent impeller blades, partial blockages, and the condition and clearances around wear rings, which all affect efficiency.

Potential Intervention *Check hydraulic restrictions against duty*

Range of Potential Savings ***Up to 5% from case studies.***

Case studies **AU-MW2; UK-UU4; UK-AW6**

Pumping Efficiency Case Study: AU-MW2 ***Melbourne, Australia***

There are six pumps at Melbourne Water's Effluent Reuse Water pump station No. 6 (ERW6) located at the Western Treatment Plant (WTP), which pump recycled water off site. Previous operation of the ERW6 pumps was to operate to a pressure set point of 51 metres head. The control algorithm was changed from pressure control, to flow and pressure control, so that the operating pressure is derived according to the ERW6 delivery flow rate.

Ref	Enquiry Item	Response information, description and remarks
1	**Location:** Country, urban or rural:	Australia, urban
2	**Sector:** clean, waste or sludge:	Waste (treated)
3	**Works Owner or Operator:**	Melbourne Water, regulated
4	**Size:**	Pump duty range up to 70 ML/d
5	**Energy Provider:**	AGL SALES PTY LTD
6	**Process:**	Physical, water supply reuse pumping
7	**Component:** all or part of the works:	Six pumps (three x 10 ML/d, three x 30 ML/d)
8	**Specific energy problem:** including quality or consent details:	The initial, simple control system provided for the system, wasted energy. The aim was to operate the pump station system more efficiently, reducing wasted energy without compromising level of service.
9	**Process/Plant changes:** mechanical, electrical or controls:	Control algorithm changed from pressure control to flow and pressure control, so operating pressure derived according to delivery flow rate.
10	**Civil/Physical Changes:**	-
11	**Operational Changes:**	*See Ref 9 above*
12	**Risks and Dependencies:** risk assessment of project and changes.	Physical tests to prove level of service agreements are being met.
13	**Implementation:** design, build, procurement, installation and commissioning:	- Hydraulic model of system built - Testing of control algorithm on the model - Implementation of control algorithm (PLC programming) - Physical testing (*see Ref 12 above*) - Total cost of project no more than $5,000
14	**Energy Efficiency gains:** kWh & kWh/m3	During 07/08 the pumps were operational for 11,325 hours consuming 2,573 MWh (0.227 MW) and pumping 13.1 GL (195 MWh/GL). During 08/09 the pumps were operational for 13,908 hours consuming 2,631 MWh (0.189 MW) and pumping 14.2 GL (185 MWh/GL).
15	**Cost / Benefit analysis:**	<1 month
16	**Project review:** could it be improved or developed?	The system is under further optimisation to achieve further energy efficiency gains; including improvements in real time monitoring (the pressure monitor is due to be replaced).
17	**Confidence grade:** on data provided.	Energy data and savings – HIGH; Flow & pressure metres, volumetric data (±1-2%)

Observations:

See Item 14 in the table above

Archimedean screw pumps are also used for raw sewage pumping. The efficiency depends on the suction sump level relative to the first flight centre line, and the fit of the screw periphery to the flume or casing. Low suction levels and high clearances will lose energy, as will a bent shaft or damaged screw. The maker's performance characteristics should be checked to optimise the suction levels as an incremental improvement from control and operation.

If the flume is concrete this can be re-screeded using a bar of the right thickness temporarily fitted to the flights. Suppliers should be consulted to check likely benefits against the current condition.

Because of slow speeds the screw drive may include pulleys and belts and a reduction gearbox. Belt drives can lose energy through wear or incorrect adjustment and an overheating gearbox is an indication of energy being lost. Overheating could be due to lack of oil, contamination or worn gears or bearings, all of which may risk failure as well as loss of energy. Toothed belts can be more reliable and efficient than Vee belts.

Sewage pumps installed downstream of screens and/or primary treatment, tend to suffer less attrition and can almost be treated as drinking water pumps with consequential higher efficiencies. However, screens are only about 70% effective resulting in rag accumulations in washwater pumps' multi-vane impellers in final effluent, and therefore provision should be made for back flushing or cleaning.

De-sludge pumps from primary or secondary settlement tanks are usually relatively small and reliability is far more important than efficiency. However, engineering to avoid partial blockages by using robust pumps, simple layouts, long radius bends and swept tees in pipework is usually cost-effective.

Return Activated Sludge (RAS) pumps are often a special application for two reasons:-

- low heads and relatively high flows,
- a need for low shear rates to avoid breaking sludge flocs.

Turbine pumps are frequently used, and low speed satisfies the second requirement. Screw impeller pumps are also used and seem to avoid ragging which can be a problem if works inlet screens are ineffective. Large bore pipes are frequently necessary and should be engineered for low headloss since flows are continuous and can be up to 60% of the works flows so the energy demand is significant.

Balancing the requirements of RAS pumping is as much a process optimisation exercise as pumping technology. As implied below, improvements are often the result of informed experience as demonstrated in the following case study.

Wastewater – ASP RAS Pumping.

Activated Sludge Plant (ASP) retuned activated sludge (RAS) pumping typically takes 5-10% of a sewage treatment works energy demand.

Description of Process *Returned activated sludge (RAS) is removed from the bottom of the final settlement tanks of an activated sludge plant (ASP).*

Final settlement tanks are used in sewage treatment to separate solids from treated liquid; the liquid is either discharged to the watercourse or to tertiary treatment. The solids are returned to the start of the activated sludge process where they combine with the incoming flow.

The required rate of RAS is normally dependent on the flow of sewage. However other parameters, such as the settleability of the sludge (commonly measured as SSVI) and the concentration of solids in the mixed liquors present in the ASP, could be used to influence the RAS flow rate.

By reducing the RAS pumping rate, less energy is used.

Potential Interventions *Test for SSVI and MLSS regularly,*
Monitor sludge age and effects such as nitrification.

Range of Potential Savings ***Up to 55% of RAS pumping energy.***

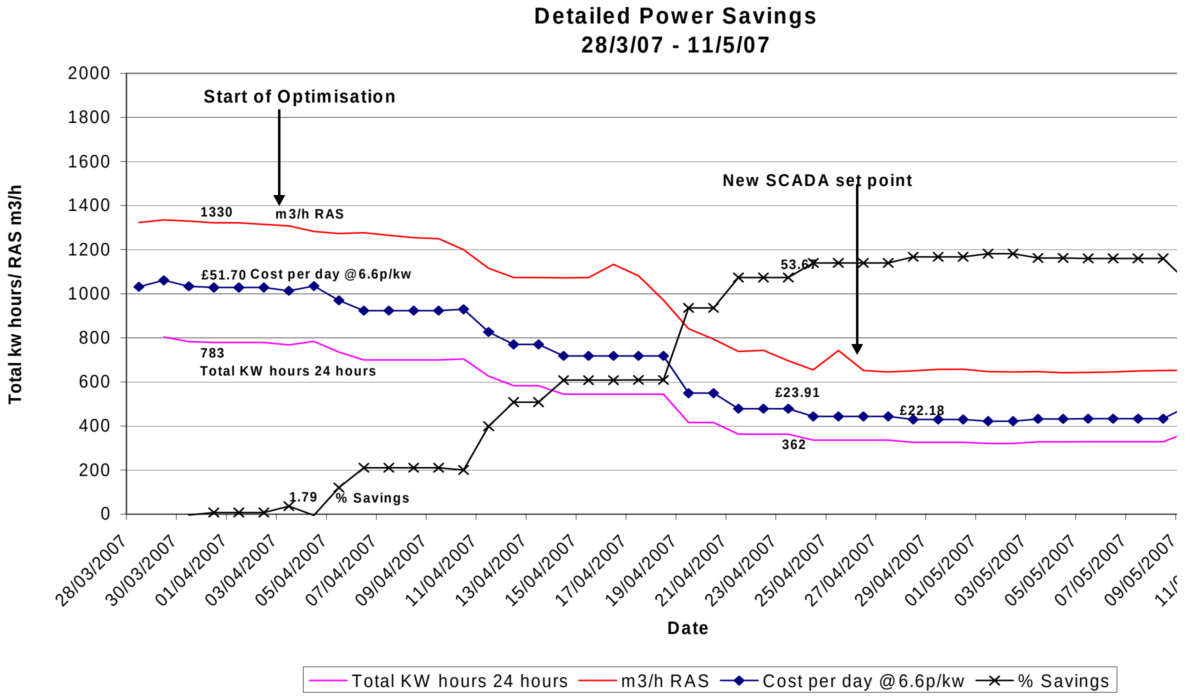
Case Studies **UK -NW1;**

Wastewater-RAS Pumping Case Study: UK-NW1 ***Northumbrian Water, UK***

Returned activated sludge rate was reduced from a fixed flow to a lower fixed flow.

Ref	Enquiry Item	Response information, description and remarks
1	**Location:** Country, urban or rural:	Hendon (Urban), UK
2	**Sector:** clean, waste or sludge:	Waste Water
3	**Works Owner or Operator:**	Northumbrian Water
4	**Size:**	n/a
5	**Energy Provider:**	Cost £0.066/kWh
6	**Process:**	Biological
7	**Component:** all or part of the works:	Activated Sludge Plant
8	**Specific energy problem:**	Cost of pumping RAS
9	**Process/Plant changes:**	Fixed RAS flow reduced from 1330m^3/d to 660m^3/d
10	**Civil/Physical Changes:**	No deterioration in final effluent consent standard.
11	**Operational Changes:**	No change
12	**Risks and Dependencies:**	Flow changes are low risk.
13	**Implementation:**	None
14	**Energy Efficiency gains:**	Saving **320kWh/d**
15	**Cost / Benefit analysis:**	Saving £9k/year
16	**Project review:** could it be improved	Operational

	or developed?	
17	**Confidence grade:** on data provided.	



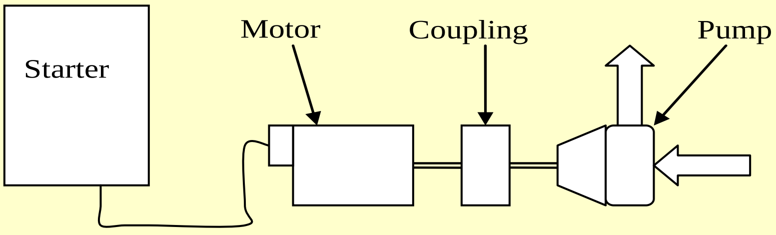
Sludge Pumping involves significant energy when sludge is transferred across sites for screening, digestion or thickening, or when it circulated around digesters. Centrifugal, screw centrifugal or progressing cavity pumps are used according to sludge thickness and other characteristics. Reciprocating pumps can be used for difficult sludges but the reciprocating motion should be derived from a mechanical crank off a rotating shaft rather than hydraulics for best energy efficiency. This is because of the relative ease of accelerating a pipe full of sludge smoothly rather than suddenly leading to more efficient use of mechanical energy and fewer burst pipes.

Reliability is the highest priority but energy efficiency can benefit from keeping sludge moving, since it tends to settle or stratify when it stands still, and attention to pipeline details and velocities. Pipework should be minimum length, use long radius bends and swept tees and the configuration should be simple. Low spots where blockages can start should be avoided and facilities for easy flushing help to minimise lost energy due to partial blockages. This particularly applies to digester heating circuits since partial blockages can result in baked sludge in heat exchangers.

Apart from heating, pumping sludge for tank or digester mixing is not energy efficient since, although some bulk transfer occurs, most of the pumping energy is used moving the sludge through the pipework. The mixing zone derived from the inlet nozzle is usually quite small, (See section 3.4).

Pump Efficiency Factsheet 8 – Intrinsic Efficiency

Use best technology for best results



Starters:

The most efficient starters are Direct On line (DOL) as there are only direct electrical connections between the power supply and the motor. Auto-transformer starters are used for large drives to reduce starting current. They can have contacts that allow switching to DOL when the motor is up to full speed, otherwise there will be transformer losses of up to 5%. Variable Speed Drives (VSDs) can also be used to start large motors and these have losses of up to 5% (See Factsheet PE5). Electronic Soft Starters are similar to VSDs but only operate during starting and switch over to DOL when the motor is up to speed.

Motors:

Motors are generally 92 to 95% efficient but high efficiency motors may be 97%.

Couplings:

The most efficient coupling is a shaft, i.e. a direct driven pump, possibly with the impeller on an extension of the motor shaft. Most pumps have couplings to allow for misalignment and dismantling. With perfect alignment losses will be minimal but more flexible couplings may absorb up to 5% of motor power.

If motor and pump shafts are on different axes drives such as belts or chains are used. Toothed (or timing) belts are available for high power ratings and are more efficient than Vee belts. Vee belts can be used for variable ratio drives, however, the belts, and sometimes the pulleys, wear quickly and lose up to 20% of motor power. Chains work at lower speeds and are rarely used for pump drives. Gearboxes with helical spur gears for shafts in the same plane can be up to 85% efficient, but bevel gears or worm drives may be only 70%.

Pump efficiency can be improved by means of close attention to fettling castings, careful alignment during assembly, accurate trimming of the impeller, correct assembly of bearings and seals, and good finish on wetted parts. Internal coatings on the impeller and bowl can increase efficiency by about 5% .

Potential Intervention *Check with pump maker or maintenance.*

Range of Potential Savings ***Up to 19% from case studies.***

Case studies **AU-SAW1**; **AU-MW1**; **SG-PUB1**; **UK-UU1**; **UK-UU5**; **UK-AW2**

Pumping Efficiency Case Study: AU-SAW1 ***Lock, Australia***

Apply new coating to pump casing volute & impeller to reduce water friction loss.

Ref	Enquiry Item	Response information, description and remarks
1	**Location:** Country, urban or rural:	Country Asset: Lock Water Pumping Station - M2 Pump Location: Lock, Eyre Peninsula Maximo Location No: LO3456
2	**Sector:**	Potable water
3	**Works Owner or Operator:**	Owner: SA Water , Planning & Infrastructure Operation: SA Water, Operations
4	**Size:** flows and loads or population equivalent:	Flow: 112.3 l/s Supply to: Wudinna, Streaky Bay and Ceduna water districts
5	**Energy Provider:**	AGL
6	**Process:** physical, chemical, or biological description:	Booster water pump that operates to meet demand especially in summer
7	**Component:**	One of the three M pumps at Lock water pumping station
8	**Specific energy problem:** including quality or consent details:	Cast iron water pumps would develop graphitisation; regular major refurbishment of the pumps is required to maintain the operating efficiency of the plant, meet the defined levels of service and to extend pump life.
9	**Process/Plant changes:**	Apply new coating to pump casing volute & impeller to reduce water friction loss
10	**Civil/Physical Changes:** to water / effluent quality, civil works, or process:	Apply epoxy coating (Belzona 1341) to pump impeller Apply epoxy coating (Thortex Ceramitech CR) to pump body and lid
11	**Operational Changes:** skill levels, procedures and maintenance routines:	Pump is hydraulic performance tested on a regular basis (3 - 4 yrs), test results are documented to identify optimal time for pump overhaul. Please refer attached an abstract from the recent pump performance test report of M2 pump
12	**Risks and Dependencies:**	*Not applicable*
13	**Implementation:** design, build, procurement, installation and commissioning:	Pump performance test is carried out by Performance Monitoring Officer in Asset Management. Capital funding is normally sought by country operations if pump overhaul is required. Pump refurbishment is undertaken by SA Water Berri workshop.
14	**Energy Efficiency gains:** kWh & kWh/m3	Energy cost prior to overhaul: 0.468 kWh/kl Energy cost after overhaul (02/03/06): 0.378 kWh/kl Annual energy saving $6,220 /yr based on annual running hrs of 1,910.
15	**Cost / Benefit analysis:** financial appraisal or payback time.	Total cost of pump refurbishment including impeller coating (excluding rotating element replacement) is approximate $20,000.Payback period of this pump is about 3.2 yrs.
16	**Project review:** could it be improved or developed?	Pump performance test was developed by SA Water Pump Testing group since 1980's. As part of the pump performance test routine, vibration monitoring on motor and pump bearings are undertaken at the same time to identify any repair work that may require.
17	**Confidence grade:** on data provided.	Pump performance data prior to and after overhaul are recorded. Please refer attached pump performance data on M2 pump at Lock water pumping station

3.3 Blowers and Compressors

Some of the principles of pumping air are very similar to those for pumping water except for the density, viscosity and compressibility parameters. Compressors are generally of two types: centrifugal or rotating lobe.

Centrifugal blowers can be likened to high speed fans and their efficiency curves can be relatively narrow so selection is important. To counter this, inlet and outlet guide-vanes can be adjusted to allow them to operate over a wider duty range. They tend to suit the larger-scale duties so there is significant energy demand. The high speeds are usually much faster than two-pole synchronous motors (2850 or 3500rpm) and sometimes are over 10,000 rpm. This implies large gearboxes and experience has shown that maintenance of these is important in maintaining essential clearances between the impeller and the casing.

A recent introduction has the motor and turbine mounted on a single shaft with inverter drives working at the speed of the motor instead of mains frequency. Magnetic bearings are used so there is no contact between fixed and moving parts which almost eliminates maintenance. Efficiency loss with operating hours is therefore minimised.

Rotating lobe blowers are developments of the Rootes type and come in various configurations. Some have spiral lobes which even out the pressure pulses to reduce noise and vibration levels and help to increase efficiency.

The most energy intensive use for blowers is for aerating mixed liquors in wastewater Activated Sludge Plants (ASPs). There is considerable scope for energy efficiency measures in these systems, either through design and engineering of new systems, or through operation, control and maintenance of existing plant.

Wastewater – Activated Sludge Plant (ASP) Aeration

Aeration typically takes 50% of a sewage treatment works energy demand

Description of Process *Aeration is required for secondary treatment to oxidise pollutants, in particular organic matter, measured as biological oxygen demand (BOD), and ammonia. Aeration is supplied by blowers through a series of pipes and diffusers into the mixed liquor in the ASP tank.*

Aeration efficiency is influenced by the following factors:-

- *Blower inlet air conditions,*
- *Blower condition, wear, seal, bearing and lubrication system maintenance,*
- *Control system accuracy, response time, instrument cleaning and calibration,*
- *Air distribution system sizing, pipes, control valves and flow measurement,*
- *Diffuser condition, type, internal cleanliness and size of bubbles,*
- *Depth of aeration tank, and diffuser floor coverage,*
- *Strength of mixed liquors, upstream treatment, homogeneity,*
- *Matching of different components in the system.*

The control system should allow for varying sewage strengths and diurnal flow variations through its variation of and response to instrument settings. It is important for energy efficiency that the parameters and set points match the effluent consent.

Potential Interventions

- *Check blower flow and head against metered electrical input.*
- *Check system pipework, valves and control set-points for best settings.*
- *Change control regime to Real Time Control using incoming flows and loads and the effluent consent by installation or upgrade of PLC controls.*
- *Install ammonia derived DO control (including ammonia and DO instruments).*
- *Install variable speed drives to surface aerators.*
- *Upgrade/replace diffuser grids, aerator paddles.*
- *Replace blower drive belts with non slip belts.*
- *Replace/refurbish blower gear boxes (reduce gear ratios).*
- *Consider blowers with no gearboxes.*
- *Maintain/refurbish air transfer pipework.*
- *Dedicated team to optimize plant performance/deliver efficiencies.*

Range of Potential Savings ***Up to 40% from case studies.***

Case Studies **AU-BW1; AU-SW1; NL-ST7; NL-ST6; UK-UU7; UK-YW3; UK-AW5; UK-DCWW1; UK-ScW3;**

Because of the high proportion of ASP energy demand, blowers and their systems have been the focus of a number of case studies.

The following example also illustrates shows the knock-on effects of reductions in drinking water flows into the waste water sector.

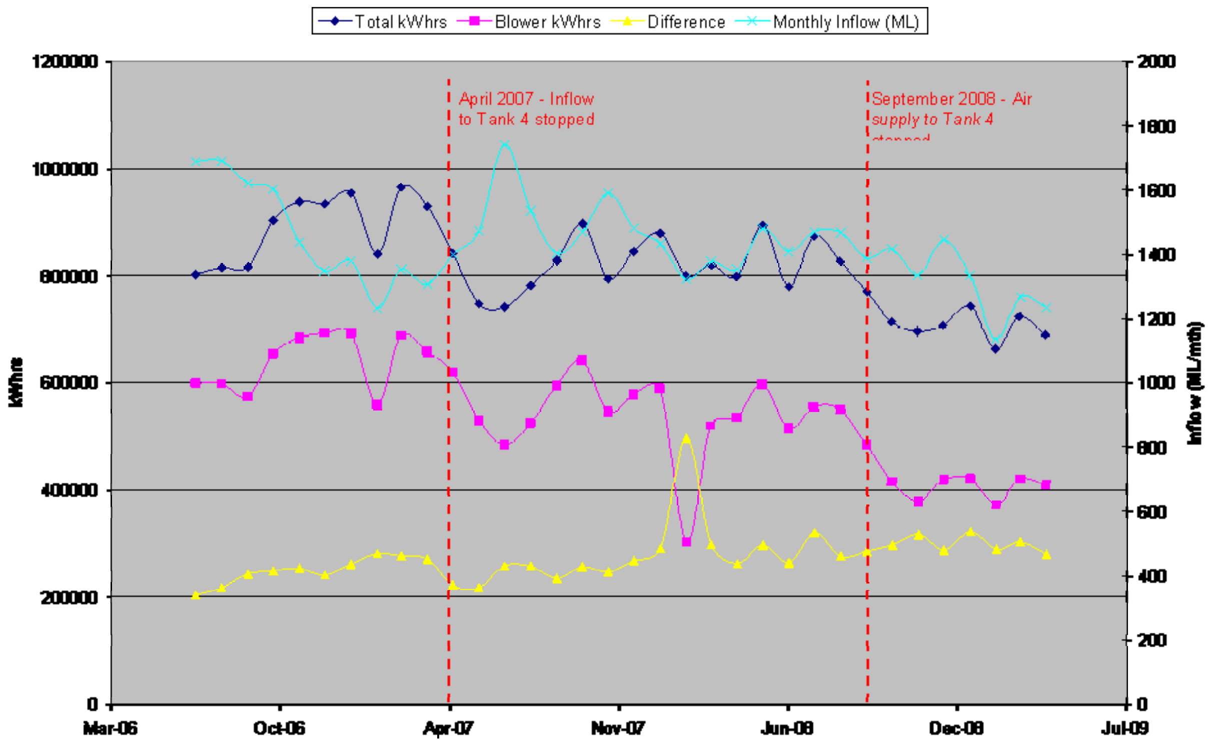
Wastewater Aeration Case Study: AU-BW1 ***Geelong, Australia***

Black Rock WRP energy efficiency investigation

Ref	Enquiry Item	Response information, description and remarks
1	**Location:** Country, urban or rural:	Australia, Geelong (regional)
2	**Sector:** clean, waste or sludge:	Wastewater
3	**Works Owner or Operator:**	Barwon Water, State regulated
4	**Size:**	218,014 Population; 50ML/day
5	**Energy Provider:**	Average electricity use 10,331 MWh per year
6	**Process:** physical, chemical, or biological description:	Intermittently Decanted Extended Aeration (IDEA) sewage treatment process. Screened sewage flows to the selector tanks and mixes with recirculated 'liquor' from the aeration tanks. This 'liquor' is rich in bacteria that digests sewage and aerobic conditions are required to maintain a high digestion rate.
7	**Component:** all or part of the works:	Aeration blowers that supply up to 60000 m^3/hr of air to the treatment tanks.
8	**Specific energy problem:** including quality or consent details:	In November 2006, the drought resulted in the introduction of Stage 4 water restrictions. This coupled with greater water conservation behaviour has resulted in a 20% drop in sewage inflows to the plant over previous years.
9	**Process/Plant changes:** mechanical, electrical or controls:	The three HV-Turbo blowers (750kW each) operate at a constant motor speed with the output controlled by inlet diffusers and outlet vanes which reduce the power draw under reduced flow rates and loads. At least one of the three blowers is constantly running to supply air with a second providing peak airflows as required. This results in a considerable base load, irrespective of sewage inflows. Efficiency and power saving opportunities led to a temporary process rationalisation down to three treatment tanks, resulting in a reduced airflow requirement and resultant power saving from the aeration blowers of 20-23%. This has now been made semi-permanent.
10	**Civil/Physical Changes:** to water / effluent quality, civil works, or process:	No changes have been made to effluent quality due to the implementation of these modifications to the treatment system.
11	**Operational Changes:** skill levels, procedures and maintenance routines:	PLC control changes were necessary to implement tnew aeration regime, including modification of aeration cycles.
12	**Risks and Dependencies:** risk assessment of project and changes.	*No risk matrix was completed for this project.* Although several problems were encountered they were not detrimental to the overall plant operation, and would not necessarily have been highlighted in a risk assessment.
13	**Implementation:** design, build,	Operation of the aeration system required PLC

	procurement, installation and commissioning:	modification to reduce high pressure spikes. There was also a requirement to adjust the timing of aeration cycles to maitain the required 2mg/l dissolved oxygen in the treatment process. Modification to inlet flow using actuated valves also allowed us to better hydraulically balance the plant while running on three tanks.
14	**Energy Efficiency gains:** kWh & kWh/m3	See graphs below. Overall saving of 1,600,000 kWhrs per annum
15	**Cost / Benefit analysis:** financial appraisal or payback time.	In the 08/09 financial year there was an overall saving of approximately A$150,000 in budgeted electricity costs. The payback time for this project is immediate as the cost to implement were in the order of A$25,000.
16	**Project review:** could it be improved or developed?	There are definite improvement possibilities of up to another 15% to be found on the work already done. These improvements have been confirmed via external reviews of the existing system. These additional improvements will however require considerable investment in the order of $3 Million.
17	**Confidence grade:** on data provided.	Data provided is extremely accurate and verified via external billing by service provider and consultants reviews of operating system.

Observations:



Similar case studies identified a number of issues which can cause problems when attempting scientific analysis of works activities.

- The starting point for exercises such as this is not always well recorded,
- It is difficult to evaluate how much of a gain is due to the control change and how much was due to the re-balancing flows through process streams and through the works,
- There may be strong seasonal effects on inflows which will only become evident after at least a year’s data, particularly in tourist areas,
- Weather will exert some influence on waste water works flows and quality performance, especially in monsoon or similar climates where dilution may occur in wet seasons and septicity in hot dry seasons.

It is also possible that close attention to performance in a part of a works, an intervention or control change, could focus cleaning and maintenance activities on instruments, controls and plant so that the system runs more efficiently. This has been noted particularly where operators are actively involved in the discussions and project processes of saving energy.

Wastewater – ASP Nutrient Removal

ASP nutrient removal typically takes 25% of a sewage treatment works energy demand.

Description of Process *Nutrient removal involves nitrogen and phosphorus removal from sewage. Nitrogen removal can be broken down into two phases*

1. *Removal of ammonia using oxygen requires the correct sludge age to ensure that nitrifying bacteria remain in the plant long enough to thrive and carry out the ammonia (NH_3) oxidation to nitrate (NO_3).*
2. *In order to remove nitrate a carbon source, anoxic conditions and denitrifying bacteria are required. The most commonly used carbon source is settled sewage whereby the returned activated sludge and, or mixed liquors are recycled to an anoxic zone upstream of the aeration zone where nitrate (NO_3) to reduced to nitrogen (N_2).*

Phosphorus removal involves precipitating the phosphorus into the sludge. This can be achieved by the addition of metal salts (such as Ferric Sulphate, Ferric Chloride or Aluminium sulphate) or by biological precipitation under anaerobic conditions.

Energy is used in providing oxygen via blowers and can be recovered by using the nitrate as an oxygen source.

It is important to note that as the sewage temperature increases during the summer months, then plants that are not required to nitrify may start to do so. This nitrification will require an increase in the energy consumption of the ASP by up to 100%.

Potential Interventions

- *Ensure that plant operates at the correct sludge age.*
- *Ensure that the mixed liquor solids concentration is maintained at the correct level for the plant.*
- *Optimise anoxic zones and nitrate oxygen to minimise oxygen required for pollutant treatment.*
- *Change control regime to Real Time Control using incoming flows and loads and the effluent consent by installation or upgrade of PLC controls.*
- *Install ammonia derived DO control (including ammonia and DO instruments).*

Range of Potential Savings ***Up to 60% from case studies.***

Case Studies **SG-PUB2; UK-WW3; UK-NW2; NL-ST1; NL-ST3; DK-VE2**

Wastewater Nutrient Removal Case Study: SG-PUB2 ***Singapore***

Reduce aeration energy and infrastructure costs.

Ref	Enquiry Item	Response information, description and remarks
1	**Location:** Country, urban or rural	Singapore, urban
2	**Sector:** clean, waste or sludge	Wastewater
3	**Works Owner or Operator:** with financial set-up, regulatory or not.	Changi Water Reclamation Plant (CWRP), PUB with financial set-up and regulated
4	**Size:** flows and loads or population equivalent	800,000 m^3/d, raw sewage: ~ 500 mg COD l^{-1}
5	**Energy Provider:** with costs, incentives, taxes and conditions	Singapore Energy, S$ 0.16/kWh
6	**Process:** physical, chemical, or biological description	Biological, secondary treatment with nitrogen removal
7	**Component:** all or part of the works	Six-lane activated sludge process with multiple feed points
8	**Specific energy problem:**	Reduce aeration energy and infrastructure costs
9	**Process/Plant changes:** mechanical, electrical or controls	Design and operate the aerobic sludge retention time (SRT) and hydraulic retention time (HRT) based on the conditions in warm climates *i.e*., the sewage temperature is 30±2^{0}C yearly around.
10	**Civil/Physical Changes:** to water/effluent quality, civil works, or process	The aerobic SRT is maintained between 3.0 and 3.5 d and HRT of ~6 h only. The volumetric ratio of the aerobic and anoxic zones is 50%: 50%.
11	**Operational Changes:** skill levels, procedures and maintenance routines	Complete nitrification (NH_4-N< 1 mg l^{-1}) can be achieved easily by controlling the DO in the range between 1.6 and 2 mg l^{-1}.
12	**Risks and Dependencies:** risk assessment of project and changes	
13	**Implementation:** design, build, procurement, installation and commissioning	Started commissioning in the second half of 2008 and under normal operation since the end of 2008.
14	**Energy Efficiency gains:** kWh & kWh/m^3	The average energy for aeration (diffusers): **0.14 kWh/m^3 sewage**.
15	**Cost / Benefit analysis:** financial appraisal	The aeration energy of **0.14 kWh/m^3 sewage** is only about 54% of 0.26 kWh/m^3 sewage, which is the average of the other four plants (mainly using diffusers but surface aerator as well) adopting much longer aerobic SRT (~8 d). The specific aerobic volume is **0.13 m^3/m^3 sewage**, which is only 40% of the average of the other four plants. The overall activated sludge tank volume is about 50% of the average of the other four plants with longer aerobic SRT
16	**Project review:** could it be improved or developed?	Automatic control of the blowers based on the NH_4-N concentration in the final effluent.
17	**Confidence grade:** based on data provided	Highly transportable and adaptable

3.4 Mixers

The science of mixing and the design of mixers of various types is well developed, but energy input may not have been high on the priority list of selection criteria until recently.

In some cases if mixing can be combined with pumping or other hydraulic processes the mixing can involve minimal energy input, particularly when there is excess hydraulic energy in the system.

Water Treatment – Mixing

Description of Process *Mixing could be either hydraulic or mechanical.*

1. *Hydraulic mixers use the turbulence created by head loss through a mixing device to induce mixing, such as a free-fall weir, flume or a 'static mixer' or any other flow restrictor in a pipe. The energy required for hydraulic mixing is derived from the raw water pumps (volume and system curve hydraulic gradient).*
2. *Mechanical mixers rely on the introduction of energy externally by an electric motor.*

Mixers are designed for maximum flow whereas works are usually operated at less than the design flow. Most mixers are designed using empirical relationships or a formula used to design flocculators. The tendency is therefore to overestimate the energy required for mixing.

Potential Interventions *Interventions relate energy demand to the flow.*

1. *Provision of extra energy to a single raw water pump is most efficient (required head related to flow rate). (See also Pumping Factsheet No 1)*
2. *Hydraulic mixers are more energy efficient than mechanical mixers because the energy is supplied by raw water pumps which are more energy efficient than mechanical mixers.*
3. *Accurate mixer sizing supported by CFD modelling to demonstrate mixing efficiency.*
4. *VSDs installed on mixer motors will allow the input of mixing energy to be varied to suit the operating flow. (See also VFD Factsheet No. 5).*

Range of Potential Savings ***up to 20% from experience***

Case Studies **NA-PC1**

The same principles can also be applied in wastewater treatment, e.g. at the inlet to various zones in ASPs, or for dispersing chemicals or recycled flows.

Mixing Case Study: NA-PC1 ***Arizona, USA***

Anaerobic Digester Mixing – Linear Motion Mixers

Ref	Enquiry Item	Response Information, Description and Remarks
1	Location:	Urban
2	Sector: clean, waste or sludge	Wastewater
3	Works Owner or Operator: with financial set-up, regulatory or not	Owner and Operator: Pima County Regional Wastewater Reclamation Department (PCRWRD) Organization set-up: Regulated public agency
4	Size: flows and loads or population equivalent	Permitted Capacity: 142,000 m^3/d (37.5 mgd (US)) Average Daily Flow: 98,000 m^3/d (26 mgd (US)) BOD: 27,000 kg/d (60,000 ppd) TSS: 28,000 kg/d (62,000 ppd)
5	Energy Provider:	Tucson Electric Power Co. US$0.08 - $0.10 per kW*hr
6	Process: physical, chemical, or biological description	Liquid Treatment Process: Primary treatment, secondary treatment, and disinfection.
7	Component: all or part of the works	Preliminary and Primary Treatment – coarse screening, fine screening, grit removal, primary settling. Secondary Treatment – high purity oxygen basins and anoxic/aerobic basins, followed by secondary clarifiers. Tertiary Treatment – hypochlorite disinfection. Solids Processing – Primary sludge thickening via gravity thickeners. WAS thickening via dissolved air flotation. Thickened sludges go to anaerobic digestion, followed by centrifuge thickening.
8	Specific energy problem: including quality or consent details	Four 5,581 m^3 (1.5 mgd (US)) anaerobic digesters were mixed using rotating impeller draft tube mixing requiring a significant input of power. Draft tube system installed power rating was 11.8 W/m^3 (0.45 hp per 1,000 ft^3) of digester volume. The digesters operate at a relatively low volatile solids loading rate of 1.3 to 1.4 kg/d*m^3 (80-90 ppd VS/kcf) and long SRT (20-30 days).
9	Process/Plant changes: mechanical, electrical or controls	Impeller draft tube mixers decommissioned on one of the anaerobic digesters with gas-holder cover. Installed one VLM mixer manufactured by Enersave Fluid Mixer, Inc.
10	Civil/Physical Changes:	No changes.
11	Operational Changes: skill levels, procedures and maintenance routines	Reduced maintenance due to fewer moving parts compared to mechanical draft tubes. All parts requiring regular maintenance are outside the digester.
12	Risks and Dependencies: risk assessment of project and changes	Digester Performance: Performance depends on good mixing to eliminate stratification, ensure biomass contact time, suspend grit, and prevent short circuiting. Mixing depends on the consistency of the fluid and the energy used to move it. The Ina Road WRF operated at low volatile solids loading rates of 1.3 to 1.4 kg/d*m^3 (80-90 ppd VS/kcf), which may require less energy for satisfactory mixing. Typical loading rates are approximately 1.6 kg/d*m^3 (100 ppd-VS/kcf). Higher solids concentration can affect fluid viscosity and thereby mixing efficiency.
13	Implementation: design, build, procurement, installation and	PCRWRD purchased and installed one VLM mixer with installation supervision by the manufacturer. Operations staff performed parallel tracer tests of the VLM-

Ref	Enquiry Item	Response Information, Description and Remarks
	commissioning	mixed digester and one digester with the old draft tube mixers. Computational Fluid Dynamics (CFD) models were run by Enersave Fluid Mixers Inc. to predict mixing, then correlated with the tracer tests to verify the model. Tracer tests and modelling suggested equivalent mixing in both digesters.
14	Energy Efficiency gains: kWh or kWh/m3 before and after implementation	Approximately 90% savings in mixing energy. Draft tubes operate at 54 kW (73 hp) and VLMM operates at 6 kW (8 hp) per digester.
15	Cost/Benefit analysis: financial appraisal or payback time	The VLM mixer cost is $100,000 per digester. This results in a 2.5 year payback, assuming 48 kW (65 hp) reduction in mixer energy use, in-service 95% of the time, and $0.10 /kW*hr electricity rate.
16	Project review: could it be improved or developed?	Replacement of the existing mixers was accomplished with no significant problems. PCRWRD has replaced all digester mixers with VLM mixers because operators were very satisfied with their performance.
17	Confidence grade: on data provided	The fact sheet presented above is based on information published by PCWRD, communications with Ina Road WRF staff, and information supplied by Enersave Fluid Mixers Inc. On a scale of 1 through 5, the confidence grade provided to the information presented is 4.

The Vertical Linear Motion (VLM) mixer is relatively recent technology. It will be interesting to monitor its mechanical performance over its design life and compare its process performance on sludge with higher biosolids or grit content.

Coarse bubble aeration can be used as an alternative means of mixing. Air is provided by compressors or blowers to diffusers on tank or channel inverts so that the rising air induces a convection type current. For wastewater this has the benefits of providing oxygen for aerobic treatment, avoiding septicity and inhibiting the formation of sulphides thus avoiding odour issues.

Aeration is generally considered to be the most energy efficient way of mixing sludge in tanks and digesters although if the process is anaerobic the compressors use the biogas generated from digestion. It avoids any tendency for stratification and sediment, or grit and surface crusts are rapidly homogenised.

For large tanks or digesters the floor plan may be split into zones and each zone mixed for a few minutes in sequence. This reduces the size and energy consumption of the blowers and encourages bulk mixing between zones. For some applications air or gas mixing is sufficiently effective to allow one compressor to be shared between a number of tanks. For others the mixing can be on timer control for, say, 20 minutes per hour.

3.5 Dissolved Air Flotation (DAF) process

Water Treatment - Clarification

Description of Process *Clarification processes remove suspended solids produced by coagulation by either settlement (sedimentation tanks) or as a suspension (floc or sludge blanket tanks) or flotation (dissolved air flotation-DAF). The clarification method used is usually a function of the raw water to be treated. Flocculation which precedes clarification is an important aspect of clarification*

1. *Flocculation is a low energy consuming process and can be either hydraulic or mechanical. Energy input depends on the size of floc required for the clarification process.*
2. *Sludge removal in sedimentation clarifiers is mechanical, in sludge blanket clarifiers hydraulic and in flotation clarifiers either mechanical or hydraulic*
3. *DAF clarifiers require an air injection system which is a high energy consumer and comprises water recycle pumps (8-12% plant flow), compressed air plant and absorbers (packed or unpacked) operating at high pressure.*
4. *Concentration of sludge produced in the clarifiers varies over a wide range depending on the clarifier type and sludge removal method used. The higher the concentration the lower the water loss and smaller the capacity of the sludge treatment plant*
5. *There are proprietary clarifiers with varying complexities and hence energy requirements*

Depending on the raw water quality and suspended solids produced following coagulation, clarification may either be not necessary or could be bypassed at times.

Potential Interventions *Interventions relate energy demand to choice of clarification process and optimisation of the design parameters*

1. *Clarification process should be selected for the water to be treated and should be of a low energy type producing sludge of higher concentration.*
2. *DAF process design parameters such as recycle rate, recycle booster pump type (see Section 3.2.6) and absorber type should be optimised.*

Range of Potential Savings ***Up to 30% from case studies***

Case Studies **UK-YW4; UK-ScW4.**

The DAF process requires the introduction of air with very fine bubble size at high pressure into water. Traditionally air is dissolved in water in separate vessels, then the mixture is pumped into the process tank. As the pressure drops the air comes out of solution as very fine bubbles which attach themselves to floc and bring it to the surface. Most of the techniques described in section 3.2. apply to this pumping plant.

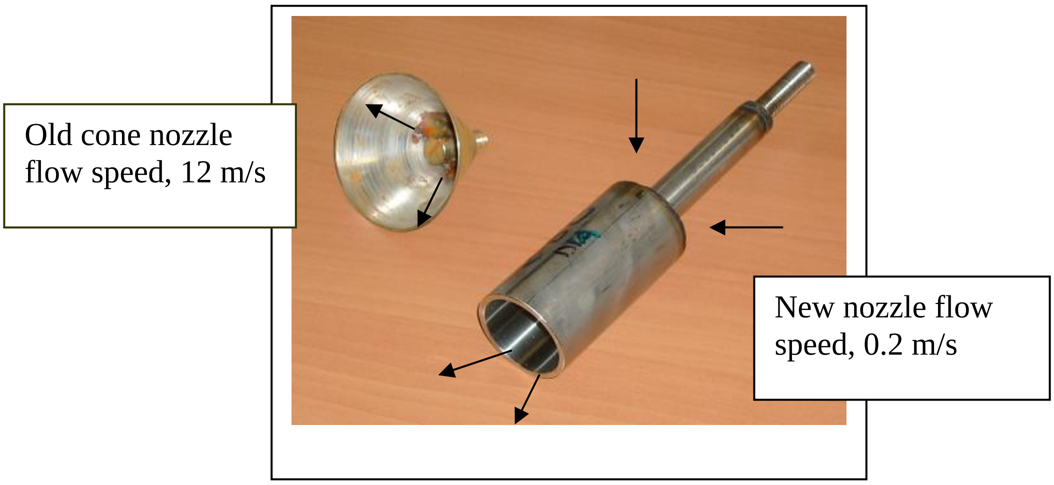
Clarification Case Study: UK-YW4 ***Yorkshire Water, UK***

Replaced nozzles in a DAF plant with more efficient nozzles for better DAF performance at Albert Water Treatment Works.

Ref	Enquiry Item	Response information, description and remarks
1	**Location:** Country, urban or rural:	Urban, UK
2	**Sector:** clean, waste or sludge:	Drinking water
3	**Works Owner or Operator:** with financial set-up, regulatory or not.	Albert WTW, Yorkshire Water
4	**Size:** flows and loads or population equivalent:	Design Capacity: 55 Ml/d Ofwat Category: W3 (More than one stage of complex treatment but excluding processes with very high operating costs)
5	**Energy Provider:** with costs, incentives, taxes and conditions:	nPower
6	**Process:** physical, chemical, or biological description:	DAF plant
7	**Component:** all or part of the works:	Nozzles.
8	**Specific energy problem:** including quality or consent details:	Reduced the absorbed power on the DAF recycle pumps due to more energy efficient nozzles.
9	**Process/Plant changes:** mechanical, electrical or controls:	Refurbishment of plant and replaced all nozzles.
10	**Civil/Physical Changes:** to water / effluent quality, civil works, or process:	Improvement in water quality. Increase in raw water throughput
11	**Operational Changes:** skill levels, procedures and maintenance routines:	None
12	**Risks and Dependencies:** risk assessment of project and changes.	None
13	**Implementation:** design, build, procurement, installation and commissioning:	*Design Principle:* The new nozzle was developed to achieve better post DAF water quality with less nozzle flow. This would allow YW to reduce both the load for later filter process, which is to safeguard final water quality, and also energy consumption for recycling nozzle flow.
14	**Energy Efficiency gains:** kWh & kWh/m3	30% energy reduction 20% increase in raw water throughput
15	**Cost / Benefit analysis:** financial appraisal or payback time.	5 Year Payback
16	**Project review:** could it be improved or developed?	
17	**Confidence grade:**	Good and Auditable

Observation:

The new nozzle design has been installed at Albert WTW. Performance monitoring has now shown that the Works can treat up to 20% more raw water and to a higher standard than previously.



Nozzle flow speed of the old and new nozzles

In addition, due to the improved efficiency of the new nozzles, a lower operating pressure is required and a 30% reduction in energy has been achieved.

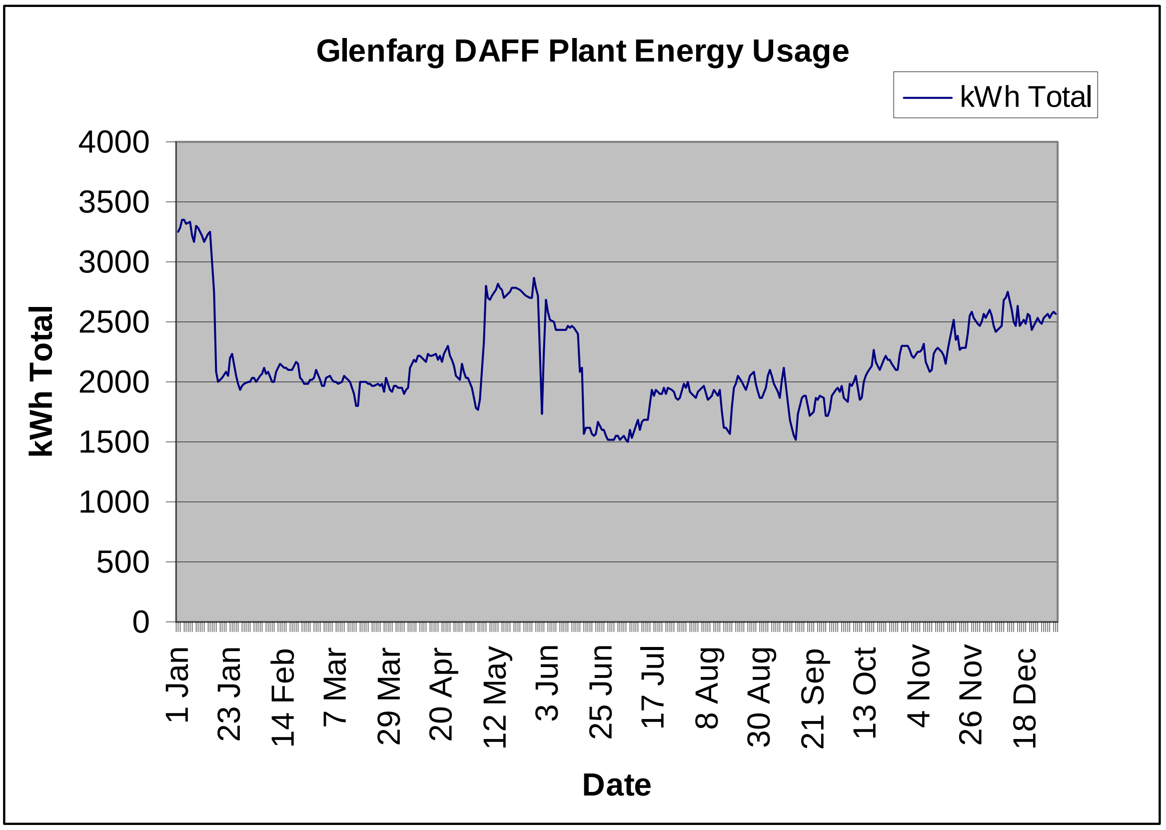
This mode of removing suspended solids is more energy intensive than sedimentation. If the raw water problems that demand DAF are seasonal it may be possible to use the DAF plant only during relevant seasons.

DAF Case Study: UK-ScW4 ***Scottish Water, UK***
Reduce energy usage by bypassing DAF when the raw water quality monitoring shows the DAF plant is not required.

Ref	Enquiry Item	Response information, description and remarks
1	**Location:** Country, urban or rural:	Glenfarg - Scotland
2	**Sector:** clean, waste or sludge:	Drinking water
3	**Works Owner or Operator:** with financial set-up, regulatory or not.	Scottish Water
4	**Size:** flows and loads or population equivalent:	Output from works approx 28 MLD based on typical week taken from telemetry data
5	**Energy Provider:** with costs, incentives, taxes and conditions:	nPower reduced tariff outwith STOD periods
6	**Process:** physical, chemical, or biological description:	Physical, Chemical
7	**Component:** all or part of the works:	DAF plant
8	**Specific energy problem:** including quality or consent details:	Decrease energy use by bypassing an item of process treatment.
9	**Process/Plant changes:** mechanical, electrical or controls:	Implement bypass depending on raw water quality.
10	**Civil/Physical Changes:** to water / effluent quality, civil works, or process:	Use raw water quality monitoring to determine if DAF plant required to treat water to outlet quality.
11	**Operational Changes:** skill levels, procedures and maintenance routines:	

12	**Risks and Dependencies:** risk assessment of project and changes.	Danger of DAF plant being off during adverse conditions
13	**Implementation:** design, build, procurement, installation and commissioning:	N/A
14	**Energy Efficiency gains:** kWh & kWh/m^3	**214445kWh** per annum. **0.021 kWh/m^3** **21.4%**
15	**Cost / Benefit analysis:** financial appraisal or payback time.	N/A
16	**Project review:** could it be improved or developed?	
17	**Confidence grade:** on data provided.	MEDIUM as DAF plant affected by weather/raw water quality

Observation:



3.6 UV Treatment

Ultra-Violet light is used as a mode of disinfection in water and wastewater treatment. For drinking water treatment a disadvantage is that it has no residual capability.

In wastewater UV is used as a finishing process so it is important to:-

- control the UV dose to comply with the effluent consent conditions,
- not use UV as a substitute for poor upstream treatment operations or processes.

Wastewater – Ultra violet (UV) Disinfection

UV disinfection typically accounts for about 10% of a sewage treatment works energy demand.

Description of Process: *UV radiation is used when a sewage works effluent is required to be disinfected to meet a bacteriological standard. The UV radiation is generated in a sealed tube located in a reactor chamber (channels or in pipe) through which the secondary or tertiary treated effluent passes. The UV dose required to achieve a bacteriological quality is influenced by:*

- *The quality of the incoming effluent ('transmission').*
- *The design and arrangement of the lamps.*
- *The cleanliness of the lamps.*
- *The standard to be achieved, this may be seasonal in which case the lamps can be switched off when not required.*

Potential Interventions

- *Only operate the plant when the quality of the effluent is likely to breach standards (for example in the UK only operate during bathing season).*
- *Vary the doing rate with the effluent quantity and quality. This is likely to require more intense effluent monitoring.*
- *Ensure quality of inflow to UV plant is maintained at a high standard to reduce power required by UV lamps.*

Range of Potential Savings ***Up to 40% from case studies.***

Case Studies **UK-WW2**

Wastewater UV Disinfection Case Study: UK-WW2 ***Wessex Water, UK***

New software to control UV operation with flow set points.

Ref	Enquiry Item	Response information, description and remarks
1	**Location:** Country, urban or rural:	Kingston Seymour WWTW England, Rural
2	**Sector:** clean, waste or sludge:	Waste water
3	**Works Owner or Operator:** with financial set-up, regulatory or not.	Wessex Water
4	**Size:** flows and loads or population equivalent:	26,000 m^3/d. Flows of < 300l/s can be accommodated in one channel of a two-channel system. Historic data suggested this occurred 75% of the time.
5	**Energy Provider:** with costs, incentives, taxes and conditions:	EDF; approx £0.08/kWh
6	**Process:** physical, chemical, or biological description:	UV disinfection
7	**Component:** all or part of the works:	UV plant only
8	**Specific energy problem:** including quality or consent	A two channel UV layout did not need to operate all of the time but did not have the facility for upstream isolation.

	details:	Estimated that 40% power saving available 50-75% of the time if flow could be controlled
9	**Process/Plant changes:** mechanical, electrical or controls:	New software to control UV operation with flow set points
10	**Civil/Physical Changes:** to water / effluent quality, civil works, or process:	Two isolation penstocks required plus associated pumps for channel drain down
11	**Operational Changes:** skill levels, procedures and maintenance routines:	No operator skill level required – maintenance procedures likely to be improved due to plant being switched off for longer periods
12	**Risks and Dependencies:** risk assessment of project and changes.	EA consent must be met at all times – control set points likely to be very conservative in the first instance
13	**Implementation:** design, build, procurement, installation and commissioning:	Implemented via sub contractor –cost ~£54,000
14	**Energy Efficiency gains:** kWh & kWh/m^3	Approximately 134,000kWh/year direct energy saving; 0.014 kWh/m^3
15	**Cost / Benefit analysis:** financial appraisal or payback time.	Added saving of £13k/year in extension of lamp replacement schedule. About 2.1 yrs payback at current operating condition.
16	**Project review:** could it be improved or developed?	Possible to alter set points to deliver different levels of saving depending on attitude to compliance risk
17	**Confidence grade:** on data provided.	More accurate data will be available as plant can be measured over a range of operating conditions

3.7 Sludge Thickening and Dewatering

There is a variety of plant and processes for this stage of sludge treatment depending on sludge type, age and origin.

There are other aspects of the sludge thickening processes, such as solids capture, which affect loads imposed back on the effluent treatment processes such as primary sedimentation tanks (PSTs). The balance of sludges drawn off from treatment may also affect thickening as surplus activated sludge (SAS) is usually difficult to thicken or dewater and often needs a centrifuge. Maximising primary sludge draw-off can help sludge handling and maximise digester potential (see section 3.8 below).

Sludge Treatment – Thickening, Dewatering

Thickening, dewatering typically takes 5-10% of a sewage treatment works energy demand.

Description of Process *Thickening and dewatering of sewage sludge requires the removal of water from the sludge.*

Thickening of sewage sludge is achieved by gravity, by centrifugal force in a centrifuge or by filtering through a membrane in a belt or drum.

Dewatering of sewage sludge is by compression of the solid matter in the sludge. This is carried out either by centrifugal force in a centrifuge or by physical force in a press.

The addition of a suitable conditioning agent such as a polymer assists the process. Primary, surplus activated and digested sludges all have different thickening and dewatering characteristics.

Energy is used in the feed pumps, the thickening or dewatering machine, the discharge pumps, the polymer equipment and the liquor treatment plant.

Potential Interventions

- *Consider low energy equipment such as drums, belts or other low energy proprietary equipment.*
- *Mixing required in storage tanks needs careful consideration. Pump mixing usually requires a high energy input relative to other types of mixing.*

Range of Potential Savings ***Up to 60% from case studies.***

Case Studies **NL-ST8; NL-ST9**

Sludge Thickening / Dewatering Case Study: NL-ST8, ***Hapert, Netherland***

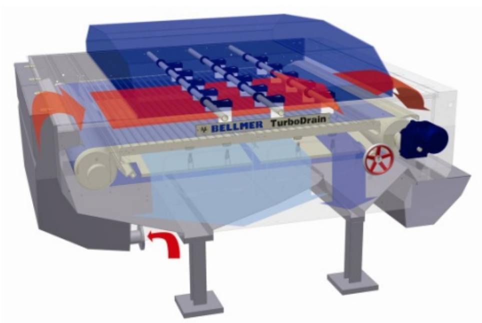
Belt thickening instead of decanters. Belt thickeners have a higher energy efficiency than decanters, resulting in 230,000 kWh/y energy savings.

Ref	Enquiry Item	Response information, description and remarks
1	**Location:**	*NL, urban*
2	**Sector:** clean, waste or sludge:	*Wastewater, sludge*
3	**Works Owner or Operator:**	*WWTP Hapert. Waterboard De Dommel*
4	**Size:**	*71.000 p.e.; 14.500 m^3/d; 1.000 ton SS/y*
5	**Energy Provider:**	-
6	**Process:** physical, chemical, or biological description:	*Replacement of decanter by belt thickener in sludge thickening process*
7	**Component:**	*Belt thickener in sludge treatment process*
8	**Specific energy problem:**	*Higher energy efficiency of belt thickener than decanters*
9	**Process/Plant changes:**	*See 6*
10	**Civil/Physical Changes:**	*Improvement of thickening at lower energy demand*
11	**Operational Changes:**	-
12	**Risks and Dependencies:**	*Experience at other WWTPs that thickening results may get worse. (See also Observations)*
13	**Implementation:**	*Two decanter replaced by two belt thickeners*
14	**Energy Efficiency gains:** kWh & kWh/m3	*Improvement energy demand of thickening from 250 to approx. 100 kWh/ton SS; 230.000 kWh/y*
15	**Cost / Benefit analysis:**	*Investments: 223.000 euro;*
16	**Project review:**	-
17	**Confidence grade:**	-

Observations

Compiled by Eef Leeuw and Cora Uijterlinde (STOWA)

The WWTP Hapert is an activated sludge plant with a capacity of 71.000 p.e. Sludge thickening has been carried by two decanters. Both decanters were replaced by belt thickeners.



The following results were achieved:

		Decanter	*Belt thickener*	
Thickened sludge	*Ton* *% SS* *ton SS.*	*19.811* *4,8* *961*	*16.289* *6,0* *980*	
Energy demand	*kWh*	*246.121*	*94.617*	
Spec. Energy demand	*kWh/ton SS*	*256*	*97*	*62%*

Sludge thickening by belt thickeners appeared to be more energy efficient than decanters. Also the thickening results improved.

Decanters at the WWTP Haaren were also replaced by belt thickeners. At this location the improvement of the energy efficiency appeared to be approximately equal as at the WWTP Hapert, however, thickening results were worse (6,9 to 5,3 %SS).
Therefore it can be concluded that although belt thickener are more energy efficient than decanters, equal thickening results might not be guaranteed.

3.8 Sludge Digestion

This section applies to wastewater sludges which are digested anaerobically to produce methane as a component of sludge gas which is used as a renewable, non-fossil fuel.

Sludge Treatment – Digestion

Digestion including gas handling typically takes 10-15% of a sewage treatment works energy demand and may be able to generate up to 100% of the sewage treatment works energy demand.

Description of Process *Sludge digestion is used to convert organic matter in sewage sludge to produce biogas and to reduce the odour from the sludge.*
Traditionally digestion has been carried out at mesophilic (32^{o}C to 38^{o}C) temperatures in the absence of oxygen and known as mesophilic anaerobic digestion (MAD). The sludge is pumped to a mixed reactor tank and heated to the required temperature where it is retained for a period of 15 days or more. Gas is collected and used to heat the tank and produce electricity in a combine heat and power (CHP) plant.

There are many methods of influencing the amount of energy produced from the MAD process as shown below:

- *Varying the type of sludge fed to the reactors (primary/surplus activated sludge mix).*
- *Varying the retention time in the digester.*
- *Adding a pre-treatment technology that allows the sludge to be more readily digested. These can include physical or thermal treatment.*
- *Increasing the digestion temperature either within the mesophilic range or up to the thermophilic range (55^{o}C).*

Potential Interventions

- *Maximise the primary sludge content of the feed to digestion.*
- *Optimise the retention time in the digester to generate maximum biogas.*
- *Consider low energy mixing technologies.*
- *Careful design of mixing system based on sludge rheology.*
- *Consider advanced digestion technologies.*
- *Ensure ancillary plant such as feed, pumps, gas holders and engines is matched to the digester size so that the maximum potential of the sludge is used to generate gas and the gas is used to produce power.*

Case Studies **AU-BCC1; AU-SEW2; SG-PUB4; UK-YW2; NL-ST5; SG-PUB6; HU-VE4; NA-CM1**

Balancing the effluent treatment processes to achieve more primary sludge should be an incremental change to operational procedures or controls. Controlling digester temperatures and mixing regimes (see section 3.4) should be informed by Hazard Analysis Critical Control Point (HACCP) requirements, but enhanced treatment of sludges is a major investment in terms of capital and operational expenditure.

Sludge digestion technology is proven and not difficult but the engineering must be robust or it will incur significant operational and maintenance costs. The outcome of sludge gas affords the industry its major opportunity to generate renewable energy within the water cycle through Combined Heat and Power (CHP) packages. Usually there are uses for both electricity and heat on most wastewater works so the technology ticks all the sustainability boxes. See also section 3.10.4.

Sludge Digestion Case Study: UK-YW2 ***Yorkshire Water, UK***

Installation of larger feed pumps and macerator to ensure consistent digester feed. This enables increased sludge throughput by allowing additional imports of sludge to site, which reduces tankering costs, and increases biogas production.

Ref	Enquiry Item	Response information, description and remarks
1	**Location:** Country, urban or rural:	Bridlington (Urban)
2	**Sector:** clean, waste or sludge:	Sludge
3	**Works Owner or Operator:**	Yorkshire Water
4	**Size:**	PE 37,375 (resident) + summer holiday PE 12,129
5	**Energy Provider:**	CE Electric
6	**Process:**	Improved Anaerobic Digestion
7	**Component:**	Sludge Digestion
8	**Specific energy problem:** including quality or consent details:	Lack of biogas production due to interruption of sludge feed to digesters caused by blockages.
9	**Process/Plant changes:** mechanical, electrical or controls:	The digester feed pumps were very small bore – and regularly blocked with screenings. This meant that the site was not always able to reliably manage indigenous sludge stocks, and so only limited imports of sludge were made – reducing the amount of biogas produced. Fitting a macerator and increasing the pump bore has enabled digester feed to be run without blockages, enabling up to two extra tanker loads of sludge to be accepted each day.
10	**Civil/Physical Changes:**	n/a
11	**Operational Changes:**	Change to tankering routes
12	**Risks and Dependencies:**.	n/a
13	**Implementation:**	Very simple – direct procure
14	**Energy Efficiency gains:**	Approx £32k/year extra energy generation benefit.
15	**Cost / Benefit analysis:** financial appraisal or payback time.	Payback – 5 months. This includes the above energy saving and an £8k reduction in tankering costs
16	**Project review:** could it be improved or developed?	Review all digester feed arrangements and barriers to optimising sludge tankered imports.
17	**Confidence grade:** on data provided.	90% - solution has been implemented for less than 1 month, but the benefits are already being seen.

Observations:
Bridlington - Energy Generation has increased by approx 60kW since we replaced the pumps, enabling import. We're bringing two extra tankers a day to site. The extra generation is in line with what we'd expect from processing extra sludge volumes.

3.9 Sludge Drying

The cost of disposal of sewage sludge is dependent on the catchment served and environmental considerations. If the catchment has intensive industry there is a chance of heavy metallic compounds which will restrict the potential for recycling sludge to land. In some areas where industrial outputs have been cleaned up this option is becoming available. Sludge drying allows land disposal without odour and with much reduced risk of increasing run-off into water courses from farmland, even in wet weather. However, drying sludge is energy intensive.

Factsheet – Sludge treatment – Drying

Drying thickened and dewatered sludge usually requires combustion-level temperatures and hence a fuel, either biogas from digestion or natural gas from the grid.

Description of Process *Sludge thickening can attain between 4 and 8% dry solids (DS) content; dewatering is used when 20 to 25% is required. For most applications to land drying is used to attain better than 45%DS.*
Sludge drying was historically done in large shallow beds with long retention times and intensive handling issues. Few large works have sufficient land available for this method and the cost of covering and odour control would be high. More compact but energy intensive heated dryers are now the norm.
Thickened and dewatered sludge is conveyed at a controlled rate through a heated chamber to achieve the required DS content. If the rate is too fast the sludge will be too wet; if is too slow the sludge can dry to a point where the dust and fibres can burn in the hot atmosphere if sufficient oxygen is available. Drying should be in a post-combustion atmosphere, i.e. with a low oxygen level to avoid sludge combustion.
Sludge handling and dryer design is complex and is usually the subject of a packaged plant or stand-alone contract. Operation is at least semi-automatic to reduce any safety risks and operators need plant-specific training. Dried sludge dust is also a problem with the consequent explosion risk.

Potential Interventions: *Thicken and dewater sludge to the highest DS content practical to reduce drying energy demand.*

- *Monitor sludge condition to optimise process control,*
- *Pre-heat sludge using waste heat from on-site processes,*
- *Burn biogas in dryer to minimise the impact of siloxanes etc.*
- *If sludge is incinerated the combustion heat can be used for drying the sludge feed or pre-heating combustion air.*

Range of Potential Savings: *Insufficient experience to generalise; depends on sludge characteristics, process equipment and eventual sludge disposal route.*

Case Studies **SGPUB5; FR SE1**

Sludge Drying Case Study: FR-SE1 ***Suez, France***

Upgrading a wastewater treatment plant with advanced processes to achieve new, strict water quality regulations and save energy may seem paradoxical, but a project in France, illustrates how these facilities can improve their overall energy balance by using sludge and other organic waste as fuel in the process.

Ref	Enquiry Item	Response information, description and remarks
1	**Location:**	France, urban.
2	**Sector:** clean, waste or sludge:	Sludge
3	**Works Owner or Operator:** with financial set-up, regulatory or not.	Lyonnaise des Eaux (Group Suez Environnement) is a private utility company responsible for the supply and treatment of sewage in the municipality.
4	**Size:** flows and loads or population equivalent:	The plant has a capacity of 400 000 population equivalent. It is able to handle annually: -26 000 000 m3 of waste water -8 300 tons of volatile matter -2 100 tons of reduced nitrogen -585 tons of phosphorus
5	**Energy Provider:** with costs, incentives, taxes and conditions:	Natural gas from the National provider. (Costs in 2009: 2-4c€/kWh)
6	**Process:** physical, chemical, or biological description:	Sludge is first gravitationally thickened, then mechanically dewatered using a centrifugal device. Then one fraction of the total sludge is thermally dried in a belt drier. Finally, a mixture of the dewatered and dried sludge is formed to be combusted in a fluidized bed.
7	**Component:** all or part of the works:	Thermal drier and fluidised bed combustors are arranged in a such a way that combustion exhaust gases are allowed to pre-heat the combustion air and dry the sludge adding only few amounts of external fuel.
8	**Specific energy problem:**	High energy consumption for the thermal drying of sewage sludge.
9	**Process/Plant changes:** mechanical, electrical or controls:	Combining heat excess from the sludge combustion and heat demand for the sludge thermal drying.
10	**Civil/Physical Changes:** to water / effluent quality, civil works, or process:	A new thermal dryer was put into the system using a heat exchanger allowing the heat recovery from the exhaust gases in a liquid thermal oil. A pre-mixing of fully dried and dewatered sewage sludge is required before combustion in order to reach auto-thermal conditions.
11	**Operational Changes:** skill levels, procedures and maintenance routines:	Combustion and Thermal drying are operations requiring specific skills which are different to those that are normally found in WWTP operators.
12	**Risks and Dependencies:** risk assessment of project and changes.	Although the system was designed to take advantage of the thermal integration of the thermal drying and combustion, these two operations may also operate separately if one of the two stops for maintenance or failure. Indeed, the sludge can be totally dried and stored if the combustor is stopped, on the one hand. On the other hand, the combustor can be operated using only dewatered sludge during the maintenance of the dryer.
13	**Implementation:** design, build, procurement, installation and commissioning:	The solution was designed and built by the thermal dryer manufacturer with a close collaboration of the utility company which verified the quality requirements during the commissioning stage.
14	**Energy Efficiency gains:** kWh & kWh/m^3	The sludge processing avoids completely the diesel consumption and significantly reduced gas thanks to the use of sludge as a fuel. (Fossil fuels consumption per ton of dry solids used to be ranged between 1 000 to 2 000kWh. Implementing heat recovery from the sludge combustion for

		the thermal drying has dropped this number to 200-250 kWh).
15	**Cost / Benefit analysis:**	
16	**Project review:** could it be improved or developed?	Implementing more advanced low temperature thermal energy recovery strategies may increase the net gain of energy from sludge combustion.
17	**Confidence grade:**	Good.

Compiled by Carlos Peregrina (SE) based on information from Large et al. (SE) Road to energy self-sustainability, World Water and Environmental Engineering, May June 2009, pages 33-34.

For observations on this case study see the Appendices.

3.10 Building Services

In this context, only buildings intended for functional use by the utility (eg. offices, maintenance buildings, plant buildings and site services) are discussed.

For electrical load reviews, bills or invoices are inadequate and accurate information is essential including: voltage, power, power factor and the time period over which demand varies including tariff bands. This data can help analyse the demand source and enable it to be managed. For heat loading reviews the above is a starter but techniques such as thermal imaging can be useful to show sources and “leaks” of wasted energy.

In addition to the interventions mentioned below, new and refurbished building designs should include:-

- Thermal insulation and building materials to minimize heat transfer (in and out),
- Maximize natural light to minimise lighting loads,
- Optimize ventilation to maximize air changes and natural convection,
- Alternative water sources: rain water harvesting, recycling and grey water reuse, on-site treatment.

Building Services

Description of Process *Efficient use of building services results from both more efficient equipment and waste reduction by employees (education and training). Energy is used in buildings for lighting, air conditioning and ventilation, including equipment ventilation and cooling, communications and IT systems, security systems and for providing staff facilities; water supply and effluent removal, catering, elevators, etc.*

Energy efficiency measures can be retrofitted into existing buildings, however a full cost benefit analysis will determine the optimum extent and timing for interventions. New build offices and plant buildings can be designed for and fitted with current energy efficient equipment.

Potential Interventions *Energy efficiency measures should be designed to reduce the demand for energy and other utility services without compromising working conditions. Interventions that can be retrofitted into existing structures include:*

- *Lighting:*
  - *Low energy light units and efficient dispersion light fittings.*
  - *Sensor control light switches.*
  - *Sensors and low voltage equipment for security lighting*
- *Heating and ventilation*
  - *Maximize use of natural ventilation; restrict air conditioning to permanently occupied rooms.*
  - *Raise working space temperature, minimize air conditioning usage,*
  - *Install natural ventilation for rooms housing heat generating equipment.*
- *Office equipment, IT and communications*
  - *Switch off all non essential equipment out of working hours (**off** not **on standby**)*
  - *Time switches on supplies to copiers, printers, vending machines).*
- *Water supply and sewerage*
  - *Base load pumping to "roof" storage (if not fed by gravity*
  - *Low capacity toilet flush cisterns and supplies to urinals*
  - *Tap aerators*
  - *Time switches on water heaters and cooling equipment. On demand equipment rather than storage.*
- *Energy generation*
  - *Solar panels for energy and heating*
  - *Wind*
  - *Heat pumps*

In addition to the above, new buildings can be designed to include:

- *Thermal insulation building materials to minimize heat transfer (in and out).*
- *Maximize natural light.*
- *Optimize ventilation to maximize air changes and natural convection*
- *Alternative sources: rain water harvesting, recycling and grey water reuse, on-site treatment.*

Case Studies **AU-SW2; UK-AW3**

Building Services Cast Study: AU-SW2 *Sydney, Australia*

Our new head office at One Smith Street, Parramatta (built and owned by Brookfield Multiplex) features water and energy efficiency and recycling. The building is forecasted to perform to 5 star NABERS.

Ref	Enquiry Item	Response information, description and remarks
1	**Location:** Country, urban or rural:	Australia, urban Temperate Zone
2	**Sector:** clean, waste or sludge:	Water Administration (Head Office)
3	**Works Owner or Operator:**	Sydney Water - Lease holder
4	**Size:**	About 1400 staff
5	**Energy Provider:**	N/A
6	**Process:**	N/A
7	**Component:** all or part of the works:	Our new head office at One Smith Street, Parramatta (built and owned by Brookfield Multiplex) features water and energy efficiency and recycling. The building is forecasted to perform to 5 star NABERS. The building is designed to reduce carbon emissions by about 30% and use at least 75% less drinking water than an equivalent commercial office building. Using less water reduces the flow of wastewater to the sewerage system by up to 90%.
8	**Specific energy problem:**	N/A
9	**Process/Plant changes:**	N/A
10	**Civil/Physical Changes:**	N/A
11	**Operational Changes:**	N/A
12	**Risks and Dependencies:**	N/A
13	**Implementation:** design, build, procurement, installation and commissioning:	• An onsite wastewater recycling plant provides recycled water for toilet flushing, cooling towers, fire system testing and irrigation. • A 100,000 litre rainwater tank provides additional water for toilets and cooling towers. • Solar heating panels supplement hot water requirements. • A high performance glass façade controls the amount of heat entering the building. It also ensures there is plenty of natural light. • Where possible, construction materials were made from renewable sources or high recycled content, and were produced with minimal greenhouse gas production and ozone depletion. • Chilled beam cooling is used in the building instead of conventional air conditioning. Chilled beams work through the introduction of chilled water through cooling elements in the ceiling. • Rising warm air is cooled by the chilled beams and then descends, due to natural convection. • There is improved air quality in the building as fresh air is continually provided and removed without being recycled. This significantly improves the office work environment and reduces the risk of ‘sick building’ syndrome. • There is state of the art water conservation

		including water efficient toilets, showers and taps. A building management system monitors water and energy use to minimise leaks and waste. • The building is located next to a major public transport interchange and has showers, bike racks and other facilities to encourage staff to commute in healthier, more sustainable ways. • The building is designed to encourage teamwork and break down organisational boundaries. It has a generous façade and public access areas.
14	**Energy Efficiency gains:** kWh & kWh/m3	Old Office Annual KWh/NLA (m^2): 46 New Office Annual KWh/NLA (m^2): 14.5 (Forecast). The new head office is expected to use over 60% less energy then the old head office.
15	**Cost / Benefit analysis:**	N/A
16	**Project review:**	N/A
17	**Confidence grade:** on data provided.	Medium – Data for the new office is forecasted for the year.

Feedback from the water industry indicates that the potential of proprietary “plug in” electrical energy efficiency devices to achieve their advertised savings seems to be limited to building services supplies where their capabilities are afforded some flexibility. In a plant power supply situation, e.g. to a pump, where power in is proportional to power out, such devices may show advantages in some parameters but will show losses on others. For significant sizes of electrical plant attention should be paid to power factor, voltage and current monitoring and specific equipment should be sought for correction.

3.11 Renewable Energy

In order to balance the energy inputs and outputs from water industry related activities various applications of renewable energy are being considered. Some, such as sludge gas CHP are proven technologies. Others require development. This section covers only those aspects relevant to regulated businesses and the generation or recovery of energy as a bi-product of water and wastewater process streams.

One difficulty with using renewable energy is that its availability rarely matches demand on a water or wastewater installation. Power demands are usually concentrated in fairly large centres whereas renewable sources are diffuse and there are always periods when they are not available. Grid connections are essential for most applications and energy storage therefore becomes an important issue and here technology requires major development to be feasible at any scale. An exception may be using combinations of small scale wind and solar energy to charge Uninterruptible Power Supplies (UPSs) which may be beneficial for remote small power application such as instruments.

3.11.1 Hydro generation

Where water or wastewater systems have excess head available, devices such as flow restrictors, vortex drop shafts, pressure reducing valves and control valves could be reviewed for possible replacement with hydro turbines. These devices are the reverse of pumps and so they need hydraulic, mechanical, electrical and control consideration.

Energy Recovery – Mini Hydro Turbines

Description of Process : *In-pipe hydro generation can be installed in locations where there is excess hydraulic head that would otherwise need to be dissipated using for example, pressure-reducing valves, break pressure tanks or pipe constrictions to convert the surplus energy into electricity. Typical applications include:*

- *Inlet to water treatment works; the flow rate being related to works output.*
- *In trunk and transfer mains with relatively consistent flow rate.*
- *Linked to district metering as part of an ALC strategy where otherwise a PRV would be installed (see Water supply – Leakage reduction) and where the flow rate is demand driven.*
- *Inlet to waste treatment works (eg hydro generator Archimedean screw).*

The design needs to take into account:

- *Variable flow rates (diurnal and seasonal) and the required pressure reduction.*
- *Available head and the required downstream minimum head for operational or level of service requirements*
- *Managing transient pressures*

Potential Interventions: *Mini hydro turbines are suitable both for retrofitting in locations of an existing pressure reduction facilities and at new locations where head is to be dissipated.*

Range of Potential Savings: *Annual generation between 1,000 MWh and 12,000 MWh.*

Case Studies: **UK-SWW2; UK-ScW1; AU-MW3; AU-SEW1; AU-SAW2; UKYW1; FR-VE1; FR-VE3; NA- CSD1**

Financial incentives are often available but these issues are complex, outside the remit of this report and should be reviewed separately. If energy is generated from flows which have been pumped, incentives may not apply and the energy cost gains should stand alone as justification.

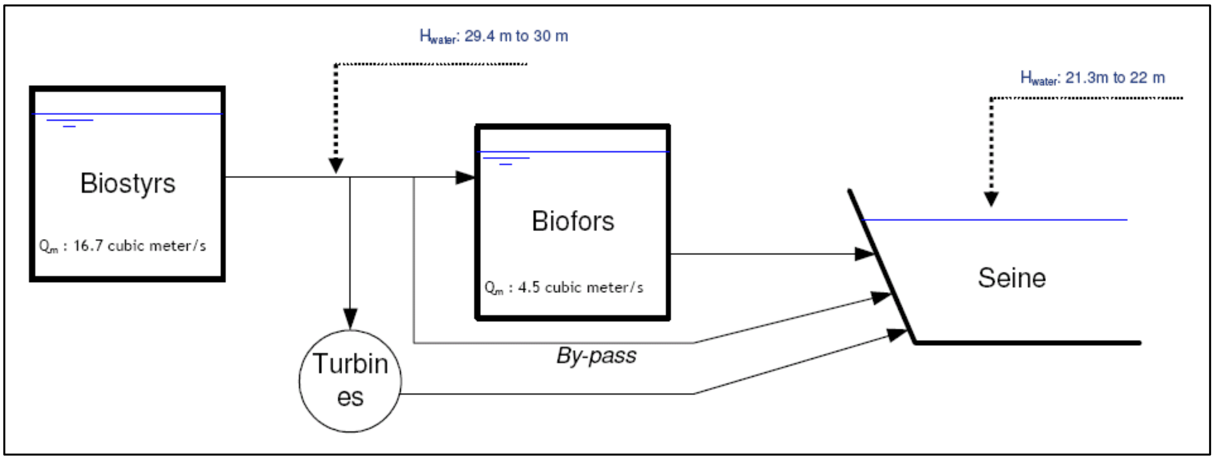
Drinking water applications usually have no media handling issues and final effluent wastewater applications are comparable. Archimedean screws can be used on some raw effluents or river water as these will handle most solids without blockages, however these pumps/generators are large and will therefore be relatively expensive. Recovering energy from low head high flow applications will also require large equipment to handle the flows without excessive hydraulic losses so these too will be costly.

Energy recovery – Mini Hydro Turbines Case Study: FR-VE3 ***Veolia Water, France***

Installation of 2 low heads micro-turbines to recover potential energy

Ref	Enquiry Item	Response information, description and remarks
1	**Location:**	France, Parisian Suburbs (Urban area)
2	**Sector:** clean, waste or sludge:	Wastewater (Seine Aval WWTP)
3	**Works Owner or Operator:**	Work owner & operator : SIAAP (Syndicat

	with financial set-up, regulatory or not.	Interdépartemental pour l'Assainissement de l'Agglomération Parisienne) Micro-turbines contractor : Veolia Water Solutions & Technologies
4	**Size:**	2.10^6 m^3 influent /day
5	**Energy Provider:** with costs, incentives, taxes and conditions:	EDF (Electricité de France) No incentive
6	**Process:**	Microturbines on nitrified WWTP effluent
7	**Component:** all or part of the works:	2 micro hydropower plants, each including 1 Kaplan turbine (installed power: 417 kW, average flow rate: 4 m^3/s, efficiency= 87%), 1 asynchronous generator + condenser battery
8	**Specific energy problem:** including quality or consent details:	The Biostyrs^{TM} hydraulic design at the nitrification plant was determined so as to allow gravitational supply of the downstream Biofors^{TM}, whereas only ¼ of the water needs to be treated by this unit, and discharge of the wastewater into the Seine occurs without pumping. Microturbines allow the conversion of the hydraulic potential energy loss resulting from this hydraulic design (8 meters) into electrical energy
9	**Process/Plant changes:**	Not process related
10	**Civil/Physical Changes:**	Installation of two micro hydropower plants
11	**Operational Changes:** skill levels, procedures and maintenance routines:	Use control systems to guarantee stability during turbine operation by active control (use of a hydraulic actuator and a regulator to optimize inlet flow); in this way, vibration phenomena are controlled (radial vibrations inside water pipes, mechanical vibrations, cavitation noise, etc.); Careful maintenance (otherwise : quick wear, drop in efficiency, erosion of materials, noise) Avoid runaway speed by using security instruments : guard gates, ball valves (Otherwise: mechanical damage).
12	**Risks and Dependencies:** risk assessment of project and changes.	No risk on process. Strong regulation on micro turbine operating conditions (minimum and maximum flows) are necessary to avoid turbine cavitation.
13	**Implementation:**	-
14	**Energy Efficiency gains:**	6 GWh/year of electricity gained
15	**Cost / Benefit analysis:**	Undisclosed due to confidentiality issues
16	**Project review:**	-
17	**Confidence grade:** on data provided.	High technical and economical confidence on project repeatability.



The economics of hydro turbines are not as simple as removing a flow control device and substituting a turbine. The electrical power connection, cabling, instrumentation and controls will have a significant impact on the cost. The benefits are uncertain because of future electricity price trends but a reasonable discount should be used for a mid-design life term of operation, say ten years.

3.11.2 Wind turbines

These devices will not be part of the regulated water businesses and so will be limited in their application to most sites and water companies. Their requirements include site space and wind resource availability, positive local planning and public attitudes, local grid connection availability and a suitable financial and business model for capital and operational expense. Small scale turbines are not usually cost-effective and will have an extended payback for units below about 1.5MW rating. There is a particular issue with matching wind resource availability with water industry energy demand and, since large scale energy storage is difficult, connection to a grid is usually the preferred mode of generation.

From the above it is evident that location is a major issue and some sites close to cities, airports and wildlife/nature reserves may not be suitable for wind turbine development. Where opportunities do exist, it is generally advisable to engage a reputable developer as the technology is commercially mature with services and equipment available on the Global market. For this reason we have not included a factsheet for this technology. One potential application also mentioned below follows the commercial availability of combined wind and solar PV generators. These small scale devices can be used for low power requirements such as instruments in places remote from power supplies.

Wind Power Case Study: NA- CWD1 ***Cleveland Water Division, NA***

Improvements in Energy Efficiency Through Personnel and Operational Changes, and Use of Wind Power

Ref	Enquiry Item	Response information, description and remarks
1	**Location:**	USA, Midwest, urban, large system
2	**Sector:**	Drinking Water

3	**[Utility] Works Owner or Operator:**	City of Cleveland, OH Cleveland Water Division (CWD)
4	**Size:** flows and loads or population equivalent:	The four treatment plants combined can produce over 540 MGD of treated water.
5	**Energy Provider:** with costs, incentives, taxes and conditions:	Cleveland Public Power; Cleveland Electric Illuminating; Ohio Edison
6	**Process:**	All projects involve physical processes.
7	**Component:** all or part of the works:	Optimizing the water system's operations involve all the works from raw water intake to the distribution system pumping facilities. Constructing wind turbines to create a new energy source involves part of the works – pertaining to the raw water intake structure. Running the treatment plant backwash pumps and air scour blowers at off-peak energy demand times involves part of the works. The impacts are on the pumping capabilities of the CWD system only.
8	**Specific energy problem:** including quality or consent details:	CWD realized that not all operations were carried out in a consistent fashion. The lack of consistent optimization in operations led CWD to believe that training in optimization would lead to the full utilization of CWD's infrastructure to its most efficient state. CWD needed power at the end of the intake crib that stretches out into Lake Erie to supply the raw water intake pumps. Running an electrical line for several miles out into the lake would be an expensive project. CWD teamed with Cleveland Public Power to create an operational schedule where the WTP could perform the treatment plant functions with a lower energy rate than CWD previously had used. The cost of peak demand time power was high compared to the cost of electricity in off-peak periods. CWD believed that it could trim the electrical costs of operating pumps and pumping stations by switching to high efficiency pumps and motors and carefully selecting specific pumps for specific hydraulic conditions.
9	**Process/Plant changes:** mechanical, electrical or controls:	Operations optimization creates process related changes as CWD has embarked on a multiple-year training process that will teach all operators to understand and adhere to the SOPs for facility operation. Installing a wind turbine to generate power for intake pumping facilities has process, mechanical, and electrical control changes. Operational changes were made to switch the routine backwash sequences from the day shift to the night shift when the cost per kW/hr of power is less expensive. CWD amended its construction standards and specifications to include language that requires all new pumps and pumping stations to be energy efficient. Where possible, multiple small pumps are specified to take the place of one large pump, or single speed motors are replaced with variable frequency drive motors given the appropriate operating conditions.

10	**Civil/Physical Changes:** to water / effluent quality, civil works, or process:	No significant physical changes are anticipated as a result of energy operation optimization. No changes are anticipated to the water or the downstream infrastructure as a result of switching power sources from the electrical grid supplied electricity to the wind power. Switching the timing of the routine operational practices has had no adverse impacts on the water quality. No significant physical or chemical changes are associated with the construction standard changes.
11	**Operational Changes:** skill levels, procedures and maintenance routines:	Operators will need to learn how the facility operations fit into the large, overall energy management scheme. That is, forethought and planning must be placed into the timing of routine tasks such as backwashing a filter so that its energy use fits into the overall management plan. Operators will need to learn how to operate the wind turbine system and make it compatible with the CWD SCADA system. Additional reliance is placed on the night shift operators to perform tasks that have been traditionally viewed as day shift operations, though night staff have always performed these tasks to some degree. Operators need to learn how to operate and perform routine maintenance on the VFD motors.
12	**Risks and Dependencies:** risk assessment of project and changes.	CWD is cautious that the significant amount of training implemented may not have the desired results of changed “thinking” or “operational behaviour.” All operators must “buy into” these new standard operation procedures (SOPs) compiled into the overlay program for optimizing performance in order to save power. CWD will need to incorporate certain safety SOP features once the wind turbine is constructed. No significant risk factors are created by switching to off-peak power consumption as all the WTP operators are trained in all facets of the plant operational processes. Filters can still be backwashed if needed during the day shift. No significant risk factors involved with switching to high efficiency pumps and motors.
13	**Implementation:** design, build, procurement, installation and commissioning:	The software manufacturer was selected by a bid process. In-house time and labor were used for developing the SOPs that fed into the proprietary software platform. The 60-meter tower was constructed with a weather monitoring station only. Construction of additional towers with wind turbines could be 5-10 additional years out due to capital financing. CWD may revise the utility’s SOP’s to create a unified approach to routine maintenance practices. The new construction standards apply to all traditional bid, design-build, and CWD procurement forms of construction contracts.
14	**Energy Efficiency gains:** kWh & kWh/m3 before and after implementation	Developing an alternate source of power in itself does not achieve any kW/hr savings as much as it allows the utility to use less expensive, more renewable and reliable sources of power.

		The purchasing of off-peak power from the power utility saves the utility money spent on energy directly, not the amount of energy consumed.
15	**Cost / Benefit analysis:** financial appraisal or payback time.	Preliminary estimates by CWD project utility savings between 10-15% of its current energy expenses when the training has been completed with all the operations staff and the proprietary software program is fully implemented. The cost to construct one 5-Megawatt capacity wind turbine is $80 million (2009 dollars). Neither the potential energy savings from not buying power from Cleveland Public Power nor the payback schedule on the investment have been determined. CWD estimates that the payback time for replacing the inefficient pumps and motors could be over 20 years. The energy cost savings could be as much as $10 million over 5 years.
16	**Project review:** could it be improved or developed?	Operations staff refine and improve the SOPs based on new operational and financial energy rate information. CWD would like to improve on the amount of time it has taken to get operations staff up to speed with the training. Possibly too early in the process to determine any areas of improvement. Operations staff continue to provide input to the SOPs for treatment process improvements.
17	**Confidence grade:**	High

Observations:
Operation optimization. Utilities can often underestimate the labour involved in training staff properly to accomplish tasks inside of new operating procedures. CWD has found that even though the cost is higher and the time period to implement the changes is lengthened, a comprehensive training schedule that covers several years and involves all operations staff is most desirable.
Installing wind turbine power. The high capital costs to start construction on this project make implementation very difficult to predict. Waiting for the economic climate to improve and for CWD to gather the necessary funds to commence construction has taken longer than originally anticipated.
Off-peak energy consumption. Effective communications and planning are keys to implementing operational changes that affect both day and night shift operators and supervisors. For example, off-peak pumping adds responsibilities to night shift operators that were formerly assigned to the day shift.
Pump and motor efficiency. Specifying high efficiency pumps and motors in CWD's construction standards and specifications is truly the key to success with this strategy.

3.11.3 Solar Energy

Solar energy can be captured in two forms: thermal through circulating fluid, or electrical through photovoltaic (PV) panels. Thermal panels are relatively efficient and are available in various states of technology development roughly in proportion to their efficiency. The simplest and cheapest will generally only realise energy from direct sunlight, whereas the more expensive technology with concentrators and vacuum tubes will be effective even on cloudy days. No case studies have been forthcoming but there may be potential if future treatment developments require low grade heat. The problem is that heat is rarely required in water and wastewater processes, except in sludge treatment where it is available through sludge gas CHP, (See section 3.10.4).

PV panels are relatively expensive and inefficient so a technology breakthrough is needed before they become more than architectural accessories. However, they are convenient to install and connect, and can impact public perception of a building or development. They can also be cost-effective for small power demands where access to a mains electricity supply is difficult, e.g. for street furniture or remote instruments and communications. A disadvantage in some areas is that they may be seen as ideal targets for vandalism. The technology is commercially available so no factsheets are offered as application will depend on individual circumstances. Geography is a consideration and distance from the Tropics is obviously important but local financial incentives will also be significant as in the case study below. Applications are normally external to the water cycle although we have heard of European applications where advantage has been taken of odour control process covers to incorporate solar PV to help power tertiary treatment stages.

Solar Power Case Study: NA-NJAW1 ***New Jersey American Water***

Canal Road Water Treatment Plant Solar Power Project.

Ref	Enquiry Item	Response information, description and remarks
1	**Location:**	USA, northeastern, urban, large system
2	**Sector:**	Drinking Water
3	**[Utility] Works Owner or Operator:** with financial set-up, regulatory or not.	Owner and Operator: New Jersey American Water (a wholly owned subsidiary of American Water - a private water utility). NJAW is the largest investor-owned water utility in the state of New Jersey
4	**Size:** flows and loads or population equivalent:	Average capacity – 38 MGD Design capacity – 80 MGD (expansion in 2007)
5	**Energy Provider:** with costs, incentives, taxes and conditions:	Public Service Electric and Gas (PSE&G) company, with energy purchase from Constellation Energy
6	**Process:**	Physical: Installation of solar panels.
7	**Component:**	Not applicable
8	**Specific energy problem:**	NJAW wanted to address rising energy costs and promote environmental stewardship.
9	**Process/Plant changes:** mechanical, electrical or controls:	In 2005, NJAW installed a 502 kW DC ground-mounted dual-array PV system. One array is located on the north side of the main building, and the other to the south. The system includes two 225 kW AC inverters, revenue-grade metering, and an Internet-based data-acquisition system. The solar array consists of 2,871 solar PV modules, each rated at 175 watts for a total direct current output of 502 kW. The system was expanded by 87 kW (a 17% increase) in 2007 for overall output of 590 kW. A third expansion of 109 k W dc was constructed on top of the filter basins in 2008 to increase the overall capacity of the site to 698 kW dc. The system provides power output to the WTP's 4,160-volt distribution network – all of the solar energy is used on-site. NJAW installed a 99 kW solar PV system at the adjacent Raritan-Millstone Water Treatment Plant in 2008. There, the PV energy generated is used to power electric golf carts used for employee transportation around this large facility. This displaces the fossil fuels that would otherwise be used, saving the associated GHGe.
10	**Civil/Physical Changes:**	Not applicable
11	**Operational Changes:**	No operator actions are required. A service agreement is in place for the limited annual service that is required.

12	**Risks and Dependencies:**	The risk assessment found no operational risks from this project.
13	**Implementation:**	The project was procured via Design/Build. The contractor was responsible for all activities through acceptance testing.
14	**Energy Efficiency gains:** kWh & kWh/m3 before and after implementation	Energy efficiency gains result from energy saved from purchase = 818,000 kWh/yr. This amount lowers the water production electrical intensity by 0.01kWh/m3. The systems supplements approximately 20% of the Canal Road WTP's peak usage and powers electric golf carts for employee transportation.
15	**Cost / Benefit analysis:** financial appraisal or payback time.	NJAW received a $2.438 million rebate from the New Jersey Clean Energy Program, which reduced the design and construction costs for NJAW to approximately $2.556 million. NJAW also took advantage of a 30% federal tax credit (10% of project). Estimated payback in less than 5 years.
16	**Project review:** could it be improved or developed?	The PV installation continues to perform above design expectations.
17	**Confidence grade:**	High

Observation:

NJAW learned three lessons during project planning, approval, and construction:

- *It had to address the potential global shortage of solar panels to ensure the project remained on schedule.*
- *During the four-month planning approval process NJAW had to "educate" the County Planning Board on a new technology, and addressed review comments by local and state agencies.*
- *It had to address unexpected construction conditions as "shale" was encountered during installation of the array system that was unidentified in previous core-boring data. Through a quick response and decision making, no delays occurred to the project schedule and they were able to maintain the budget.*

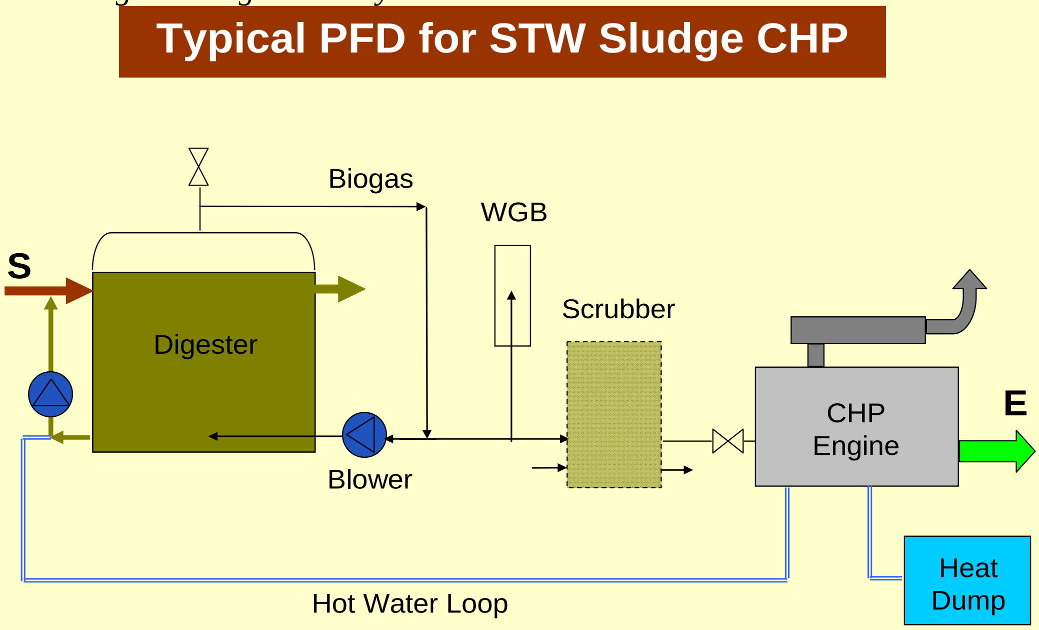
3.11.4 Biogas Combined Heat and Power and Co-digestion

Biogas in the form of sludge gas from digesters has been used extensively for some decades. In some business models it can be viewed as only marginally cost-effective but rising energy prices and carbon reduction strategies may affect this perception.

Although the technology is mature it is frequently subjected to "value engineering" which can benefit CAPEX but result in a less than efficient operational regime and hence higher than necessary operating costs. A more thorough long term cost benefit approach is to make the plant robust as this will minimise operation and maintenance problems and costs and allow a cost-effective design life to be realised.

Combined Heat and Power (CHP) Systems

Match generator size to average gas production
Combined Heat and Power (CHP) refers to the thermodynamics of combustion that realise up to 60% of the fuel energy as heat and only about 40% is available for useful work such as generating electricity.



Description of the Process
Sludge gas from digesters contains about 65% methane and can be used as a fuel. Historically it has been used in boilers to warm digesters but for CHP it is conveyed to spark ignition engines which are coupled to electrical generators. Low grade heat is recovered from the engine cooling jacket, oil coolers and charge intercoolers and this is sufficient for warming digesters. Higher grade heat can be recovered from exhaust heat exchangers but these can suffer a high attrition rate.

The gas contains various impurities such as hydrogen sulphide, carbon dioxide and siloxanes and is saturated with water vapour which is usually controlled by condensate knockout pots. Other impurities can require removal or their effects can be managed through an intensive "maintenance by replacement" programme on the engine and its accessories.

Potential Interventions *Check the business model: run treatment processes to benefit digestion and optimise digesters for gas output to maximise CHP output. This turns digestion from a cost centre to a profit centre. Using co-digested waste in the digester could increase returns through improved ROCs allocations.*

Range of Potential Savings *CHP is capable of running a complete sewage treatment works, saving imported power and yielding ROCs or Carbon Credits.*

Case Studies AU-SAW3; AU-MW4; AUSW3; AU-SW4; UK-UU2; UK-SWW1 CH-EAW1; NA-CWW1; NA CM1; NACB1; NACC1; NA-KC1; NA-LAC1

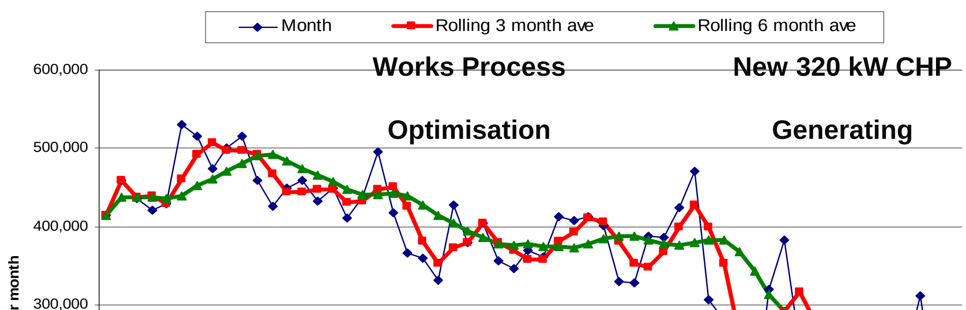
Renewable Energy - CHP Generation Case Study: UK-UU2 ***United Utilities, UK***

Increased CHP generation with new 320kW CHP engine at Lancaster WwTW .

Ref	Enquiry Item	Response information, description and remarks
1	**Location:** Country, urban or rural:	England ,Urban
2	**Sector:** clean, waste or sludge:	Wastewater
3	**Works Owner or Operator:** with financial set-up, regulatory or not.	United Utilities
4	**Size:** flows and loads or population equivalent:	Population Equivalent = 113,000 Average flow = 54 Ml/d
5	**Energy Provider:** with costs, incentives, taxes and conditions:	Gas De France cost per Kw of electricity 8.3p(Total)
6	**Process:** physical, chemical, or biological description:	Anaerobic Digestion producing methane gas
7	**Component:** all or part of the works:	Part of the works
8	**Specific energy problem:** including quality or consent details:	Energy efficiency - carbon reduction – reduces imported energy requirements
9	**Process/Plant changes:** mechanical, electrical or controls:	Additional new 320kW CHP engine to reinforce an existing CHP generation comprising 104kW and 165kW engines previously optimised
10	**Civil/Physical Changes:** to water / effluent quality, civil works, or process:	None
11	**Operational Changes:** skill levels, procedures and maintenance routines:	None
12	**Risks and Dependencies:** risk assessment of project and changes.	n/a
13	**Implementation:** design, build, procurement, installation and commissioning:	Commissioned Aug 2007
14	**Energy Efficiency gains:** kWh & kWh/m^3	**Approx 2.0 GWh/year** **0.101kWh/m^3**
15	**Cost / Benefit analysis:** financial appraisal or payback time.	Saving approx £140k pa. 2.5 years payback period
16	**Project review:** could it be improved or developed?	Generation capacity has been increased but with remaining capacity to be utilised post EEH project
17	**Confidence grade:** on data provided.	Good data and confidence with data extracted from actual imported energy bills

Observations:
See attached graph derived from UUs energy suppliers' website.

Data extracted from suppliers energy bills – imported energy reduced from 500,000kWh per month to less than 200,000 kWh per month through various initiatives with new CHP the major benefit.



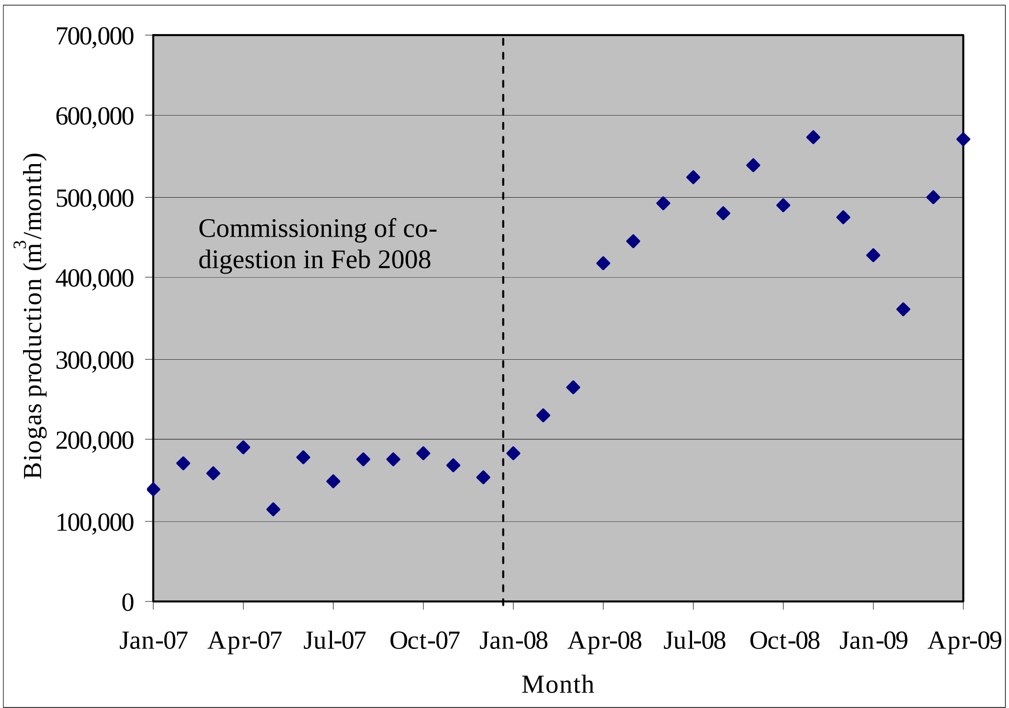
Changing demographics and consumer habits mean that different substances turn up in sewage. Siloxanes are compounds which persist through sludge treatment and digestion and form glass when burnt as part of sludge gas in engines. The deposits occur in cylinder heads and on valves and limit the service life of these components. This means an intensive maintenance programme to avoid engine damage, although some experience of siloxane filters has been successful. Activated carbon filters are used but hydrogen sulphide must be low for these to avoid a high carbon usage rate. There is also evidence that gas turbines (see case study UKSWW1) are less susceptible to the effects of siloxanes than reciprocating engines although turbines are usually only economic for larger size power plant.

Where Municipal Authorities dispose of green waste by separation at source, it is possible to mix the waste with sewage sludge streams for co-digestion. Such an arrangement would have two potential benefits: to allow cost-effective and environmentally friendly disposal of municipal waste and to increase the gas output of the sludge digesters, thus increasing income from the energy generated. There are also possibilities for similar disposal of food wastes but this implies strict control of the waste types which may not be practical.

Sludge Digestion Case Study: SG-PUB6 ***Singapore***

Ref	Enquiry Item	Response information, description and remarks
1	**Location:** Country, urban or rural	Singapore, urban
2	**Sector:** clean, waste or sludge	Sludge
3	**Works Owner or Operator:** with financial set-up, regulatory or not	Jurong Water Reclamation Plant (JWRP), Public Utilities Board (PUB); with financial set-up and regulated
4	**Size:** flows and loads or population equivalent	180,000 m3/d, ~ 1,000 mg COD l^{-1}
5	**Energy Provider:** with costs, incentives, taxes and conditions	Singapore Power
6	**Process:** physical, chemical, or biological description	Biological, conventional activated sludge process, anaerobic digesters with CHP
7	**Component:** all or part of the work	One-stage mesophilic anaerobic digestion with dual-fuel engine CHP.
8	**Specific energy problem:**	To generate more electricity through increase of biogas production by co-digestion.
9	**Process/Plant changes:** mechanical,	The Greasy Waste Receiving Facility (GWRF),

	electrical or controls	commissioned in February 2008, introduces about 250 m^3/d of fats, oils and greases (FOG) waste into the anaerobic digesters
10	**Civil/Physical Changes:** to water/effluent quality, civil works, or process	The FOG waste is firstly screened for gross solid materials and the screened waste is then pumped into a dissolved air flotation (DAF) unit. The concentrated FOG is then blended with thickened sludge (5% TS) in the mixing tank and is then pumped into anaerobic digesters for co-digestion at a ratio of about 7% concentrated FOG to 93% consolidated sludge
11	**Operational Changes:** skill levels, procedures and maintenance routines	The Greasy Waste Receiving Facility (GWRF) unit needs daily operation and regular maintenance
12	**Risks and Dependencies:** risk assessment of project and changes	The pipes transferring the mixture of sludge and FOG need to be cleaned regularly to prevent clogging
13	**Implementation:** design, build, procurement, installation and commissioning	The total cost including materials and installation is S$ 5.8 millions
14	**Energy Efficiency gains:** kWh & kWh/m^3	About **4.2 GWh** of energy is generated **annually** from the biogas of FOG digestion and meets about **15%** of the total energy consumption
15	**Cost / Benefit analysis:** financial appraisal	About **S$ 660,000** annual saving is achieved due to the co-digestion of FOG
16	**Project review:** could it be improved or developed?	Further recovery of heat from the CHP exhaust gas; and installation of new power generation capacity to accommodate biogas currently flared off and increased biogas production in future
17	**Confidence grade:** based on data provided	Highly transportable and adaptable



Source of details

Oon S.W., Koh T.G., Ng K.S., Ng S.W. and Wah Y.L. (2009) *Maximizing Energy Recovery from Sludge – Singapore's Approac*h, Water Convention, Singapore International Water Week, 23-25 June 2009, Singapore

4 Discussion

This section reviews and discusses the general conclusions derived from the case studies in Section 3 and the Appendices.

4.1 Energy usage and improvement estimates

4.1.1 The UK water industry

The UK water industry is regulated by the Water Services Regulation Authority, known as Ofwat, and their statistics on energy use are useful. However, they use cost as an indirect metric and because tariffs vary between water companies, the energy usage figures may be distorted.

The annual June Returns to Ofwat for the reporting year 2008/09 (from Ofwat Tables 21 and 22 for Water and Sewerage Services) require the energy costs to be divided into components of the Water and Sewerage Services. Table 4.1 includes the percentages by components together with the maximum and minimum figures of individual companies. Figure 4.1 illustrates the percentages by component and includes sources and ranges of potential energy savings discussed below.

Table 4.1 Energy Usage, England & Wales, 2008/09

		Water *(Ofwat Table 21)*			Sewage *(Ofwat Table 22)*			
		Abstraction & Treatment	Water Distribution	Water Service Total	Sewerage	Sewage Treatment	Sludge Treatment & Disposal	Sewage Service Total
By Service Component	£M	110.522	130.286	240.808	44.436	149.085	28.346	221.867
	% Average	48.6%	51.4%		21.1%	68.1%	10.8%	
	% Maximum company	96.7%	83.8%		42.1%	80.5%	23.1%	
	% Minimum company	16.2%	3.3%		11.1%	57.1%	-22.6%	
Whole Water Cycle	% Average	23.9%	28.2%	52.0%	9.6%	32.2%	6.1%	48.0%
Initial estimates		35%	65%	45%	25%	60%	15%	55%
Range of returns from individual companies [1]		45 - 60%	40 - 55%	45%	28 - 30%	68 - 70%	0 - 2%	55%

Source: Ofwat June Returns 2009

In terms of the overall cost of energy the table demonstrates that Water Services consume 52% of the energy and the Sewerage Services about 48%. The split for the 10 Water and Sewerage Companies (WASCs) is 47% and 53%, in line with initial project assumptions. However a significant percentage of the water demand is supplied by the 11 "Water Only" (WOCs) which when included in the analysis results in the larger demand for energy being for water supply and distribution.

Pumping represents upwards of 70% of water supply energy demand and at least 30% for waste water. For sewage services the major single energy demand is for aeration; up to 60% or more of the usage for the service. Clearly the best opportunities for reducing energy demand are linked to these high usage components.

The table demonstrates that the wide range of energy usage for the water service split between raw water pumping and treatment, and distribution varies in percentage terms, is between 16/83 and 97/3, with a UK industry wide average being 49%/51%. The range of maxima and minima figures illustrate specific groundwater abstraction, geographic supply characteristics and population density factors for two companies. If these are removed the ranges reduce to approximately +/- 20%. To a lesser extent the percentages also recognise the limited energy demand for water treatment processes. The percentage figures combine treatment with abstraction. However treatment energy demand is generally considered to be relatively low compared with abstraction and raw water transfer pumping costs.

For sewage the Ofwat reported figures differentiate between sewerage, treatment and disposal with an industry average of 21/68/11. The ranges within each component are significantly narrower than for the water service; being 11~42/57~81/(23)~23. However these figures highlight the benefit gained from renewable technology being used to power sewage treatment processes, mainly energy from waste. The numbers also hide extreme differences, for example, between percolating filter treatment which uses minimal energy, and activated sludge.

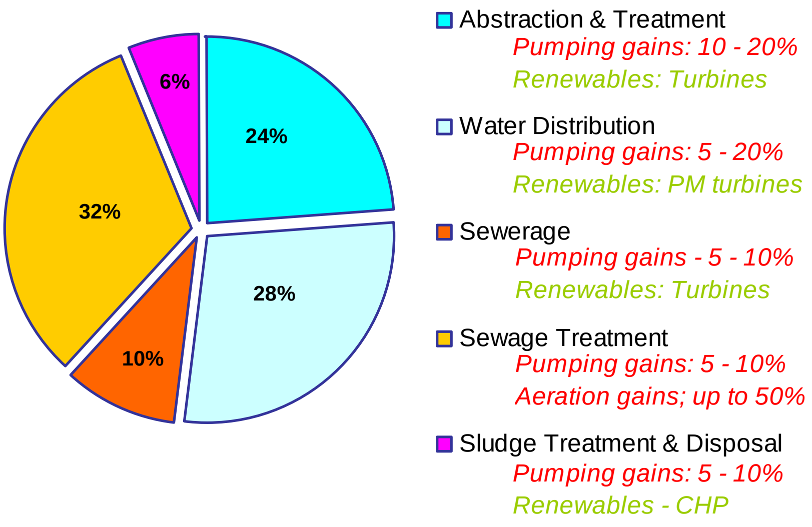


Figure 4.1 Energy usage by service component (% of cost)

The real potential for incremental improvements in the UK seems to be lower than was initially estimated. This could be due the effects of recent electricity price rises resulting in energy saving projects having been implemented but the changes not reported explicitly. This applies to both clean and waste water.

However, for significant improvements the estimated potential for drinking water was reasonably close to company estimates at about 10% whereas for wastewater it was over-estimated at about 15%. The potential for significant clean and waste water improvements is therefore about equal.

The returns above show potential for about 15% improvement in drinking water and perhaps 25% in waste water including the potential for net reduction through the implementation of CHP projects. With the incentive of the Carbon Reduction Commitment (CRC) this may be substantially achieved during the 2010 -15 regulatory AMP5 period.

4.1.2 The European water industry

In Europe the financial model appears to operate over longer payback periods than in the UK so more energy saving projects are viable. '*Feed-In*' tariffs, which provide incentives for innovative renewable energy projects, have operated in Europe for some time whereas they are only now being introduced to the UK. The result is that energy saving science and engineering appear to be more advanced and are spread across a wider range of processes and technology.

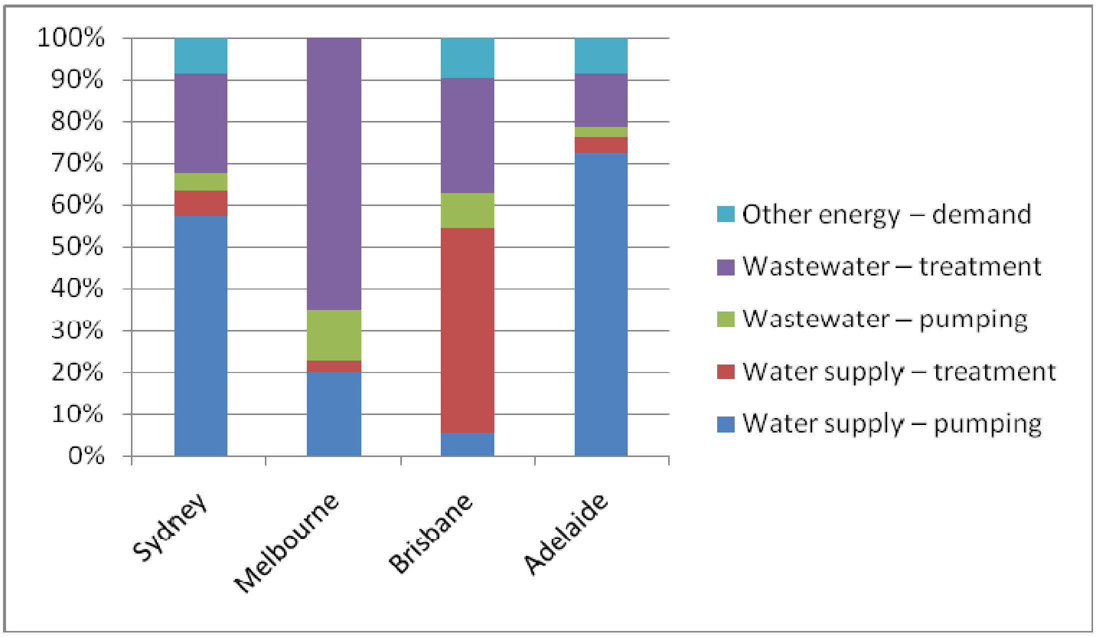
The variability of geography and climate across Europe suggest that we would not expect average or typical figures for energy usage. Plant types also vary widely from large sophisticated high technology processes for the larger cities to smaller, simple process rural works. Case studies show a variety of means of saving energy with more focus on process optimisation than elsewhere. Because optimisation is usually applied to existing assets it can be very cost effective, achieving savings with minimal capital investment. A variety of approaches to saving energy is evident, especially in wastewater treatment, with improvements to chemical dosing models and instruments, even though pumps and blowers are the main users of that energy.

Because of the diversity of European geography, cultures, policies and drivers it is difficult to quantify the potential for energy savings. Technical innovation will doubtless continue and this may result in energy savings per connection similar to, or even exceeding the UK. But population pressures are also varied across Europe and this will heavily influence the outcome.

4.1.3 The Australian and Singapore water industries

There are energy returns from the four main coastal cities in Australia which show that their individual circumstances have a significant effect on energy use. Table 4.2 below shows three temperate climate cities, Adelaide, Melbourne and Sydney and one sub-tropical city, Brisbane. The differentiator, however, is not climate but availability of water, and disposal of sewage waste.

The adoption of energy efficiency initiatives is also varied, perhaps due to low energy prices. However the increasing need adopt energy hungry technologies such as desalination and membrane technology to achieve effluent standard changes for water recycling/reuse and overcome raw water resources constraints, will help to raise awareness.



Sources: Melbourne data (2008-09) – supplied by Melbourne Water
Sydney, Brisbane and Adelaide data (2006-07 FY) – CSIRO study 2008

Figure 4.2 : Energy Usage by component for Australian cities

Adelaide draws its water supply from the Murray river which entails high energy cost, especially in drought conditions. Disposal of sewage is easier as the main works is 20m below the average level of the city, and about 30% of the waste treatment energy demand is generated by biogas CHP through gas turbines.

Melbourne's water is mainly from protected sources gravity fed to the city so its raw water pumping is minimal. However, sewage is treated to high standards and some has to be pumped about 60 miles to a sea outfall so its treatment and disposal costs are much higher. The table 4.2 below shows the details.

Table 4.2 Energy Usage in Melbourne, Australia

Water cycle	MWh	% of Water	% of Total
Other	51	0.1	0.0
Pumping	49,541	85.7	19.4
Transfer	1,502	2.6	0.6
Treatment	6,741	11.7	2.6
TOTAL	**57,836**		**22.6**

Sewage cycle	MWh	% of Sewage	% of Total
Other	7	0.0	0.0
Pumping	30,345	15.4	11.9
Re-use	358	0.2	0.1
Transfer	547	0.3	0.2
Treatment	166,306	84.2	65.1
TOTAL	**197,563**		**77.4**

The proportional usage by sector and process are not typical of a source to tap/toilet to disposal utility reflecting that Melbourne is a bulk supplier of treated water and collects sewage for treatment and disposal from the municipal areas around Melbourne.

Sydney Water's water supply is mainly gravity fed from a dam, but during droughts water is pumped from a different system which increases costs. Waste water treatment is mainly primary followed by pumping to long sea outfalls. One such pump system involves pumping over a headland with consequential high energy costs.

Brisbane Water has high pumping energy costs for both raw water and for treated sewage disposal. The company generates only a small proportion of its power from digester biogas.

Singapore is a geographically small island state of 710km^2 with intensive population growth. Although its rainfall averages 2400mm per year, the demand for water to supply the population of 4.8m requires water resource sources to be diverse. The water and wastewater industry is administered and engineered by the Singapore Public Utilities Board (PUB).

Treated water is imported from Johore from mainland Malaysia. Raw water is also collected for treatment on the island by active conservation and rainwater harvesting. Wastewater treatment has been intensified with some novel techniques reported in the past. Recycled water was introduced in 2003 and desalination in 2005. Singapore's energy costs have increased significantly since the installation of the desalination plant although this has been partially off-set by biogas power generation and optimised plant operations.

4.1.4 The water industry in North America

North America represents a collection of diverse geographical, social and economic regions. This variation is reflected in the water and sewerage utilities; size region, resource availability, etc. Awareness of current and potential water and energy problems also varies with some utilities adopting leading edge process and environmental technology while for others the subjects are not yet a priority. One factor is significant migration from industrial areas with good infrastructure and resources to warmer dryer areas which are already water stressed. Solutions tend to be based on conservation and indirect re-use of wastewater, but desalination is also being considered, particularly on the West Coast with the energy coming from new nuclear generation.

There are no overall numbers for energy usage but discussions suggest that the split between drinking water and wastewater is about even and that pumping takes between 80 and 90% of the total water industry energy demand. Total energy demand will rise as the requirement for re-use increases and effluent standards are raised and the demand for water will also rise through population increases and higher per capita demand in warmer climates. Increases in water and energy demand can be balanced by conservation to some extent but in wealthy areas, such as parts of California, and extreme cases, such as Las Vegas, significant energy increases are expected as has occurred in Singapore. In New York State it is estimated that most utilities can save between 10 and 20% of their energy demand, with 50% being possible in some cases, whereas nationally the US Environmental Protection Agency estimate that an average cost saving of 10% is possible.

As in some parts of the UK, there are signs that where intensive industry has declined, pollution loads have significantly reduced with corresponding reduction in energy and chemical demands. There is awareness that where regeneration of industrial sites is carried out in empathy with nature, the loop of spiralling costs and contamination can be broken. There are cases where natural process solutions are being used from Edmonton in Canada, through the USA down to Colombia in South America. In parallel US water utilities are investing in renewable energy sources, including solar and wind power, to reduce their net energy demand.

4.1.5 The global picture

The rising global demand for drinking water and sanitation is increasing the industry's energy demand as sources become more difficult to treat and wastewater becomes more difficult to dispose of safely. Climate change is also affecting the water cycle, but as demonstrated in Australia, its impact can be managed through social and economic responses as well as technical developments.

There is direct correlation between energy demand and the location, availability and quality of natural resources and treatment and disposal of sewage and sludge disposal. The key energy demand areas are; pumping from distant or deep water sources; distribution of potable water over wide areas, asset condition and leakage potential; treatment of sewage by aeration, and pumping raw and treated effluents. A customer's utility bill will be further impacted by where he is living, with consumers in areas of high population concentration with severe resource and disposal constraints paying increasingly higher tariffs for their services. On the supply side the net energy demand can be significantly reduced by exploiting CHP from wastewater sludge digestion and perhaps other renewable energy sources.

4.2 Case Study Returns

The Water Cycle Matrix and Global Case Study Summary presented in Table 4.3 shows that the majority of companies providing case studies have focused on pumping and waste water aeration. This aligns with initial conclusions on the processes with the higher energy demands and with the Priority Short List findings. The case studies also illustrate logical fine-tuning for incremental improvements and application of proven principles for more substantial gains.

In most areas outside Europe there is poor coverage of the treatment sections, particularly for drinking water. This confirms the initial view that "*water only*" companies have few options for reducing net energy consumption. However, it is likely that ongoing process optimisation and incremental changes are being implemented but for which the documentation was not available for this study. In addition opportunities to optimise treatment processes may arise through plant replacement or refurbishment so gains may be hidden under other subject headings.

As expected a number of potential case studies were not felt to achieve the standard of a recorded case study for inclusion in the Compendium. However, they still represent a useful record of anecdotal or informal information and could be reinforced with a more objective or analytical approach, and therefore are referred to herein. A side benefit of a more rigorous approach could include a higher probability of acceptance of proposals for management investment.

Table 4.3 Water Cycle Matrix and Global Case Study Summary

Africa – Yellow **Australia & Singapore – Pink** **Europe – Red**
North America – Blue **UK – Black**

WATER CYCLE ENERGY SAVING MATRIX		Drinking Water			Waste Water		
		Raw Water	Treatment	Distribution	Sewerage	Treatment	Disposal
Energy Estimate (% of whole)		25	10	65	25	60	15
Demand Manage-ment	Conservation (Water & Energy)	BW1, AW1, AWU2, CRWD1, CWW1		BW1, SESW1, MC1, AW1, AWU2, CRWD1, CWW1			
	Leakage Reduction	SESW2, EM1	SESW2, EM1	SESW2, EM1, SW5			
	Infiltration/Inflow Reduction				HW2, HW3	HW2, HW3	HW2, HW3
Pumping	Optimise Gravity Flow	KWR1					
	Pumping and pumps	UU3, ScW5, SSW2, AW1, TVW1, TVW2 SEW1, SWW3, NM1, HW1, SAW1, MW1 AWU1, ND1, KF1		SSW1, TVW3, TVW4, UU1, AW2, ScW6, KWR2, PUB1, SAW1, WC1, WC2 MCW1, QWD1	ScW2, UU4, UU5 SAW1		AW6, SAW1, MW2
	Catchment Transfer	KWR1					
Treatment	Clarification / Primary		YW4, ScW4			ST4, ESP1	
	Aeration					AW4, AW5, AW7, DCWW1, ScW3, SnW1, WW1, YW3, YW5, UU6, UU7, ST6, ST7, BW1, SW1	
	Mixing / Coagulation		KWR3,			PC1	
	Nutrient Removal					WW3, NW2, PUB2 ST1, ST3, VE2	
	RAS Pumping					NW1,	
	Membrane Treatment					ST2, PUB3	
	Disinfection / UV		KWR4			WW2	
	Ozonation		KWR5				
Sludge	Thickening / Dewatering					ST8, ST9	
	Digestion / Co-digestion					YW2, ST5, VE4, EAW3, PUB4, PUB6 BCC1, SEW2 CM1	
	Sludge Drying					PUB5, SE1	
	Building Services		AW3, SW2			SW2	
Generation	Mini Hydro-Turbines	ScW1, SWW2		VE1, MW3, SAW2, SEW1	YW1, CSD1		VE3
	Wind Turbines			CWD1			ACUA1
	Solar Power		NJAW1			IEUA2	
	Biogas / CHP					UU2, SWW1, SE2, EAW1, EAW2, MW4, SAW3, SW3, SW4, CWW2, IEUA1, CB1, CC1, KC1, LAC1	

The matrix shows the area where potential savings are expected, together with the case studies received from the water companies. When the report is being read in its electronic format, a fact sheet on a subject will be opened in a new window by clicking on the subject title.

Each case study is identified by a code, colour coded by continent. As for the factsheets, by clicking on the case study code, the full case study will be opened in a new window. The best case study in each subject group has been chosen to be presented against the relevant subject area in the Section 3, Result. All factsheets and cases studies are enclosed in Appendix 3.

4.3 Subject Area Results

This section discusses a brief analysis of the case studies and information gathered on the various subject topics shown on the left-hand column of the water cycle matrix.

4.3.1 Conservation and leakage reduction

The results show that efforts to conserve water and reduce leakage are also effective at reducing energy demand. American Water has taken pro-active steps to reduce leakage and energy by pipe replacement as part of an environmental stewardship programme. This is against a national average leakage rate of about 14% across the US. There are also implied savings to be made through conservation measures in domestic and non-domestic premises. There is currently little impact on UK water consumption from water pricing but the leakage of treated water is a high profile subject which becomes emotive in a drought situation. Public attitudes to water in Australia have certainly changed over the period of seven year of drought. Examples from South Africa demonstrate that the resultant savings in water and energy justified the investment of re-plumbing private houses. This was particularly relevant since energy is a critical national issue.

Table 4.4 Energy Saving from Demand Management

Means of saving	Water Conservation	Leakage Reduction
Saving (%)	10	25

Leakage is an easy subject for which to set arbitrary targets but reductions are less easy to realise. Currently studies are being undertaken to consider alternative ways of assessing leakage levels, sustainability and the Sustainable Economic Level of Leakage (SELL), all of which will impact target setting. However, the potential energy savings are directly proportional to the water saved through any loss reduction activity.

Gravity flow opportunities are included here as an energy conservation ideal, with Melbourne as an example. Opportunities to change from pumped to gravity systems appear to be minimal but this may be because systems have evolved over time with additions not necessarily replicating the original design compared with if the system had been delivered as one from the outset, and because often systems are re-worked for operational purposes rather than for energy efficiency. There is also a perception that there is a strong price penalty for increasing the size of pipework, particularly if it is buried, but this view should be challenged through a more comprehensive cost / benefit exercise using future pumping energy prices.

Insertion or retro-fitting of additional processes into existing works often incurs inter-stage pumping. However, an example from Wales in the UK added a DAF plant above an existing works but below the supply reservoir so the gravity powered hydraulic gradient was retained and no pumping was required.

4.3.2 Pumping

Pumping represents upwards of 80% of drinking water energy and at least 30% for waste water. Until recently some UK utilities focused on reducing energy bills by adopting tariff management. This approach may have distracted attention from saving energy, however, the Carbon Reduction Commitment may redress the balance. No single energy saving technique stands out but some relatively quick wins are evident, usually through changing control regimes, and this is repeated globally.

A few studies of borehole pumps have shown that attention to the aquifer draw-down can save energy. One case shows that running the most efficient pump of a group of boreholes in an aquifer gives good results. A second case study demonstrates that using multiple pumps, each at low flow, instead of running a single pump at the required total flow results in less aquifer draw-down, lower pumping head and thereby lower energy demand. In other applications sump level adjustments have yielded similar benefits and most cases demonstrate the value of accurate real time data for aquifer management.

Most pumps are direct driven but on belt driven pumps a very simple modification has been to replace Vee belts and pulleys with toothed timing belts. These do not wear or loose tension and there is no variation in pump speed through an extended working life. Belt drives can be used with synchronous motors to change the pump speed and align its best efficiency point with its required duty point if fixed speed operation is required.

A few case studies show that scheduling controls on water abstraction and distribution can bring benefits. One example in Yorkshire Water, UK, working over a wide distribution area uses a real-time software model incorporating unit electrical costs of pumping different water sources to schedule use of the least costly sources first and only run more costly resources if necessary. While this technique incorporates some tariff management the same principles could apply to energy saving. Other examples show benefits from optimising the control philosophy of single, albeit complex, stations.

Performance testing has been used to assess the potential for savings and to quantify the benefits. In most cases worthwhile savings were demonstrated, however, there is a risk that for some installations there are limited opportunities for efficiency savings and that the testing costs are not recovered. In two examples, Pump Rescheduling from Southern Water UK, and Pump Efficiency Testing Plan from American Water US, the testing covered a complete zone, which may be a more economical approach, and pumps showing the best potential gains were highlighted for attention.

Internal coatings for pumps have been accepted practice for some years and can be a convenient addition to a routine or major maintenance overhaul including, for example, replacing packed glands with mechanical seals or sleeve bearings with roller elements on older pumps. The consequence of multiple activities is that the economics may become clouded in these instances due to the combined effects of the changes and their costs. However, the converse is that a single driver may not achieve an economically viable payback and a broader approach may be needed to justify expenditure, for example taking account of social and environmental factors.

Variable Speed Drives (VSDs) have been installed in some pumping applications to realise savings. Some VSDs have enabled turn down of machinery to match operating conditions, with one example allowing an energy wasting throttling valve to be removed. Where only one pump is expected to cope with a wide duty range or seasonal or diurnal variations a VSD is an economical solution. Modern VSDs include power factor management and one case study showed an 83% saving. However, VSDs use power to drive their electronics and take typically 4 to 5% of the rated motor power. There are examples of pumps being replaced to allow efficient fixed speed operation thus dispensing with VSDs.

If pumps can be accurately sized for their duties the 4 to 5% power savings can be added to significant capital cost savings. One example confirms that with high static head and low friction head a VSD will have little influence over the pump system efficiency. Operating one VSD pump with other fixed speed pumps leads is inefficient because the best efficiency points (BEP) will not being matched. For a number of parallel duty pumps, VSDs should be fitted to all, and their speeds should be controlled as one to match the pumps' BEP to the duty point.

Borehole pumps and their long, small diameter motors are not very efficient and one study shows that replacement by line-shaft pumps with conventional surface mounted motors can be beneficial. This may act as incentive to manufacturers to look at raising the efficiency of their multi-stage pumps and submersible motors. Modern VSDs can be used where control speed is important for aquifer management. Older types generated significant harmonics and on long cable runs from VSD to borehole pump motor there would be unacceptable losses, but these are now much reduced.

There are few examples of pumps being replaced on energy efficiency grounds. Most replacement installations are for other reasons such as reducing blockages, operating regime changed from original design and incorrect original selection. The small number of examples reflects the relatively high cost of plant replacement and the payback time involved. Utilities have reported a number of instances where pump refurbishment or replacement had been proposed but shelved due to uncertainty and risk. It is expected that rising energy prices will increase the viability of schemes that are currently only marginal.

Table 4.5 Energy Saving from Pumping Interventions

Means of saving	VSDs	Duty Point	Intrinsic Pump	Duty Change	Waste Water	Duty Range
Saving (%)	12 to 30	3 to 63	6 to 11	10	8.4	3

There were no specific examples of pipework being re-sized or modified to reduce headloss and improve energy efficiency. However, some of the pump station optimisation exercises may have included minor alterations not highlighted in the case study.

4.3.3 Process

Most examples of drinking water process savings have come from Europe, however, we have one case study from the UK replacing DAF nozzles. Opportunities may exist for updating similar equipment and system controls elsewhere.

Generally the following guidance (from the Priority Short List) still stands:-

- Clarifiers are cheaper to run than Dissolved Air Flotation (DAF) processes,
- Use direct air injection rather than recirculated water for DAF processes,
- For nitrate removal use a biological rather than a chemical dosed process,

- Design pipework for minimum headloss rather than cheapest Capex,
- Use hydraulic rather than electro-mechanical mixers,
- Optimise filter media for dirt collection to minimise backwashing,
- Review efficiency of backwash pumps and air scour blowers systems,
- Optimise chemical dosing for minimum plant energy demand.

An important lesson from the European studies is that improvements in one stage have knock-on effects downstream; for example, correcting pH before dosing coagulation not only reduced coagulant dose but reduced the UV energy requirement. Another example saved energy by replacing chlorine oxidation with ozonation, and by adding GAC, backwash sequences were reduced and the process became more stable. Research into coagulant dosing not only reduced the dose but also reduced sludge loads and allowed longer filter runs between backwashes.

No case studies involving preliminary waste water treatment were offered. It was hoped that the debate on whether to de-grit before or after screening could be settled through energy efficiency but there is apparently no experience here. One report compares overall energy demand for the various stages of treatment, i.e. secondary treatment energy demand is double that for primary; and tertiary is double that for secondary. It is therefore more likely to be energy efficient to focus on front end processes than to solve problems by adding tertiary treatment, especially if this requires additional pumping.

Waste water treatment process optimisation is focused on reducing aeration energy demand and increasing biogas yield from primary sludge digestion. Polymer dosing at primary sedimentation, two stage aeration, following seasonal variations in oxygen demand by varying the Mixed Liquor Suspended Solids (MLSS) and replacing aeration nozzles with plate aerators all reduced aeration energy demand. Where primary sludge loads are increased there are three consequences: reduced aeration energy demand, increased biogas yield and reduced surplus activated sludge (SAS). Lower sludge volumes through improved digestion efficiencies also reduce energy demand for post-digestion sludge treatment from chemicals, dewatering and drying.

Case studies in waste water aeration for Activated Sludge Plants (ASPs) have focused on changing dissolved oxygen control to ammonia based control. Significant savings of up to 50% have been reported from Wessex Water in the UK by relatively simple means of changing instruments and control software. An Australian case study suggests similar benefits have come from monitoring reduced inlet loads and flow rates resulting from drought restrictions on water use and in another example slight modifications to the aeration zones enabled a 13% reduction in blower duty. Changes in the operating regime either allowed blower output and energy demand to be reduced, or allowed better control over secondary processes such as nitrification, which were seasonal and incidental to the consent standard but taking a lot of energy.

On complex sites where more than one treatment stream is operating, the flexibility to change the emphasis between an activated sludge plant and a filter process has obvious advantages. This is also evident where the need for tertiary treatment may be marginal and could be reduced or avoided by efficient operation of primary and secondary processes.

There is evidence that successful optimisation exercises have resulted from team efforts between engineers and operators, or where operators are given access to engineering expertise. This approach allows for minor alterations to instruments or controls to be cost effectively implemented with no costs for training or commissioning and may result in new instruments being cleaned and new procedures being followed to allow savings to be realised and maintained.

More material changes to aeration systems include changing belt drives to optimise blower speed and installing VSDs on blowers or surface aerators to allow their speed to be reduced to match flows and loads. This is important for energy efficiency and, particularly in oxidation ditches, may be partly responsible for reducing filamentatious bacteria. A bigger investment is an example of replacing submersible aeration systems with more efficient diffused air nozzles, or the more efficient plate diffusers. These emit smaller bubbles facilitating easier transfer of air into the effluent. Instrumentation is important; one example is of the blower pressure being used to indicate when diffuser nozzles need changing to avoid energy efficiency losses.

Table 4.6 Energy Saving from Process Interventions

Means of saving	Clarification	Aeration	Nutrient Removal	RAS Pumping	UV
Saving (%)	21 to 30	7.5 to 40	22	-	40

The energy user in an aeration system is the machine, but a whole system should be assessed and optimized to achieve energy efficiency benefits, including its operation and maintenance. Inlet filters, pipework, instruments and controls, valve positions and operational modes, tank bottom grids and diffusers, flows and loads and consent standards and parameters should all be reviewed against their performance and maintenance records and their potential for improvement. Process optimisation has knock-on effects in subsequent processes such as RAS pumping, sludge treatment and CHP biogas generation, with significant savings demonstrated.

4.3.4 Mixing

Mixing covers a variety of plant from flocculation of drinking water through refinements to ASP zones and maintaining homogeneity in sludge. However, the only case study on mixing addresses the replacement of powered mixers with static or hydraulic types.

There is evidence of strong corporate preferences for different types of mixing technology so there may be an opportunity here for some objective testing and assessment of the best types for standard situations. Certainly there are specific applications for different types in clean and waste water, but the industry should be in a position to pool knowledge, for example in digester mixing comparisons could be made between pumps, big blades, propellers, draft tubes, linear motion mixers, gas and zoned gas mixers. This may become more important with increasing numbers of works dealing with enhanced sludge treatment processes and CHP systems (see Section 4.3.7).

4.3.5 Sludge

There is one case study on sludge handling where the bores of pumps and a macerator were increased to avoid blockages due to rags. This is a common experience, particularly with progressing cavity pumps, e.g. Mono, Seepex or PC, which are much more reliable when correctly sized to run slowly, rather than when sized for low Capex but run at higher speeds. If sludge handling is linked to digesters, more reliable pumps will result in more digester gas and energy production and improved utilisation.

It was expected that experience on mixing and thickening sludge would provide some case studies but only one has been forthcoming. It may be that this area will be a focus for development in future as sludge, advanced treatment and CHP become more important means for reducing net energy demand (see section 4.3.7 below) and ensuring quality for return to land. The example from the US has a novel mixer working in a linear motion causing eddy currents. This is said to use 90% less energy than previous draft tube types and with fewer working parts. Although the digesters are working at low solids loadings, it will be interesting to monitor grit deposition and mechanical fatigue at this plant in future years and compare energy inputs with zoned gas mixing which is known to be effective and energy efficient.

4.3.6 Building services

Building services are on the edge of normal core business for most engineers and managers in the water industry. Standard solutions may therefore be implemented in the interest of expediency and thereby introduce additional energy demand. For example where blowers or VSDs are housed in GRP kiosks which are subject to solar heat gain, air conditioning (A/C) is often installed as a standard solution. Such engineering decisions should be challenged and subjected to Value Engineering. In addition when installed A/C tends to be run continuously, which is energy expensive, whereas, for most machinery installation, conditions probably only require A/C cooling a few days each year. Alternatives could include better kiosk and building insulation and simple natural ventilation systems which would have minimal Opex and Capex. If VSDs or other plant cause a heat problem then plant-specific cooling could be more cost effective than a general A/C solution.

There may be scope for improvement to plant heating for frost damage prevention. It is evident that conventional fibre insulation with aluminium sheathing for external pipes, fittings and pumps is subject to damage during access and is difficult to maintain in a dry condition. Once wetted by rain, condensation or snow the insulation value is minimal. Material or design improvements could allow access without damaging the insulation and would result in less energy demand, probably during high tariff periods..

There is a surprisingly large number of examples of proprietary controls for supply voltage regulation. Most of the case studies discuss office buildings which are the ideal application. However, similar results could be achieved by adjusting tappings on supply transformers, with significant Capex savings.

Lighting is traditionally regarded as a small load, but substantial savings have been demonstrated on two fronts. Old equipment can be significantly less efficient than modern fittings and luminaries such as high frequency fluorescent technology. Replacement can be cost-effective. The other measure is turning lights off when they are not needed, either manually or by installing appropriate sensors. However, this strategy has to be managed with Safety and Risk requirements in mind, particularly in areas without natural light, and is best approached through a behavioural change management process.

4.3.7 Renewable Energy

Hydro-turbine generators are the conventional way of recovering energy from a high pressure system. The case studies present examples from clean and waste water systems. Hydro-turbines are hydraulically direct replacements for pressure reducing valves (PRVs) and similar controls although they are usually installed in parallel with such valves to allow flow transfer in the event of generator or supply failure. There are reports of occasional problems with flow controls and possible surge events on turbine start-up or shut-down apparently linked with external emergency stop events or other failures. There are opportunities here for sharing ideas and experience on technical solutions.

The case studies show a variety of turbine types and sizes depending on the head and discharge configuration. Electrical outputs vary from tens of kW to 2MW. Drinking water applications are usual, but an Archimedean screw is being used to generate power in a raw wastewater flow in Yorkshire UK and large Kaplan type generators are being used for low head final effluent in Paris, France.

There appears to be significant potential for this technology as electricity prices rise and utilities look at PRVs and other head loss devices as potential sources of income rather than as operating and maintenance cost items. For drinking water only utilities energy from pressure management may offer the only opportunity for renewable energy generation. However, direct comparison with energy saving exercises on pumps and similar plant is unfavourable as generators also need additional electrical switchgear and metering to input the power to the local grid.

Wind turbines do not fit within the water industry in the same way as hydro-turbines do. This is reinforced by the UK Regulator's stance that public funding shall not be used for their installation, although there are reports of exceptions to this ruling. Research outside this report shows that small turbines up to 1.5MW are not generally commercially viable unless they are part of a public relations or architectural package. Turbines over this size require considerable space, a robust local grid and sympathetic planning authorities and stakeholders including local residents. Consequently they are unlikely to have wide scale application in the water industry.

In the USA some utilities including American Water are looking at large installations on utility-owned land. One offshore pilot turbine in Cleveland and one onshore wind farm in New Jersey with five 1.5MW turbines are in operation. Wind turbine projects are only likely to be considered where they fit into a carbon reduction strategy and the wind resource and planning issues allow them to deliver cost effective savings. In practice it is more likely that water turbines will be used since their output would more closely match any pump energy demand.

There are some applications where a small power supply is required remotely from mains electricity supplies and there are proprietary solutions offering wind and solar photo-voltaic (PV) packages. Energy storage such as a battery is essential so these applications are restricted to low power requirements. No case studies are presented but some schemes have been installed.

There are two case studies for solar energy, a 700kW array on a waste water plant in California and an 800kW facility at two water treatment plants in New Jersey, USA. The relatively high capital cost, the low efficiency of PV and the lack of demand for heat energy on water works from solar thermal systems means that such projects are aimed at net energy demand reduction or grid independence but may be viable only with subsidies.

On waste water works gas from digested sludge is a convenient, robust and reliable source of heat and power. The technology is mature. Using gas bags or digester floating roofs also provides a form of energy storage which solar or wind power facilities cannot.

Approaches to sludge gas and CHP energy vary across the globe. Some utilities restrict CHP to large works, some concentrate their sludge at strategic treatment centres and some install site specific solutions. The type of process and plant varies too, with pump types, mixers and gas blowers being subject to corporate preferences. Most generators are powered by reciprocating engines but gas turbines are apparently less susceptible to the effects of siloxanes. Small gas turbines are not usually economic but there are examples from the US and the UK which are apparently viable. There are also examples of fuel cells and Stirling engines used for powering electricity generation from biogas. Where the heat cannot be used on site a Swiss example shows that treatment and export to a gas grid is feasible.

A recent development is advanced sludge treatment and although the primary driver may be sludge quality for recycling there are significant benefits for the quantity of gas generated. This particularly applies when proportions of Surplus Activated Sludge (SAS) are high, which may be from oxidation ditch treatment, or in an ASP may reflect back on opportunities for optimising effluent treatment and sludge production. There are case studies on enzymic hydrolysis and thermal hydrolysis. Case studies are also given on ultrasonic and electrical pulse treatment of sludges which break down the sludge cell structure to release more biogas.

Another method of increasing gas production is to co-digest sewage sludges with other materials. Case studies illustrate using fats, oils and greases (FOG) in the effluent and using external wastes such as municipal green waste and dairy manure. Outputs are dependent on quality and consistency of the external wastes and there may be regulatory issues about what sort of wastes may be digested depending on the sludge disposal route.

5 Conclusions

The demand for drinking water and sanitation across most of the world will continue to rise. As human populations increase and migrate to cities the intensity of demand for water will become more difficult and energy intensive to service. This trend is against national and international environmental and regulatory requirements to reduce carbon and energy in the industry so there are major technical, management and governance challenges. Most water utilities are also subject to financial limitations such as the availability and cost of capital investment and some increased expenditure will be required to meet the uncertain challenges of climate change.

This report focuses on energy efficiency, current technologies and achievements, and the potential for further gains. Most of the case studies have inevitably shown successful instances of energy savings but these cannot be taken as a potential average across the industry. If we take the improvements made on the 119 case studies and examples we cannot assume that these gains will be applicable to the thousands of works around the world, or even where they are relevant, that they will achieve the same savings. However, it is hoped that as water utilities embrace energy efficiency, they will follow and improve on some of the best practices described in this Compendium. As a consequence the international water industry will be able to limit increases in energy demand to a practical minimum that delivers the required level of service to the consumer.

It is also evident that cost-benefit exercises use historic data for energy costs due to uncertainty. Over the last ten years UK energy prices have more than trebled and within the medium term, say over the next ten years, global energy prices will only increase annually. Ten years is equivalent to about half of the design life of most mechanical and electrical equipment being installed today, so it is strongly recommended that forecast future energy costs be used in cost benefit and feasibility studies to encourage more energy efficiency features to be incorporated into capital and maintenance projects. This is a sensible addition to the essential use of wholelife costing instead of just capital costs for plant selection.

The case studies show that different companies have historically adopted widely varying approaches to energy and are at different stages of adopting operational energy efficiency within the water cycle. For those companies just starting to look in depth at performance efficiency the savings quoted will probably be achievable. Those companies that have been investigating and implementing efficiency interventions for some time will be closer to the optimum and therefore are less likely to be able to make further significant gains.

5.1 Energy usage

It is misleading to generalise on energy usage, even across a relatively small regional area such as the UK. The energy demand percentage split for drinking water cycle divided between raw water, treatment and distribution could vary between 35/10/55 and 40/20/40, depending on geology, geography, population density and the concentration and type of industry. Geography seems the most important differentiator as this determines the source and reliability of clean raw water and the need to pump it for treatment and distribution.

For wastewater the variations are less pronounced and an average split of 28/70/2 between sewerage, treatment and disposal seems reasonable. However, this hides extreme differences between traditional percolating filters, where the treatment energy demand is minimal, and advanced activated sludge plants represented by the above numbers. Geography may also determine the required standard of effluent treatment and the discharge pumping energy.

Apart from the cost of energy data derived from the Ofwat annual return data for England and Wales, (see Section 4 above) there is limited energy demand information of the split between clean and waste water cycles. Comparisons are made more problematic because of the need to reflect common areas for drinking water supply and sewerage. However the perception is that the split is probably 45% to 55% water to sewage cycles, but with a potentially wide variability depending on site specific and catchment area characteristics.

There is strong evidence that up to about 15% of wastewater energy demand can be offset by biogas generation and CHP.

5.2 Potential Savings - Pumps

Various methods of saving energy in pumping have been demonstrated by case studies across different areas of the industry. Although some have shown significant improvements the general level of awareness of operation and engineering seems to be good. This tends to indicate that the potential for further savings may be reducing and the original estimates of between 5 and 10% being available for both incremental and significant investment seems about right.

Improvements could occur in different areas, for example incremental changes may get close to the best for some pumps, particularly in drinking water, whereas other pumps may need significant interventions. The other possibility, probably more applicable to waste water, is

Shenley Grounds Pumping Station, Anglian Water

that minimal investment, for example on portable instrumentation, may lead to significant operational improvements and indicate where further gains could be achieved through more expenditure such as on maintenance, refurbishment, changing the pump speed with a belt drive or VSD, installing a better suited impeller or replacing the complete pump.

Subject to the caveats at the end of the introduction above and recognising that experience suggests that many pumps are operating close to their best efficiency points, it is likely that the industry’s pumping energy efficiency could be improved by between 5 and 10%.

5.3 New Technology - Pumps

Apart from some smaller and multi-stage small diameter pumps, it is unlikely that technical advances will realise substantial improvements in pump efficiency. There are limits to the hydraulic efficiency of impellers and volutes for centrifugal pumps and although some pumps may benefit from analysis using techniques such as Computational Fluid Dynamics (CFD) modelling, the potential here is small. Coatings simulate or present an improved surface finish which can gain 5% over a typical sand cast equivalent, but this is probably the upper limit.

Electric motors are generally 95% efficient or better so only a limited number of large older drives will be economic to replace with newer high efficiency types of 97%.

Technical improvements may therefore realise between 3 and 7% improvement. The problem with single figure gains is that investment purely for energy efficiency is not economic so replacements and improvements will only arise when other investment drivers tip the financial balance. The exceptions may be on submersible and borehole motors where manufacturers may find there are more gains to be made.

5.4 Potential Savings – Process

The energy usage in water treatment process is low so the overall potential for achieving large reductions is also low. The paucity of case studies of drinking water processes suggests that this conclusion is correct.. European studies suggest that improvements to one component of a process cycle highlighted optimization opportunities within the whole or other processes. Higher energy prices may stimulate some research and optimisation in this area.

The disappointing response on Dissolved Air Flotation (DAF), membrane technology, Ultra-Violet (U/V) systems and ozone may indicate a perception that these areas are static. However it could be worth checking technical advances against the efficiencies of older systems to see if equipment or control updates would yield cost effective energy saving investments. Membrane suppliers advertise the performance of their latest technology so it should be worth challenging them to update potentially less efficient existing cartridges, reduce pumping pressures, decrease reject filtrate and reduce chemical use for clean in place systems.

No new technology has been highlighted for drinking water but a hierarchy of alternative interventions is given in Table 5.1 for current processes based on their energy efficiency.

Table 5.1: Water Treatment Processes Energy Hierarchy

← Low energy use	High energy use →

Clarifiers	Hydraulic Mixers	Media back wash	Chemical dosing	UV Disinfection	Dissolved Air Flotation

The potential for wastewater processes is much more variable. As stated in Section 5.1 above, a trickling or deep bed biological filter process has very low energy requirements, but where pollution and standards demand activated sludge plant (ASP) or their derivatives there may be significant gains. Case studies have reported between 15 and 50% possible gains on aeration energy demand, so, given that some works must be operating close to ideal efficiencies, the average may be as high as 25%. The case studies also show that such gains can come from incremental changes, such as matching instruments or controls to consent parameters, as well as more capital intensive exercises. It is important to remember that, while the blowers are the high energy consumers, the whole system from inlet air filters through controls to diffusers will determine the energy they use.

Savings can be achieved of up to 55% on RAS pumping through process optimisation. Again, although the pump represents the energy demand, it is the whole system which needs attention to optimise gains.

5.5 New Technology – Process

In addition to improvements to existing processes there is potential in two other directions. In some cases there are both trickling filters and ASP streams on the same site. This indicates that the pollution loads against the consent standards are marginal and in these cases either technical or operating improvements to the filters or a debate on the consent standard could result in significant energy saving. Technical developments include recirculation and polishing filters.

Activated sludge plant - Naburn, York, UK

There is also an opportunity for significant potential energy saving if discharge consents can be rationalised. The two debates centre on the issues of appropriate treatment standards for discharge into the receiving water or reuse potential, and the balance between the need for enhanced treatment for increasingly higher standards versus the increased pollution caused by the energy generation required for meeting the standard. However the conflict is managed, there will need to be a compromise between sustainable processes, natural resources, the environment and stakeholders.

One wastewater process not fully explored is anaerobic treatment. There appears to be potential for converting air-tight odour control covered processes from aerobic to anaerobic treatment with the benefit of higher yields of biogas and therefore higher energy recovery through CHP. Although there are no case studies included in the Compendium, we are aware of two operational plants in the world, one pilot plant in the UK and a second plant in the Middle East. This is therefore a possible technological development.

Table 5.2 lists the hierarchy for sewage treatment processes. By optimising current processes it is feasible to increase primary sludge production which reduces load on aeration blowers and increases digester biogas production. Net energy efficiency is thereby increased particularly with sludge digestion and CHP on site.

Table 5.2: Sewage Treatment Processes Energy Hierarchy

← Low energy use					High energy use →
Biological (percolating) filters	Anaerobic membrane bioreactor	Bio-aerated flooded filter	Step fed activated sludge(ASP)	Nutrient removal ASP	Conventional membrane bioreactor

5.6 Sludge

The principles of efficient sludge handling should be well established but other priorities such as reliability are more important. For mixing, zoned air or gas is effective and uses least power but the use of this technique is far from universal. Where relevant, air mixing keeps sludge 'sweet' thereby reducing odour and corrosion, particularly in steel tanks.

The characteristics of the sludge are the key parameters for thickening. An energy hierarchy (see Table 5.3) favours picket fence thickeners (PFT) or drum thickeners over belt thickeners or centrifuges.

Table 5.3 Sludge Thickening Process Energy Hierarchy

← Low energy use				High energy use →
Picket fence thickeners	Drum thickeners	Belt thickeners	Belt presses	Centrifuges

For maximum biogas production, volatile solids destruction and hence energy generation, digesters would appear to prefer low rate continuous feed rather than batch feed; zoned gas mixing to maintain homogeneity and maximum effective volume; pumped recirculation for maintaining temperature, and a consistent feedstock. Pre-treatment techniques for enhancing gas yield from Secondary Activated Sludge and enhancing pathogen kill are useful but primary sludge is the ideal for digestion. Maximising the primary sludge production from a works has three benefits:-

- reduces the loads carried forward to the secondary treatment process thereby saving aeration energy,
- improves the ability of the digesters to break down organic matter thus increasing biogas production for energy generation through CHP plant,
- reduces the SAS solids load which may

Thermal Hydrolysis plant - Milton Keynes, UK be difficult or energy intensive to treat.

There are a number of advanced digestion techniques available and some have full scale results showing energy gains. Some techniques use electricity as a source of energy to break down sludge cells and claim that this energy usage is off-set by the increased biogas production. Both thermal and enzyme hydrolysis have numerous installations with good results, however, there is no clear preference between thermal and enzymic hydrolysis on the grounds of energy efficiency.

There are two case studies for co-digestion of sewage sludge with other biodegradable wastes. More local and municipal authorities are now separating their waste types at source so there should be opportunities for flexible use of digestion. Current incentives in the UK include an improved allocation of Renewable Obligation Certificates (ROCs) for generating electricity from co-digested sludge against ordinary sewage sludge.

5.7 Building Services

For plant in kiosks or control rooms the provision of air conditioning (A/C) plant should be challenged. Plant generating waste heat, such as VSDs, should be direct cooled and natural ventilation optimised for a lower energy solution.

Insulation methods for external pipes and plant should be reviewed: although this is only seasonal use of energy in most places it probably coincides with peak tariff periods. If the insulation is wet it may be ineffective.

There are opportunities for installing automatic lighting controls, more efficient fittings and changing workplace operational practices to reduce the lighting energy in unmanned areas. Lighting schemes should be reviewed with operational staff to ensure compliance with Health & Safety regulations. Older fittings could be cost effectively replaced.

The potential for energy efficiency improvements in building services may be up to 15% but apart from simple control changes these are unlikely to be cost effective when installed piecemeal. The larger gains will be achieved when buildings are refitted for other reasons or a new building is constructed.

5.8 Renewable Energy

Hydro-turbines are mature technology and generally can be fitted as direct replacements for PRVs in pressure managed pipes and water distribution areas. Hydro-turbines can also be considered for situations where hydraulic head is currently being dissipated. Feeding electrical power back into the grid by fitting an electrical incomer into the existing distribution system may be more difficult. Controls to avoid transient hydraulic pressures under emergency conditions may also need careful consideration.

Most hydro-turbine installations will be relatively small, between 50kW and

Point Loma WWTW, Hydro Power Demo, California, USA

500kW and will probably not make a big impact on the net power demand of the water industry.

There seems to be limited appetite for solar or wind power for most water utilities. Some small solar photo-voltaic (PV) installations exist for remote low power applications, such as instrumentation and communications, but the panels are known as a target for vandals. Both solar and wind power opportunities are very dependent on the availability of the resource and location of the installation. Planning approval remains a potential obstacle in countries such as the UK, and installations are unlikely to be funded within a regulated business. Furthermore there will be few opportunities where the process demand profile matches the energy supplied from wind or sun.

Combined heat and power (CHP) from sludge gas is still the major source of renewable energy in the water industry and there is potential for its development in conjunction with enhanced sludge digestion and possible co-digestion schemes. CHP is usually only considered above 150kW capacity, but schemes up to 12MW have also been installed. The technology has the potential for a significant impact on the water industry's net energy demand at both ends of the scale.

There are major technical development efforts in most branches of renewable energy but materials and thermodynamic laws impose practical limits. Solar PV panels are the best example where high value materials are used and unit costs remain high but efficiencies are low. Solar thermal panels are commercially more reliable but of limited use to the water industry, whereas hydro, wind turbines and sludge gas CHP are mature technology.

5.9 Future Energy Balance

We conclude therefore that the potential for energy savings are :-

1 A minimum of 5% to 10% though water conservation and water loss reduction but with significantly greater opportunities where companies are resource constrained

2 5% to 10% from existing pumps,

3 3% to 7% through improvement to pump technology,

4 Up to 20% from drinking water processes, but the energy use in this category is low,

5 Up to 25% in ASP wastewater plant,

6 Up to 15% improvement in building services,

7 Renewable energy, mainly in the form of CHP from sludge gas, could contribute significantly to the net energy demand of the water industry.

8 'Drinking water only' companies have limited opportunities for net energy gains.

Overall energy efficiency gains of between 5 and 15% seem realistic across the water cycle. However this conclusion must be taken in context. The case studies demonstrate that historically different companies and regions have adopted widely varying approaches to energy management. For those companies just starting to look in depth at energy efficiency, the savings quoted will probably be achievable; conversely, those who have been intensively investigating and implementing energy efficiency for some time will be closer to the optimum and therefore less able to make further significant gains.

Users of the Compendium cannot assume therefore that all the efficiencies gained from the case studies will be applicable to the thousands of works around the world, or even where they are relevant, that they will achieve the same savings. However, it is hoped that as water utilities evolve and changes are made they will follow and improve on some of the best practices described here.

The study has not identified any major imminent technological developments to reduce demand for energy in the water cycle or to increase efficiencies substantially.

This report has set no timescale for realising potential energy gains, but if the right financial conditions are put in place, incremental improvements should be achievable with two to three years. More substantial changes will depend on infrastructure development and asset maintenance business plans which typically identify projects in 5 or 10 year programmes of work.

With the above limits on efficiency gains, and without significant technical breakthroughs, more emphasis will be needed on routine issues such as training, team working across traditional departmental boundaries, and improved operation and maintenance to achieve best practice on energy efficiency across the industry. This implies that the balance of emphasis between Capex and Opex may need to change and financial models such as “spend to save” projects should be encouraged. The Carbon Reduction Commitment or its local equivalent will help, but national or regional targets for significant carbon cuts may require different thinking from all concerned in the global water industry.

6 Recommendations

The main opportunities that will impact energy efficiency in the water industry in the near future are summarized in Section 5.9 above. However, in order to optimize efficiency gains, we recommend that companies also:

1. Consider where incremental improvements or technologies are relevant in the local or regional context and follow the advice and examples where applicable.

2. Use future electricity prices in financial analyses, projected to about half the design life of the proposed facility; say ten years.

3. Review drinking water processes, including DAF, membrane packages, U/V systems and ozone to implement current optimum performance and energy demand.

4. Align wastewater process controls with discharge consents.

5. Pursue treatment improvements for waste water bio-filter technology in combination with negotiating realistic discharge consents; both absolute and varying seasonally,

6. Rationalise energy required to achieve consent standards with pollution from energy generation. Include overall fuel-electricity-water pump system efficiency (about 20%).

7. Review energy demand for sludge mixing regimes and sludge thickening plant.

8. Reassess comparative energy demand of various enhanced sludge treatment processes.

9 Pursue sludge gas CHP and opportunities for co-digestion with other wastes.

10 Obtain more case studies relating to operational management, and maintenance, process, research, finance and regulation, all of which are inextricably linked to the process.

11 Undertake a more in-depth statistical analysis of water industry data to validate or correct energy usage and potential savings.

12 Update this compendium bi-annually with current case studies/industry best practice. Include more contact with academia for research on new processes, such as anaerobic effluent treatment.

Appendix 1 – Acknowledgement

The companies listed below supported this project and contact names and details have been supplied where available.

Organisation	Contact	Position	Phone	Email
Continental Coordinators				
KWR	Jos Frijns	Knowledge and Program Mgr	Office: +31 3060 69583	Jos.Frijns@kwrwater.nl
PUB of Singapore	Puah Aik Num	Deputy Director	Office: +65 6326 2988	PUAH_Aik_Num@pub.gov.sg
STOWA	Cora Uijterlinde	Research Manager	Office: +31 30 232 1199	uijterlinde@stowa.nl
Water Environment Research Foundation	Lauren Fillmore	Program Director	Office +1 571 384 2100	lfillmore@werf.org
Water Research Foundation	Linda Reekie	Project Manager	Office: +1 303 734 3423	lreekie@waterresearchfoundation.org
Water Research Commission	Jo Burgess	Research Manager	Office: +12 330 0340	job@wrc.org.za
Water Services Association	Adam Lovell	Manager of Science and Sustainability	Office: +61 2 9221 0082	adam.lovell@wsaa.asn.au
UK Participants				
UKWIR	Gordon Wheale	Programme Manager	Office: +44 (0)1422 823683	gordon@wheale.fsnet.co.uk
Anglian Water	Matthew Pluke	Energy Manager	Office: +44 (0)1733 414100	mpluke@anglianwater.co.uk
Bristol Water	Patric Bulmer	Environment Manager	Office: +44 (0)117 9665 881	Patric.Bulmer@bristolwater.co.uk
Dwr Cymru Welsh Water				
Northumbrian Water	Ken Black	Optimisation Manager	Mobile: 07802678968	ken.black@nwl.co.uk
Scottish Water	Peter Beveridge	Energy Efficiency Manager	Office: +44 (0)1413 55 5541	Peter.Beveridge@scottishwater.co.uk
South East Water	Kevin Clark	Energy Efficiency Manager	Office : +44 (0)1323 870810	kevin.clark@southeastwater.co.uk
South Staffordshire Water	Matthew Bates	Carbon & Energy Manager	Office : +44 (0)1922 638282	matthewbates@south-staffs-water.co.uk
South West Water	Alan Burgess	Energy Manager	Office : + 44 (0)1392 443768	aburgess@southwestwater.co.uk
Southern Water	Martin Ross	Energy & Carbon Manager	Office: + 44 (0)1273 663153	Martin.Ross@southernwater.co.uk
Sutton & East Surrey Water	Alison Murphy	Distribution Engineer	Office : + 44 (0)1737 772000	alisonm@waterplc.com
Sutton & East Surrey Water	Rob Baldry	Distribution Engineer	Office : + 44 (0)1737 772000	robb@waterplc.com
Veolia Water Central (formerly Three Valley Water)	Darren Hewerdine	Energy Optimisation Engineer	Office : +44 (0)1707 268111	Darren.Hewerdine@veoliawater.co.uk
United Utilities				
Wessex Water	John Leonard	Energy Manager	Office : + 44 (0)1225 526290	john.leonard@wessexwater.co.uk
Yorkshire Water	Ilyas Dawood	R&D (Energy)	Office : + 44 (0)1274 804664	ilyas.dawood@yorkshirewater.co.uk

Appendix 2 ~ Appendix 5

In electronic format only, contained on accompanying CD.

Please follow the links below in electronic version of report on CD.

Appendix 2 - Case Study Guidelines

Appendix 3 - Case Studies and Factsheets

Appendix 4 - Literature Review

Appendix 5 - Continental Reports

Australasian Report

European Report

North American Report – Drinking water

North American Report –Wastewater