SUSTAINABLE DESIGN THROUGH THE TWELVE PRINCIPLES OF GREEN ENGINEERING

Anita Lloyd, Harrison Grierson Consultants Ltd

ABSTRACT

Sustainability and sustainable design have historically occurred as a portion of the project. Such as mitigating environment effects associated with water takes by ensuring no take reduces water flows below the 85% fish protection level or for treated effluent discharges all potential downstream effects are considered for example of soil and groundwater analysis and dispersion modelling.

Sustainability of the entire project from design through to construction and operation is now considered a minimum requirement with focus being applied to how this is consistently achieved. While these specific project outcomes are targeted to achieving sustainable design the outcome tends to be sustainable design elements incorporated sporadically throughout the project as opposed to a holistic approach.

The 12 principles of green engineering have been developed by Anastas, P.T and Zimmerman, J.B to enable engineers to incorporate elements of sustainability throughout all areas of a project in a systematic and comprehensive approach. This paper discusses these 12 principles and outlines how these parameters can be implemented throughout the design process to optimize the sustainable outcomes of that design for the water and wastewater industry.

KEYWORDS

Sustainable Design, Green Engineering

1 INTRODUCTION

In today's society engineers are being driven to create processes and products that are sustainable, environmentally friendly and financially viable. Sustainability as defined by the World Commission on Environment and Development is, forms of progress that meet the needs of the present without compromising the ability of future generations to meet their needs.

Historically sustainability and sustainable design tends to have been incorporated into a portion of the project typically the outcomes such as mitigating environment effects associated with water takes by ensuring no take reduces water flows below the 85% fish protection level or in treated effluent discharges ensuring all potential downstream effects are considered for example of soil and groundwater analysis and dispersion modelling. This incorporation is typically more sporadic than comprehensive.

Additionally there is the perception that sustainability costs more than the historical ways of doing things. Traditionally products and processes often do not reflect their "full" cost, that is, the cost of the environmental and social impacts from this product or process. An example of this is in terms of pollution cost, is products that are made with polluting materials generally do not include the extra cost of clean up or disposal. This cost is paid by tax-payers and the environment therefore allowing the product to be sold at a cost lower than the full product lifecycle cost.

Where the sustainable product or process does in fact provide a cost saving, particularly over the entire lifecycle of the product or process in terms of both operating and capital costs these tend to have been implemented into the water and wastewater industries as technologies advance and upgrades to the plants occur.

Sustainability of the project outcomes is now considered a minimum requirement and more focus is being applied to how the outcome is achieved in the design and construction of the plant. Green engineering is the term that has been coined to encompass the sustainability component into good engineering design.

The 12 principles of green engineering have been developed by Anastas, P.T and Zimmerman, J.B to provide a framework for engineers to implement when designing new materials, products, processes and systems. These principles have been developed with broad statements so they can be applied over a wide variety of engineering and science fields, the purpose of this paper is to illustrate how they can be applied to the water and wastewater industry.

2 INHERENTLY NON-HAZARDOUS

Principle one of the twelve principles of green engineering states that engineers need to ensure that all material and energy inputs and outputs are as inherently non-hazardous as possible. In implementing this principle this requires the engineer to consider the selected material and energy inputs and outputs to ascertain the hazardousness of each and evaluate whether there maybe a less harmful option which still meets the needs of the client and project.

For situations where a hazardous input or output is selected there is the additional cost to the project of clean up or purification of that input or output. This clean up often involves a significant amount of time and resources (human, materials and energy). As well as this additional cost there is the risk of failure of the clean up or purification steps thus potentially releasing hazardous materials to the environment, and/or affecting workers and general public health.

In the water and wastewater treatment industries the hazardous inputs and outputs are often created from the addition of chemicals to treat the water or wastewater, and often choices regarding chemical use are cost driven rather than by the consideration of the hazardous nature of the chemicals or outputs they create. It is usually more cost effective to transport concentrated chemicals, which are inherently more hazardous than their dilute forms due to the difference in quantity required.

In a number of New Zealand locations septic tanks have been installed upstream of the wastewater treatment plant. Septic tanks typically remove a significant portion of carbon measured as biological oxygen demand, from levels of 250mg/l to 150mg/l. Removal of ammonia in the wastewater is typically achieved through nitrification, which is dependent on a carbon source. With the septic tanks upstream of the wastewater treatment plant this can make carbon the limiting factor to achieving good ammonia removal. To remedy this lack of carbon methanol can be dosed into the wastewater treatment plant. Methanol is a hazardous chemical both to the environment and general human health this requires careful handling and storage. An alternative carbon source to methanol is molasses. Molasses is significant less hazardous than methanol however there are difficulties with this in terms of handling and this can level a residual colour in the wastewater.

Principle one drives engineers to take into account the inherent nature of the selected or provided inputs of outputs to ensure it is as non-hazardous as possible, in terms of toxicity, minimal energy and material inputs to complete the process.

3 PREVENTION AS OPPOSED TO TREATMENT

Principle two states that it is better to prevent waste than to treat or clean up after it is formed. This is a generally well understood principle that has existed in concepts such as the recycle pyramid “prevention, minimisation, reuse, recycle, dispose” and the “zero waste” aim. Waste can be defined as a material or energy that an existing process can not convert into further useful products. The generation of this waste and further handling in turn creates further waste in terms of finances and resources (human and material). So prevention of waste saves money in both creation and treatment.

Engineers are often asked to design solutions to treat the waste once created, whereas this principle states that review should be held to ascertain if source reduction can be achieved.

This principle is particularly applicable to the wastewater industry where a large portion of the influent to a wastewater treatment plant is in effect water. Water comes from the many washing functions at individual houses such as dishwashers, shower, washing machine and from groundwater infiltration and stormwater inflow into reticulation pipes. This large portion of water can place hydraulic strain on the plant. Under principle two this would encourage the reduction of infiltration and inflow into the wastewater treatment system. This can be achieved by repairs to the reticulation network and/or upgrades such as sealable manhole covers and pressurised mains. Low pressure mains can reduce the effects of infiltration and inflow on the hydraulic load to a plant by thirty percent. Additionally the use of these systems can smooth diurnal variations. This is achieved by settling up the grinder pumps so that they pump out sequentially ensuring a consistent flow to the wastewater treatment plant.

In addition to reducing flow to the treatment plant by modifications to the reticulation network principle two guides the engineer to investigate reduction at the source i.e individual houses by methods such as water reducing fixtures, dual flush toilets, grey water reuse.

Another example of principle two in the wastewater situation is the regulation of industrial wastewater sources to the treatment plant through the implementation of a trade waste bylaw. Trade waste bylaws enable the District Council to reduce the concentrations of pollutants from industrial sources by setting maximum concentration or load limits and requiring pre-treatment before discharge to the sewer. This can reduce levels of metals to the treatment plant which in turn lowers the levels of these in the biosolids and therefore means these biosolids are more re-usable as a fertiliser type product.

Principle two steers the focus of design towards using materials and processes that generate minimal waste thereby removing costs and risks associated with wastes that would otherwise have to be processes, treated and disposed of.

4 DESIGN FOR SEPARATION

Principle three states that separation and purification operations should be designed to minimize energy consumption and materials use. The separation of products is a process that can expend large amounts of energy and resources. Decisions at the earliest stage of design can impact the ease of separation and purification for later reuse and recycling of components.

In the water treatment industry a large numbers of water sources are from streams, and therefore the quality can be affected by upstream pollution. Therefore engineers should ensure no industrial or domestic wastewater sources discharge upstream of the take point. Whilst there maybe controls on the discharges no system is fail proof and may potentially contaminate the water source, thus requiring additional treatment at the water treatment plant.

Another example of designing for separation in a wastewater treatment plant is in the solids treatment stream. Centrifuges are typically used to dewater the sludge to enable reuse of the product. Installing a gravity belt thickener prior to a centrifuge reduces the water and enables the centrifuge to work more efficiently, thus a smaller centrifuge could be installed or if installed prior to an existing centrifuge then this may provide sufficient increase in capacity to prevent additional upgrade by the installation of another centrifuge.

Treated effluent from wastewater treatment plants can be beneficially reused due to the nutrients nitrogen, phosphorus and potassium. These can be used as a fertiliser for agriculture The main source of these in wastewater is from human urine. Separating the urine, which only accounts for about one percent of the total wastewater flow, and using it as fertilizer makes it possible to utilize most of the nutrient content of wastewater. When a urine separating system is introduced, nitrogen discharge into water is reduced by about sixty percent irrespective of the type of treatment. This has been trialled in the ecocity Kullön within the municipality of Vaxholm in Sweden where the town was planned and built based on knowledge about urine diverting systems at the end of the 1990s. As the system was installed when the new houses were built the separation process works well and provides reuse of the urine as fertiliser for local farms crops.

Designing products and/or processes for self-separation can decrease waste, saves cost and reduce processing times.

5 MAXIMISE EFFICIENCY

Principle four states that products, processes and systems should be designed to maximise mass, energy, space and time efficiency. This is stating simply that if a system or process is designed and applied at less than the maximum efficiency then resources are being wasted throughout the process.

This principle is easily applied to the water and wastewater industries. An example of this is treatment systems control. Historically control systems for chemical dosing and aeration have been based on either time or feedback loop from influent flow. This does not provide an accurate picture of the needs of the process and can lead to poor effluent quality or overdosing and high client operating cost. Online real time monitoring ensures that just the right amount of chemicals and other inputs such as air from blowers are being added. The addition of real time monitoring can be a large cost to the client upfront but has a financial payback over time and can save significant operating costs through reduction in chemical and energy use.

A significant amount of wastewater treatment plants are designed on peak hydraulic loads, this maybe due to storm events and the effects of inflow and infiltration or holiday fluctuations in population. Designing a wastewater treatment plant to treat this maximum capacity is inefficient. Possible solution is to discharge this peak directly to disposal but this has unacceptable environmental, cultural and public health issues associated.

Principle four guides the designer to consider the overall efficiency of the system over its lifetime. Thus achieving the aims of sustainability whilst still providing a financial incentive.

6 LE CHATELIER'S PRINCIPLE

Principle 5 states that products, processes and systems should be "output pulled" rather than "input pushed" through the use of energy and materials. This principle was developed based on Le Châtelier's principle which states that when a stress (such as temperature, pressure or concentration gradient) is applied to a system at equilibrium, the system readjusts to relieve or offset the applied stress.

There is a tendency consider projects based on the inputs provided such as the water source to a water treatment plant or influent to wastewater treatment plant. The aims of the project should be the treatment of water or wastewater in a sustainable manner. In addition to the water source or influent the choice of process, chemicals and energy sources can all be considered as inputs to the overall system and therefore the sustainability of these should influence the chosen inputs.

In wastewater treatment system an example of an output pulled process could be oxidation ponds. Once constructed these have very low operator input and low operational cost. Disadvantages are that they require a large land area and can not produce the high effluent quality that more technologically advanced plants produce. Oxidation ponds can be upgraded or retrofitted to produce higher quality effluent by adding baffles to prevent short circuiting and improve flow paths and/or by installing floating wetlands into a portion of the pond. Floating wetlands can remove nutrients such as nitrate and phosphorus and metals from the wastewater further to the treatment achieved through the ponds. The biofilms and microbial activity begins on the root zones and amongst the matrix itself, these microbes then convert nutrients, to an available food source for plants and invertebrates. In addition to the treatment provided floating wetlands provide the habitat for birdlife.

Approaching design using this principle requires the designer to minimise the amount of resources consumed to transform inputs into the desired outputs.

7 CONSERVING COMPLEXITY

Principle six states that embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse or beneficial disposition. More and more products and plants used in the wastewater and water industries are highly technologically advanced and are complex combinations of a number inputs. Recycling by separation of the individual components would be a difficult and time consuming process with little financial reward. Therefore for these highly complex products or process recycling is an inappropriate option.

In the wastewater industry the recycling of membrane sheets from water treatment plants to be used in wastewater treatment plants. These membrane sheets would have otherwise been discarded to landfill because the complexity makes it difficult to break down to recyclable parts. The membrane sheets are removed from the water treatment plant refurbished and supplied to the wastewater treatment plant with standard supplier guarantee.

Recycling components that have high complexity in many cases comes at a loss of value, where as materials of minimal complexity have more favourable properties for recycling.

8 DURABILITY OVER IMMORTALITY

Principle seven states that targeted durability, not immortality, should be a design goal. Over time technologies evolve and improve and therefore designing a process or product to last forever does not make financial sense.

The process or product need to be durable enough to last for the expected lifetime albeit with effective and efficient maintenance and repairs. Effective and efficient repairs can be defined as the minimal addition of time and energy to maintain them.

Asbestos pipes have a long life and have been used extensively in wastewater reticulation. However over time the pipes degrade and begin to have issues with inflow and infiltration into the system lending to their required replacement. Removal of asbestos pipes is hazardous due to risks from a inhaling the mineral's microscopic fibres'. The risk is also dose-related: the more you inhale, the greater your chance of long-term harm.

Products that last beyond their useful life can often be the cause of environmental problems in disposal due to their persistence and bioaccumulation. By designing products/processes that withstand the typical operating conditions but still possess a targeted lifetime such issues can be avoided.

9 MEET NEEDS BUT MINIMISE EXCESS

Principle 8 states that design for unnecessary capacity or capability solutions should be considered a design flaw. In the water and wastewater industries post the individual household each project has its own set or unique constraints and varied inputs and outputs. Therefore in most, if not all situations a "one size fits all" solution is unlikely to provide satisfactory outcomes.

In wastewater treatment the lack of influent data in terms of flows and loads can lead to over design due to the tendency of engineers to err on the side of caution by the inclusion of large safety factors. It is far better to understand the design requirements fully than to over design a system to treat what may or may not be occurring in the local environment.

The use of flow balancing at wastewater treatment plants over an increase in treatment capacity is another example of meeting needs whilst minimising excess. The flow balancing ensures that the wastewater treatment plant is not overloaded in peak storm flows. Works well with biological treatment systems as these can take time to acclimatise to sudden influxes of flows and loads. This flow balancing can utilise existing tankage or ponds which may otherwise not be used.

Another example of design that meets the needs of the users but minimises excess is the one use toilet bag. This addresses the needs of 2.6 billion people in the world who don't have access to proper wastewater management systems. The bag is coated with a thin film of urea. This non-hazardous chemical is a natural fertilizer, and it breaks down the enzymes in the faeces or urine to inactivate the diseases within in a short period of time. The bag itself is biodegradable and thus can be buried. The bag addresses the needs of the community without putting a large cost for treatment and disposal onto the residents of poorer nations.

Over designing processes or products to have significant flexibility and the ability to meet worst case scenarios can often result in high cost in terms of capital and operational. Process and plant should be targeted to the specific demands of the users not only minimises waste and cost.

10 MINIMISE MATERIAL DIVERSITY

Principle nine states that material diversity in multi-component products should be minimized to promote disassembly and value retention. An increase in components means that the product or process can be more difficult to disassemble and therefore less likely to be recycled or reused and more likely to be wasted.

In the wastewater and water treatment industries using similar components over a number of plants can allow the District Council to interchange these components between plants as growth or other constraints require. This not only saves cost for the Council but maximises the usage of the product. District Councils should develop a list of "approved supplies" to ensure consistency between plants, this list could include two suppliers for various items to ensure competition.

Less material diversity means more options for recyclability and reuse.

11 INTEGRATE MATERIAL AND ENERGY FLOWS

Principle ten states that the design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows.

This principle guides the engineer to use existing resources, that is re use existing assets or energy. This reuse of the existing assets in upgrades may not be practicable for all cases, but for Council's that have a large number of wastewater treatment plants over the district they maybe able to make use of the assets at another plant for an overall district gain.

In pond systems the existing sources are well utilised with the energy from the sun providing disinfection through the pond system. The sunlight also provides source for growth of algae. Another wastewater example is in solid waste treatment from wastewater treatment plants the gas generated from the digesters can be used to fed a boiler to heat the digester.

An example of material integration in the water treatment industry is at Hikurangi water treatment plant. The plant is located significant distance away and power reticulation to the site was costly. The installed plant is a membrane treatment system and thus requires power item to run. To address this the head from the raw water pipeline was used to drive a turbine to produce power for the plant.

Products, processes and system should be designed to use local materials and energy resources i.e as close to the source of possible to minimise efficiencies and consumption associated with transport.

12 COMMERCIAL AFTERLIFE

Principle 11 states that products, processes, and systems should be designed for performance in a commercial "afterlife."

As technology advances components tend to be prematurely retired to make way more systems more technologically advanced. Therefore in selection of products and processes the consideration for this component to be reworked or reused should be considered.

In the wastewater industry sludge treatment can be considered a process that should be designed for the commercial afterlife. Sludge is a by-product from the biological treatment of the wastewater. This has been historically disposed of to landfill for many wastewater treatment plants around the country. The sludge is high in phosphorus and can be used as a fertiliser either in a liquid form to large farm areas or by further treatment to a bagged product suitable for at home use. This additional treatment has a large capital cost, but when balanced against the environmental cost of disposal can prove to be financially viable.

Designing products, processes and systems such that their components can be reused or reconfigured to maintain their value and usability for new products.

13 RENEWABLES RATHER THAN DEPLETING

Principle twelve states that material and energy inputs should be renewable rather than depleting. This principle is generally well understood and even the general public are making moves to change their behaviours, by the use of cloth bags instead of plastic.

The origin of materials and energy inputs can be major influence on the overall suitability of the processes and plants, as assessed through a lifecycle analysis. In New Zealand a portion of the energy is generated from renewable sources such as dams and wind farms. And being an agricultural and horticultural based country a large amount of renewables are readily available.

An example of a change to renewables is in the use of timber tanks for water tanks, replacing the old concrete or plastic tanks.

The use of materials from a finite source has significant environmental effects due to the inability to be cycled back to the source for resource. Renewable materials by their nature can be recycled to replenish the source and provide a virtually infinite service with minimal if any waste.

14 CONCLUSIONS

Green engineering promotes innovative thinking towards sustainability which may not be achieved by applying the newest technology or process. The green engineer must redefine the project to evaluate the full lifecycle of the inputs and outputs to achieve sustainability throughout the project.

The twelve principles provide a framework to guide engineers into considering suitability though all stages of design. They encourage the redefinition of the task to consider the full lifecycle, inputs and outputs. A number of these principles are already implemented in the water treatment and wastewater treatment industries. The twelve principles aim to allow systematic incorporation of green engineering throughout the entire project to the benefit of the environment and society.

REFERENCES

Anastas P. and Zimmerman J (2003). 'Design through the Twelve Principles of Green Engineering'. Environ. Sci. Technol., 37, 94A – 101A.

Kirchhoff M (2003). 'Promoting Green Engineering through Green Chemistry'. Environ. Sci. Technol., 37, 5349-5353.

Mchdonough, W et all. (2003). 'Applying the Principles of Green Engineering to Cradle to Cradle Design.' Environ Sci Technol, 37, 434A-441A.

Ritter, S.K (2002). 'Green Chemistry Gets Greener'. Science and Technology, 80, 38-42.