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Foresighting for Industrial Wastewater Treatment: WW2018-01

Prepared for:

Scottish Enterprise

Scottish Enterprise
Atrium Court
50 Waterloo Street
Glasgow, U.K.
G2 6HQ

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Acknowledgement

This report has been prepared for the use of Scottish Enterprise (SE). This report is based on information and data collected by Mabbett. Should any of the information be incorrect, incomplete or subject to change, Mabbett may wish to revise the report accordingly.

This report has been prepared by the following Mabbett personnel:

MABBETT & ASSOCIATES LTD

James Forbes, CEng, CEnv, CWEM, MICWEM
Manager, Process Engineering

This report has been reviewed and approved by the following Mabbett personnel:

MABBETT & ASSOCIATES LTD

Michael Lynch, CEng, MIChemE, MIEnvSc, MIAQM
Director, Process Engineering & Safety

Executive Summary

Scottish Enterprise (SE) commissioned Mabbett to undertake research to provide insight into the supply chain opportunities and global market outlook of the Scottish industrial wastewater treatment sector. This research was commissioned in order to inform the SE Energy team about future opportunities in the wastewater sector and to help SE to develop support for innovation and investment in this area.

In order to provide context to the industrial wastewater treatment market, an evaluation of the market size was undertaken. The size of this market, which is reported to be growing at an average of 5% per annum, is estimated as follows:

- Global industrial wastewater market £129,500 million
- European industrial wastewater market £34,600 million
- UK industrial wastewater market £3,400 million
- Scottish industrial wastewater market £307 million

The Scottish market is further broken down in to the constituent parts of design/consulting (2%), build/construct (7%), water and wastewater technology (18%), process control and management (17%), chemicals (9%), operation (35%) and maintenance and monitoring (12%).

An estimate of Scottish content in Scottish industrial wastewater treatment plants indicated that around 56% of content is Scottish (although this is expected to vary notably between plants). The components which had the most Scottish content were those associated with the operational cost of a plant rather than the capital cost. Also, Scottish content tends to be associated with services that favour local support (e.g. on-site operation).

A breakdown of estimated Scottish content and value by component is provided below:

Component	Estimated Component Value*	Estimated Scottish Content	Estimated Scottish Value
Design/consultancy	£7.6 million	75%	£5.7 million
Build/construct	£21.8 million	83%	£18.1 million
Water and wastewater treatment technology	£54.2 million	17%	£9.2 million
Process control and management	£50.9 million	13%	£6.6 million
Chemicals	£27.2 million	32%	£8.7 million
Operation	£107.9 million	90%	£97.1 million
Maintenance and monitoring	£37.8 million	85%	£32.1 million
Total	**£307.4 million**	**56%**	**£177.5 million**

* *Component value to Scottish industrial sites, regardless of geography of provider.*

The key drivers and barriers for industry investment and for entry to the market were considered. These include drivers for market growth, barriers to new market entrants and barriers to industry investment. For example:

- The charging mechanisms associated with wastewater discharge can drive the market as improved quality can result in reduced discharge costs.
- Regulations governing wastewater discharge quality and/or quantity provides a driver as sites aim to maintain or reach compliance. The market reports that environmental regulations appear to be tightening in Scotland, further strengthening this driver.
- Proving the efficacy of a new technology can be a barrier to market entrants as this can require multiple repetitions of the same tests by multiple potential clients. With testing coming at a cost to the developer, this can restrict growth.

- Reputation is an important aspect of involvement in the industrial wastewater treatment market. If this has not been developed it can be a barrier for new entrants to the market.
- On-site wastewater treatment at an industrial site can have a high associated capital cost. This is a common barrier to industry investing in the market.
- Wastewater treatment can be viewed by industry as an add-on activity that is required as a result of site activities, rather than an aspect crucial to production. Therefore, prioritisation in terms of time, effort and capital is often focussed on production with wastewater treatment only addressed if compliance is at risk.

A database of companies in the Scottish industrial wastewater treatment supply chain has been developed and is presented in Appendix C. Appendix C1 provides details of companies in the industrial wastewater treatment market who have a base in Scotland; Appendix C2 lists companies who actively work in Scotland but do not have a Scottish base.

The industrial wastewater treatment market utilises a wide range of technologies that can be applied depending on the industry subsector, quality of wastewater, contaminants to be removed, volume of wastewater flow, etc. In order to provide a high-level understanding of common technologies, a number of technology descriptions are provided in Appendix D.

In addition, emerging and developing technologies are considered in Section 7.2, including potential developments in membrane technologies, biological treatment and anaerobic digestion as well as the emergence of ultrasonic reactors and photocatalytic oxidation. These technological developments/ innovations have been driven by factors such as enhanced technology treatment efficacy, improved treatment energy efficiency, focussed removal of specific contaminants, recovery of resources from wastewater, technology affordability, etc.

An overview of Scotland's research and development (R&D) capabilities and testing facilities are explored. Scottish Water Horizons' Gorthleck and Bo'ness development centres are important features in Scotland's R&D offering as they allow for testing of technologies in realistic conditions that may be found in industrial or municipal applications.

Analysis of current R&D activities shows a high level of innovation centred around existing technologies. This is in terms of technology optimisation, improved resource efficiency, increased affordability, use of technology in new sectors and incorporation of technologies into new systems.

Following the research undertaken the following recommendations have been made that could support both the market and industry:

- Employment of capital payment models beyond the payment of capital up front.
- Inclusion of operational performance targets (beyond compliance) in treatment plant operation contracts.
- Scottish adoption of the internet of things (IOT) for industrial wastewater treatment.
- Introduction of qualifications/accreditations for wastewater treatment facility operators.
- Utilisation of industrial sites for the testing and development of technologies.
- Introduction of/adherence to a recognised standard for the verification of wastewater treatment technologies.

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Section 1.0: Introduction

1.1 Background

Scottish Enterprise (SE) is currently engaged in exploring and exploiting the opportunities in the industrial wastewater treatment sector and has been involved for five years in the Scottish water sector through, for example, the Hydro Nation Water Innovation Service (HNWIS).

SE commissioned Mabbett to undertake research to provide insight into the supply chain opportunities and global market outlook of the wastewater treatment sector.

Specifically, this research considers industrial plants and manufacturers who produce large quantities of wastewater. These companies may choose to operate their own wastewater treatment plant to save money, reuse water, to meet regulations or because Scottish Water may have insufficient capacity to take their wastewater.

This research was commissioned in order to inform the SE Energy team about future opportunities in the industrial wastewater sector and to help SE to develop support for companies in this area. This will improve the company's productivity, enable companies with innovative treatment technologies to demonstrate their products and in some cases, help the major user overcome any production or discharge limits.

1.2 Scope of Research

As determined by SE, the scope of the research includes:

- A list and description of Scottish based companies with experience or expertise in industrial wastewater treatment, water reuse and related activities.
- Estimated percentage of Scottish content in wastewater treatment projects.
- R&D capabilities, research strengths – companies and universities.
- Barriers to entry for new companies accessing the industrial wastewater market.
- Any export capability or inward investment opportunities.
- A description of the various technologies (including their uses, advantages and disadvantages) for industrial wastewater treatment, water reuse and associated activities.
- A description of research and likely future technologies (within next 10 years).
- Existing or planned test, demonstration or state of the art facilities (including outwith Scotland).
- Any technology barriers/ market barriers in getting new products to market.
- Current market size in Scotland, UK and global.
- Forecast market growth and market size in 10 years time - Scotland, UK and global.
- A description of the drivers for growth.
- Recommendations of interest to major water users and technology companies to help them in this market.

This research included multiple interviews with individuals working in the Scottish industrial wastewater treatment sector. This included representation from across the component parts of the sector as well as representation from industry. Industry comment and case studies have been anonymised throughout. A list of interviewees by company name is provided in Appendix B.

It should be noted that, due to the cross over between water treatment and wastewater treatment and the regulatory encouragement of water reuse (effectively merging water treatment and wastewater treatment in some cases), water treatment is also considered in some elements of this research.

Section 2.0: Industrial Wastewater Market Size

2.1 Evaluation of Current Market Size

The Scottish industrial wastewater treatment market could be relevant to any industrial business discharging wastewater from their site. From data released by Scottish Water, as of 2016, there were 1,337 issued trade effluent consents in Scotland, which represent the discharge of wastewater related to a process. In addition, other sites may discharge directly to the environment (via relevant consents) or have wastewater uplifted.

In order to provide context to the industrial wastewater treatment market, an evaluation of the market size by expenditure is shown below. This is considered from a global, European, UK and Scottish perspective. Due to the global nature of wastewater treatment services and technology provision, an understanding of the wider markets is key.

The market considered includes the following components:

- Design/consulting;
- Build/construct;
- Water and wastewater treatment technology;
- Process control and management;
- Chemicals;
- Operation, and
- Maintenance and monitoring.

Further detail regarding the make-up of these components is provided in Section 3.0.

An indication of current market sizes is provided below:

- **Global** industrial wastewater market **£129,500 million**
- **European** industrial wastewater market **£34,600 million**
- **UK** industrial wastewater market **£3,400 million**
- **Scottish** industrial wastewater market **£307 million**

Notes:

- Global market value is as per Frost and Sullivan's "Global Outlook of the Water Industry, 2018";
- European and component breakdowns are also as per Frost and Sullivan's "Global Outlook of the Water Industry, 2018";
- USD ($) to GBP (£) conversion is taken as 1.2886 (2017 average);
- Conversion of European market size to UK market size is based on the percentage of GDP made up from manufacturing and industry. It is considered that this is a representative interpolation due to the common legislative requirements across much of Europe resulting in common application of wastewater treatment in European industry;
- GDP based (inclusive of GDP of manufacturing and industry - as defined by the World Bank) on 2017 data as provided by The World Bank [1];
- Conversion of UK Market size to Scottish market size is based on a percentage of GDP. It is considered that this is a representative interpolation based on the average of Scottish location quotients as provided by the Office of National Statistics for the manufacturing, professional services and water collection, treatment and supply sectors[2].
- Scottish GDP data based on Scottish Government published Quarterly National Accounts Scotland[3].

[1] https://data.worldbank.org/indicator/nv.ind.manf.zs
[2] https://www.ons.gov.uk/
[3] https://www2.gov.scot/Topics/Statistics/Browse/Economy/QNAS2018Q1

A breakdown of the Scottish market into component pieces is provided below:

Figure 2.1: Estimated Scottish Industrial Wastewater Market Breakdown - 2018

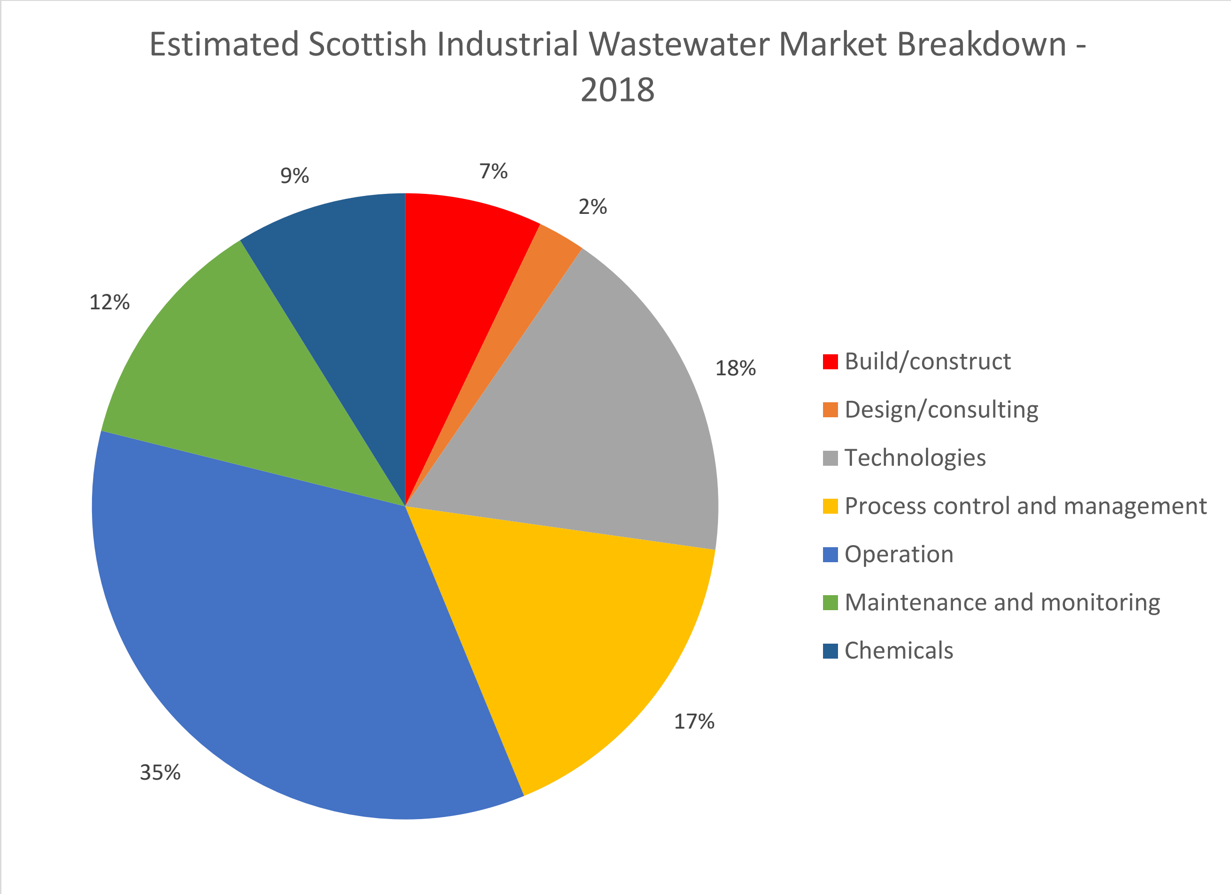


Table 2.1: Estimated Scottish Industrial Wastewater Market Breakdown - 2018

Component	Value	Percentage
Build/construct	£21.84 million	7.1%
Design/consulting	£7.60 million	2.5%
Technologies	£54.25 million	17.7%
Process control and management	£50.94 million	16.6%
Operation	£107.84 million	35.1%
Maintenance and monitoring	£37.75 million	12.3%
Chemicals	£27.16 million	8.8%
TOTAL	**£307.38 million**	

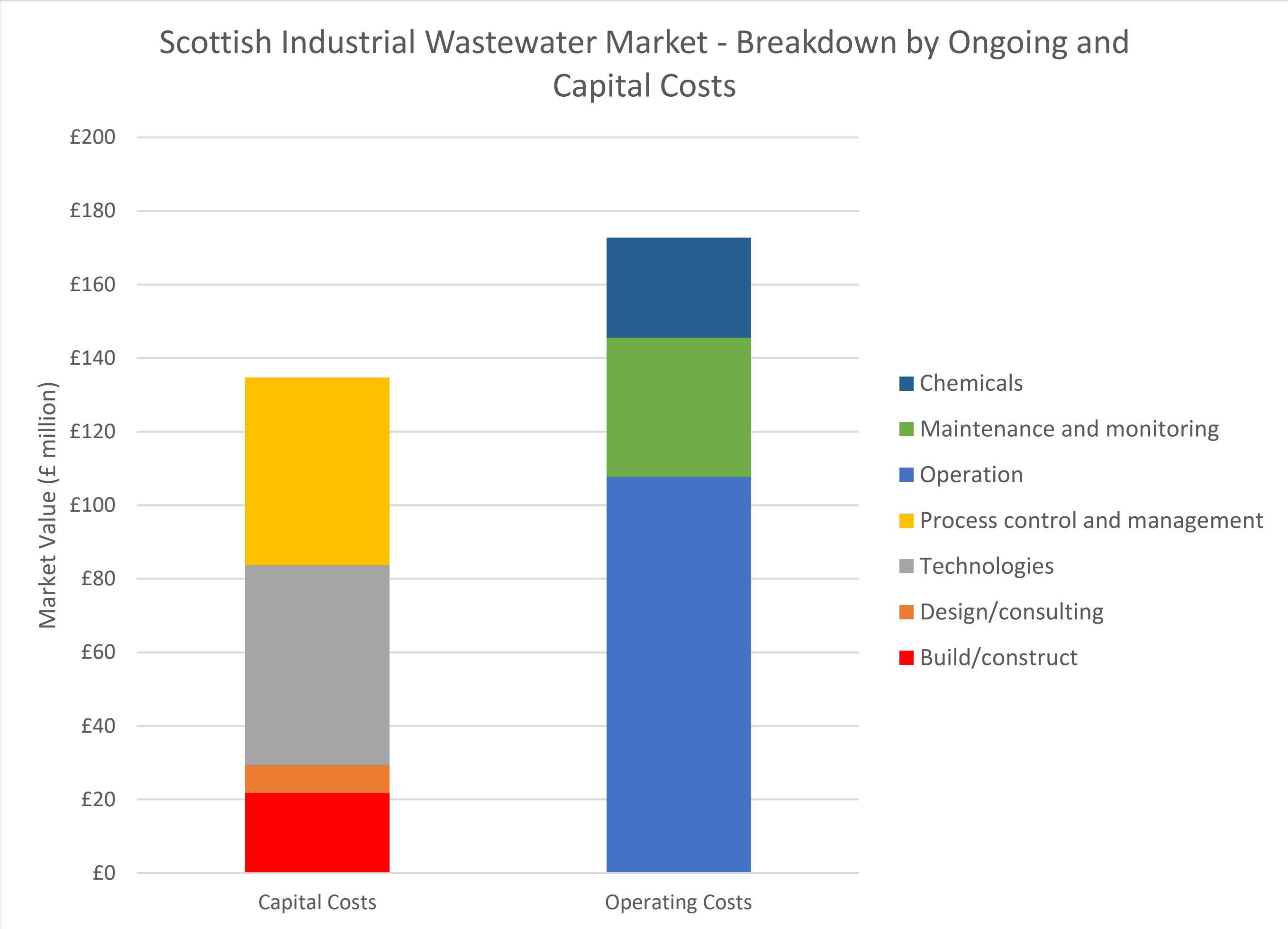
As can be seen, the most substantial component within this breakdown is associated with operation of a wastewater treatment facility. As the typical average lifespan of a wastewater treatment plant is anticipated to be around 20 years[4], it is to be expected that this on-going cost would be a substantial component of total costs.

[4] A Comparative Life Cycle Assessment of a Wastewater Treatment Technology Considering Two Inflow Scales - Guereca et al.

By grouping the components that would typically be considered on-going costs (operation, maintenance and monitoring and chemicals), we see that they equate to around 56.1% of the total market value. Those components typically associated with initial implementation capital investment (build/construct, design/consulting, technologies and process control and management) therefore account for less than half of the value at 43.8%.

The chart below provides a further breakdown of the components by ongoing and capital costs.

Figure 2.2: Scottish Industrial Wastewater Market, Breakdown by Ongoing and Capital Costs - 2018



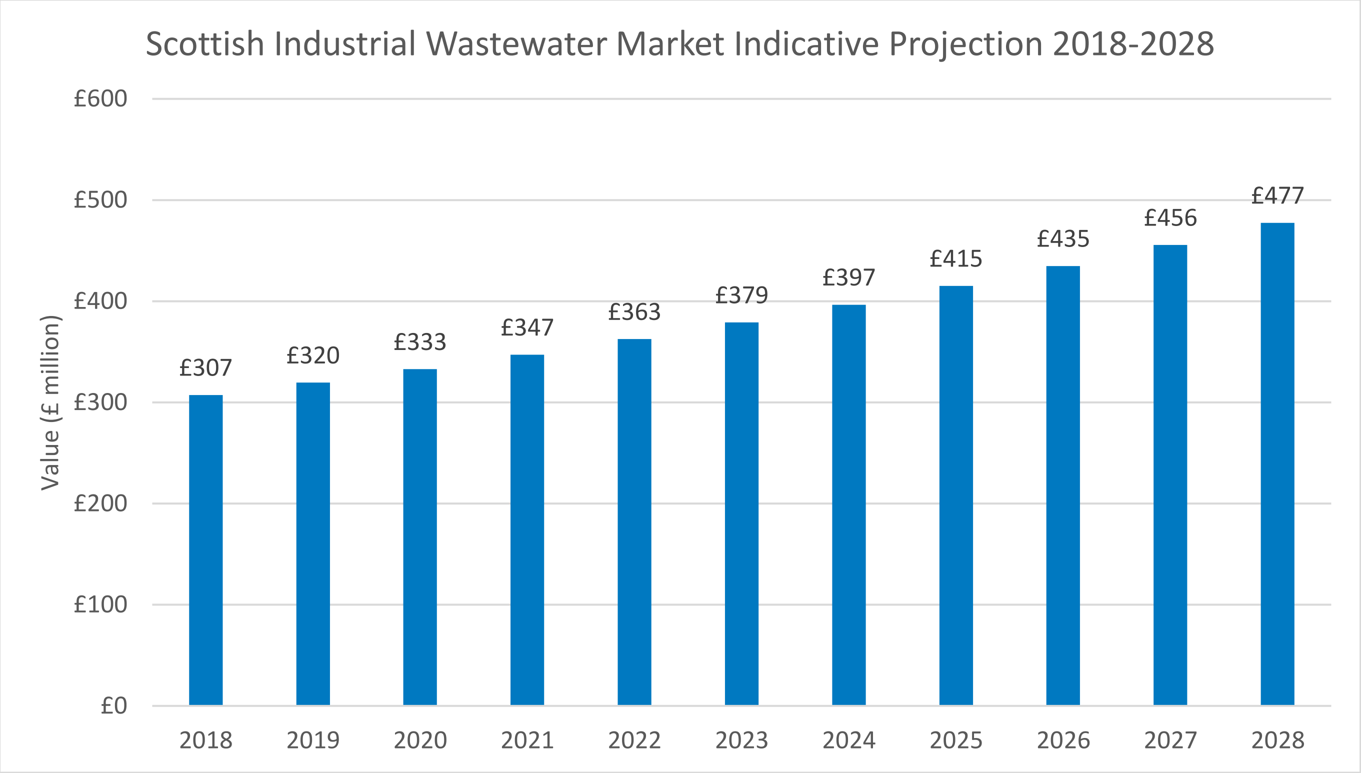
2.2 Market Growth Forecast

The industrial wastewater treatment market is a growing market, with growth averaging around 5% per annum between 2015 and 2018[5] in the European market. It is also anticipated that the market will continue to grow in the coming years.

[5] Frost and Sullivan, Global Outlook of the Water Industry, 2018;
Frost and Sullivan, Global Outlook of the Water Industry, 2017;
Frost and Sullivan, Global Outlook of the Water Industry, 2016;

The chart below provides an overview of potential market growth in Scotland over a ten-year period (2018 to 2028):

Figure 2.3: Scottish Industrial Wastewater Market Indicative Projection (2018-2028)



The anticipated growth of the global, European, UK and Scottish markets by 2028 are provided below:

- **Global** industrial wastewater market **£201,100 million**
- **European** industrial wastewater market **£53,750 million**
- **UK** industrial wastewater market **£5,270 million**
- **Scottish** industrial wastewater market **£477 million**

Notes:

- On-going rate of market increase based on data provided in the Technavio report "Global Industrial Wastewater Treatment Equipment Market 2018-2022". This is a different source than used to understand the market size, however, is considered to illustrate a section of the same market.
- Data extrapolated based on polynomial line of best fit between data points.
- This approach is considered to be representative as regression analysis of published data points showed a perfect relationship (r-squared value of 1) allowing for extrapolation.
- It is assumed that the global, European, UK and Scottish markets will have a proportional growth.

Based on the predicted growth of the market, the total value of industrial wastewater treatment to Scotland could increase by over 55% in the next 10 years. This would equate to a compound annual growth rate (CAGR) of 4.5%.

Section 3.0: Scottish Content in Wastewater Treatment Projects

The wastewater treatment market is a global market, with component parts and services in a treatment plant potentially being brought together from across the world. This section provides an overview of the estimated Scottish content of an industrial wastewater treatment plant project in Scotland.

This overview of Scottish content is to be taken as indicative only and should not be directly applied to all wastewater treatment projects in Scotland, as these will show significant variation. The approach to this evaluation and associated limiting factors are described below:

- The data presented is based on findings from the following:
  - Review of a number of relevant industrial wastewater treatment projects;
  - Discussion with individuals experienced in the industrial wastewater market from a number of organisations including representation across the component services;
  - Evaluation of the Scottish wastewater treatment market to determine Scottish capabilities and reach;
  - Review of existing research on the industrial wastewater market in both Scotland and globally.

- Scottish content in this evaluation refers to both Scottish registered companies and non-Scottish registered companied with a Scottish base. For the non-Scottish registered companies with a Scottish base, it is not necessarily considered that all of the company input is via their Scottish base (and is broken out as such).

- No two industrial wastewater treatment projects are anticipated to have the exact same Scottish content (even if projects are similar to each other). Content is expected to vary due to a number of variables such as:
  - Project and associated plant size;
  - Effluent data available at the start of the project;
  - Industrial site effluent characteristics (e.g. flow and quality);
  - Partner companies involved in the project (i.e. design, project management, operation, maintenance, etc.);
  - Treatment plant footprint availability on-site;
  - Industrial site location;
  - Existing site wastewater infrastructure.

  Some of these variables, and their impact on Scottish content, are discussed in more depth in the component sections below.

- The breakdown of Scottish content is likely to change over time. As discussed elsewhere in this document, the industrial wastewater treatment market is continuously developing and changing. This breakdown should be viewed as a time-limited snapshot.

3.1 Design/Consulting

Design and consultancy are key components in the implementation of an effective wastewater treatment project. These elements can include the following:

- Assessment and understanding of raw effluent characteristics (e.g. quantity and contaminant loading, typical fluctuations in effluent characteristics);
- Study into the viability of a wastewater treatment system and associated potential risks;
- Evaluation of wastewater discharge limits and, therefore, understanding of the level of wastewater treatment required;
- Advice and support with regards to regulatory requirements associated with the implementation of a wastewater treatment solution an industrial site (e.g. wastewater discharge consents, environmental regulations, application of Best Available Techniques (BAT));
- Understanding of key site constraints to include available footprint for the project, existing effluent infrastructure, utility availability, etc.;
- Selection of appropriate wastewater treatment suppliers and technologies to meet site requirements;
- Completion of detailed design.

In some cases, this element of the project will be undertaken by a single service provider in the form of a turnkey solution. However, it is not uncommon for some of the consultancy services to be separated from the design services (design services can then be provided by the technology provider). The required level of service provider support at this stage is dependent on scale and complexity of the wastewater being treated, the availability of robust data to allow design works to progress, limitation of the preferred technology provider(s), etc.

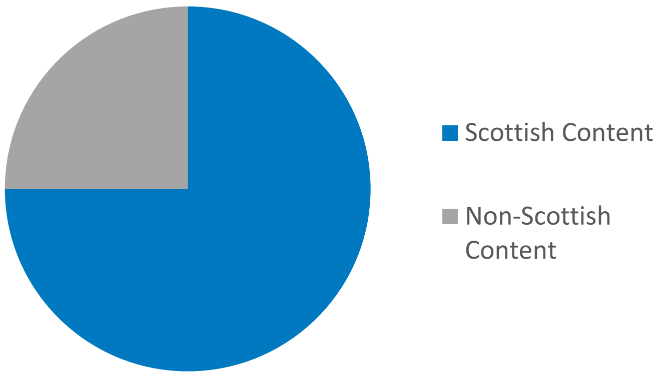
These services are not necessarily geographically bound to a locality, with most consultants and designers being willing to travel. However, these service providers will typically report a higher density of workload closer to staff bases. This is typically due to the following reasons:

- There is a cost implication associated with working away from a staff base. Although this is not expected to be notable when compared to the total project value, it can make a difference at the early stages of a project before the full scale of costs are realised, and when preliminary tasks at lower cost are being undertaken.
- It is common for companies to have stronger reputations in their local area, where they are likely to have worked previously.
- Service providers are likely to have existing relationships with industrial sites in their locality. It is common for sites to return to tried and trusted service providers.
- Although these services may not be geographically bound, there is a tendency within industry to prefer local business where possible. Also, sites may have the impression that locality brings additional benefit (whether substantiated or not).

Whilst not geographically bound to a locality, it is common that service providers operating in Scotland will be at least UK based. This is can be largely attributed to familiarity with UK legislative requirements and absence of language barriers.

Based on the data available (as discussed in Section 3.0), an indication of the Scottish content in design/consulting of wastewater treatment projects in Scotland is provided below:

Table 3.1: Estimated Scottish Content: Design/Consulting

Estimated Scottish Content - Design/Consulting		
	Scottish content	75%
	Scottish Value	£5.7 million
	Non-Scottish content	25%
	Non-Scottish Value	£1.9 million
	Component Value	£7.6 million
	Component 2.5% of Total Value	

3.2 Build/Construct

The building and constructing associated with a wastewater treatment project accounts for the supporting/ancillary elements around the actual implemented technology and instrumentation. For example, this could include the following elements:

- Civil works associated with the project (e.g. ground works or concreting);
- Construction of an associated shelter or building;
- Provision of utilities to the plant;
- Final fabrication of the treatment plant on-site;
- Works associated with the wastewater input and discharge from the plant; and
- Treatment plant pipework.

The costs associated with this component can vary significantly between sites. One of the main contributors to this cost can be cases where notable civil works are required, to divert the raw wastewater to the treatment facility, and subsequently discharge treated wastewater to sewer of the environment in a suitable manner. It is not uncommon for existing drainage to be located beneath thick layers of hard standing or factory floors.

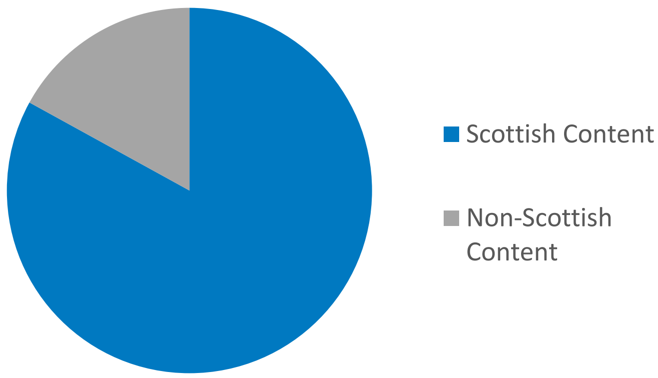
In many cases, external contractors not strongly linked to the industrial wastewater market can be brought in to assist with this element of a project (e.g. civils contractors). Due to the potential complexities and risks involved with civil works, many wastewater treatment specialists will either leave this element to the client to manage or sub-contract the work.

Due to the requirement for site-based work, it is common for local labour to be utilised. Even wastewater treatment specialists who employ fabricators or labourers may defer to local labour in the case there is financial benefit to doing so.

An indication of the Scottish content in the build/construction of wastewater treatment projects in Scotland is provided below:

Table 3.2: Estimated Scottish Content: Build/Construct

Estimated Scottish Content - Build/Construct



Scottish content	83%
Scottish Value	£18.1 million
Non-Scottish content	17%
Non-Scottish Value	£3.7 million
Component Value	£21.8 million
Component 7.1% of Total Value	

3.3 Water and Wastewater Treatment Technology

This category considers the technologies utilised in the treatment of water and wastewater (not inclusive of instrumentation). A summary of common wastewater treatment technologies is provided in Section 7.1.

Generally speaking, Scotland is not heavily involved in the full manufacture of water and wastewater technologies. The majority of technologies that are in use in Scotland are typically manufactured elsewhere in Europe, with some also being sourced from further afield.

In the case of technologies that require specialised production, these would typically be fully constructed in a specialist production facility prior to being transported to sites. The demand for technologies is such that these production facilities typically have a continental (if not global) client base. Scottish content in technologies is considered to be low.

There is typically some Scottish content in technologies, although it can vary significantly. This component can be dependent on a number of factors as discussed below:

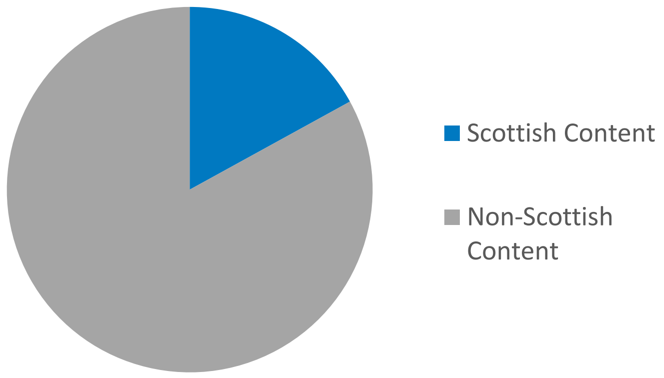
- Some wastewater treatment companies in Scotland undertake a level of system assembly, rather than purchasing fully packaged plants. This allows the company to select component pieces based on preferred operability or cost and assemble them in a workshop prior to transport to site. In many cases, the component pieces will not have Scottish content, but will be assembled in Scotland.

- There are a number of wastewater treatment vendors in Scotland who will purchase technologies for implementation in Scotland (in many cases, these vendors also design the system). The systems are sold on with a mark-up and represent revenue to the vendor. This mark-up will vary depending on a number of project specific considerations (e.g. project size, presence of competition, end client).
- Almost every treatment facility will have tanks associated with it - either for balancing upon entry or to undertake reaction/treatment, etc. Due to tanks being relatively simple in design, often large (therefore, potentially difficult to export) and in relatively high demand (not just used in wastewater treatment), there's a reasonable degree of tank construction in Scotland.

An indication of the Scottish content in water and wastewater technologies of wastewater treatment projects in Scotland is provided below:

Table 3.3: Estimated Scottish Content: Water and Wastewater Technologies

Estimated Scottish Content - Water and Wastewater Technologies



Scottish content	17%
Scottish Value	£9.2 million
Non-Scottish content	83%
Non-Scottish Value	£45.0 million
Component Value	£54.2 million
Component 17.7% of Total Value	

3.4 Process Control and Management

Process control and management refers to items that are part of the treatment plant, but not part of the core technology. Examples include:

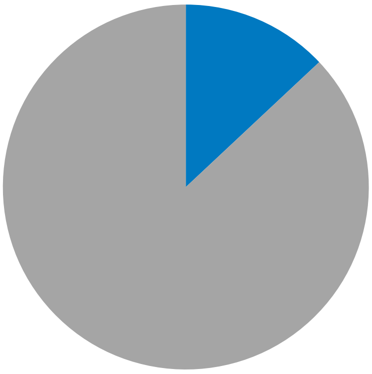
- Valves;
- Pumps;
- Instrumentation;
- Controls;
- Telemetry; and
- Plant automation.

Scottish content in this area is typically limited to operating as a vendor (specification and sale) or assembly as part of a project. The majority of process and control components are not manufactured in Scotland (with some limited exceptions). This especially applies to the majority of instrumentation which, depending on system specification, can be a notable cost component in a treatment facility.

It is estimated that this component is worth around £50.9 million to the market serving Scotland (although the market is not made up fully from Scottish based companies). Typically, process control and management costs are a notable component cost in wastewater treatment, account for around 38% of system capital costs.

It is anticipated that this is a component that may grow over the next few years. This is due to the advancement in automation and control being offered by technologies.

Table 3.4: Estimated Scottish Content: Process Control and Management

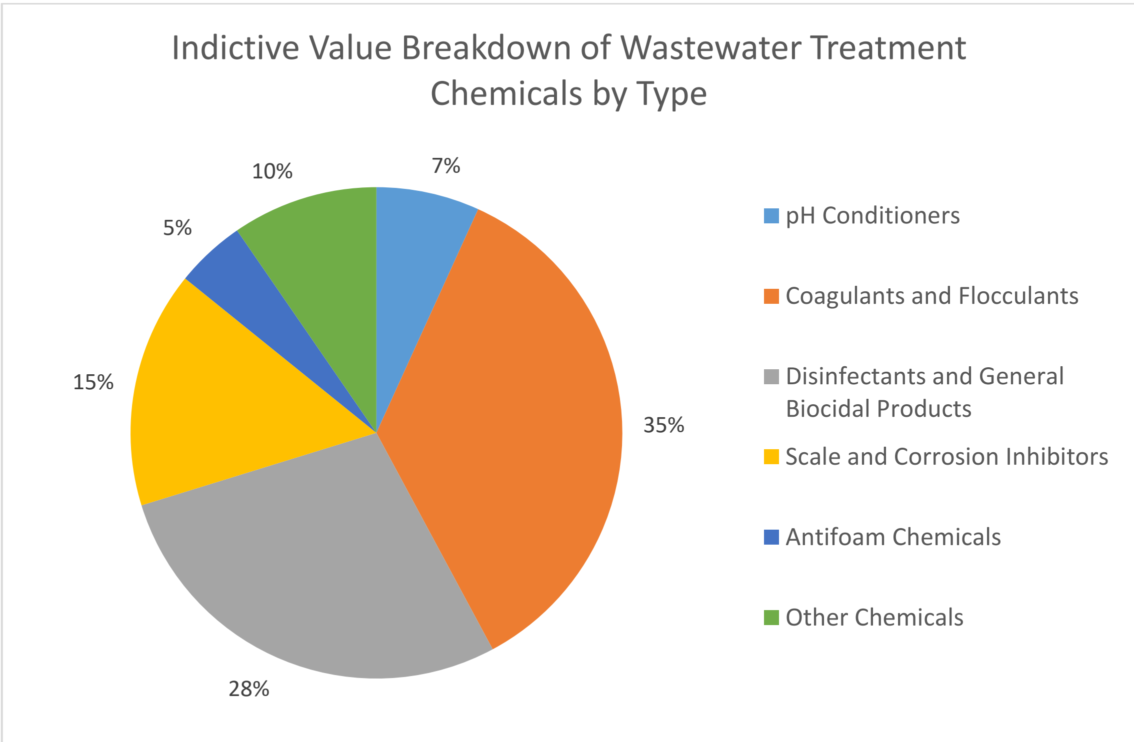
Estimated Scottish Content - Process Control and Management		
	Scottish content	13%
	Scottish Value	£6.6 million
	Non-Scottish content	87%
	Non-Scottish Value	£44.3 million
	Component Value	£50.9 million
	Component 16.6% of Total Value	

3.5 Chemicals

Chemicals play a key role in the operation of almost all wastewater treatment plants, for a variety of purposes e.g. from pH adjustment to clarification, from disinfecting to corrosion inhibitors. As chemicals are required throughout the lifespan of a treatment solution, this is a sizable market, worth an estimated £11.13 billion globally[6]. In Scotland, this equates to a market of £27.2 million.

The figure below provides an indicative breakdown of the differing chemical types used in wastewater treatment.

Figure 3.1: Indicative Value Breakdown of Wastewater Chemicals by Type



Coagulants and flocculants play a key role in wastewater clarification and represent the highest proportion of use.

[6] Frost and Sullivan Global Outlook of the water Industry, 2018

There are differing roles in the wastewater treatment chemical market, which have differing levels of Scottish content. Roles in the market are broadly described below:

- **Original Chemical Manufacturer**

  This refers to the manufacturer(s) involved in the preparation of a concentrated chemical. Due to the nature of chemical manufacture, by the stage a concentrated chemical has been produced, a series of different manufacturers may have been involved in the production of a number of component parts.

  It is reported that, although some original chemical manufacturers are present in Scotland, the majority of manufacturers operate outwith Scotland. As per data provided by the Office of National Statistics (ONS), Scotland has a location quotient in the sector entitled "Manufacture of chemicals and chemical products" of 0.7[7]. A location quotient indicates a geography's share of jobs in a certain sector relative to the rest of Great Britain (1.0 would indicate an even share).

- **Chemical Handlers**

  A chemical handler will purchase concentrated bulk chemicals from chemical manufacturers and make up chemicals to required strengths to be sold on to wastewater treatment plants. Chemicals are also packaged for end use at this stage.

  In some cases, chemical handlers may also combine chemicals to form a final product, however, this would not typically involve chemical reactions in order to avoid the legislative and regulatory impacts of being a chemical manufacturer.

  In many cases, a chemical handler will also be a chemical vendor (as discussed below). There are a number of Scottish based chemical handlers.

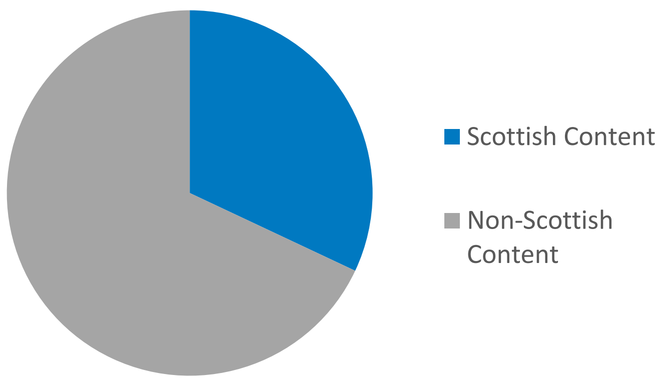
- **Chemical vendor**

  The role of the chemical vendor is to sell chemicals on to the end user (e.g. the wastewater treatment plant). There are a number of chemical vendors that are based in Scotland. In many cases, in order to reduce transport related costs once chemicals have been mixed to specification, chemicals will be purchased from vendors that are based relatively locally to a site.

The roles above are a typical overview only. In some cases, one company may undertake all three roles. Each link in the chemical supply chain will include a margin on sale, therefore, potential Scottish content is based on a number of variables.

An indication of the Scottish content in wastewater treatment chemicals utilised in Scotland is provided below:

Table 3.5: Estimated Scottish Content: Chemicals



Estimated Scottish Content - Chemicals	
Scottish content	32%
Scottish Value	£8.7 million
Non-Scottish content	68%
Non-Scottish Value	£18.5 million
Component Value	£27.2 million
Component 8.8% of Total Value	

[7] Office of National Statistics: The Spatial Distribution of Industries in Great Britain.

3.6 Operation

The operation of a wastewater treatment plant is a key part of its lifecycle and is often overlooked during the initial design phases of a project. As can be seen in Figure 3.2, this element accounts for almost 30% of the total lifetime cost of a treatment project, the single largest cost component.

This category also includes elements such as utilities and some raw materials (excluding chemicals). Depending on the configuration of a plant and technologies selected, these can be key components of cost. The energy costs associated with a treatment plant can be a notable, but poorly understood element of operational costs. As plants can have mixers, pumps and controls continuously running, energy demand over time can be a large component. Unless a treatment plant is electrically sub metered, it is unlikely that the true demand of a plant is quantified.

There are a few models of operation that an industrial site may elect to utilise when considering this on-going cost. Potential options are shown below:

- Full operation by external contractor. This model is more likely to be seen at industrial sites with larger wastewater treatment facilities and comprises of a specialist wastewater treatment plant operator being contracted to the industrial site.

  Pros:
  - Specialist operator brings a higher level of confidence in operation, especially useful where this would be outwith the skill set of on-site staff.
  - Industrial site is required to provide little input in the running of their plant.
  - Operator can rely on wider support from a specialist parent company where required.

  Cons:
  - Typically, the most expensive approach.
  - Operator will often only be compliance focussed (unless contractually obliged to do otherwise), potentially compromising the efficiency of the plant.
  - Separation of duty from site responsibility can mean that the wastewater treatment plant is less likely to be brought into the site's continual improvement plans.

- Full operation by on-site staff. With a view to minimising the costs associated with this element, it is not uncommon for key on-site staff members to be trained up to operate a plant. It is more likely that this would be the case at smaller treatment plants.

  Pros:
  - A cost-effective approach towards operation, especially where this is only a part-time duty.
  - Allows for on-site personnel to develop an understanding of the treatment plant, and potentially aim to improve efficiency beyond simply compliance.

  Cons:
  - On-site operator may have understanding of how generally to operate a specific plant but would be less likely to have a background on why a plant is operated as it is. This could have negative consequences during periods of abnormal operation i.e. they are less able to troubleshoot. Wastewater treatment can often have a complex chemical or biological design basis and understanding this may be required for effective and efficient operation during all conditions.

- Operation by on-site staff with periodic specialist support. This approach is effectively a combination of the two approaches described above. Although operation would be the primary responsibility of the site, a contract with a specialist organisation would allow for routine site visits to assess the plant, advise on specialist technical issues and provide operator training.

  Pros:
  - Allows for a more cost-effective approach than contracting a full-time specialist whilst also allowing for regular specialist input for site staff without a wastewater treatment background.
  - Gives less experienced treatment plant operators a specialist to fall back on when required.

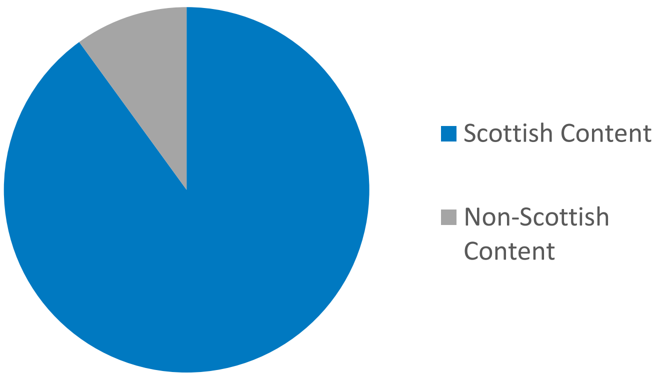
Cons:

- Due to the partnered approach, this can result in neither the site nor the specialist fully taking responsibility for the plant. Each side may defer to the other on issues regarding plant upgrades or running efficiency.

The selection of operation model is dependent on a number of variables e.g. the size of the site, existing on-site experience, site's attitude towards risk, finance constraints. However, due to the on-site nature of treatment plant operation, locality is key, resulting in a high Scottish content in this component. The majority of support provided for this item will utilise Scottish based personnel.

An indication of the Scottish content in operation of wastewater treatment projects in Scotland is provided below:

Table 3.6: Estimated Scottish Content: Operation

<table>
<tr><th colspan="3">Estimated Scottish Content - Operation</th></tr>
<tr><td rowspan="6">
</td><td>Scottish content</td><td>90%</td></tr>
<tr><td>Scottish Value</td><td>£97.1 million</td></tr>
<tr><td>Non-Scottish content</td><td>10%</td></tr>
<tr><td>Non-Scottish Value</td><td>£10.8 million</td></tr>
<tr><td>Component Value</td><td>£107.9 million</td></tr>
<tr><td colspan="2">Component 35.1% of Total Value</td></tr>
</table>

3.7 Maintenance and Monitoring

Maintenance and monitoring of a wastewater treatment facility is an unavoidable ongoing cost. This is traditionally closely linked to the operation of a treatment plant, with plant operators also having maintenance and monitoring responsibilities.

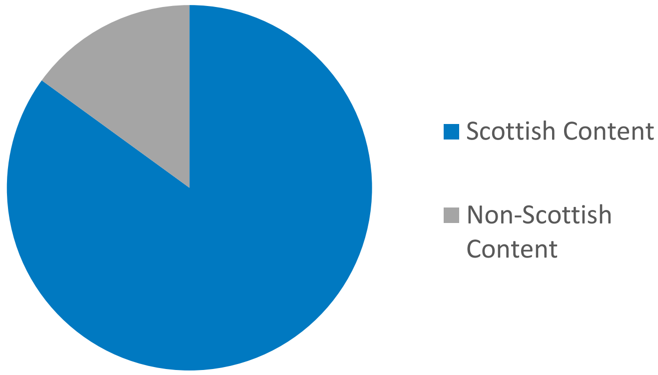
It should be noted that this component includes costs for replacement parts but does not include costs for full replacement of technologies (this falls under the water and wastewater technology component). This component is largely a function of staff costs associated with operation.

Therefore, like operation, the component generally has a strong geographic focus. This means that most services provided under this component are Scottish based. However, due to maintenance potentially requiring spare parts, it is anticipated that there is likely to be a higher non-Scottish content requirement than that required in operation.

An indication of the Scottish content in maintenance and monitoring of wastewater treatment projects in Scotland is provided below:

Table 3.7: Estimated Scottish Content: Maintenance and Monitoring

Estimated Scottish Content - Maintenance and Monitoring



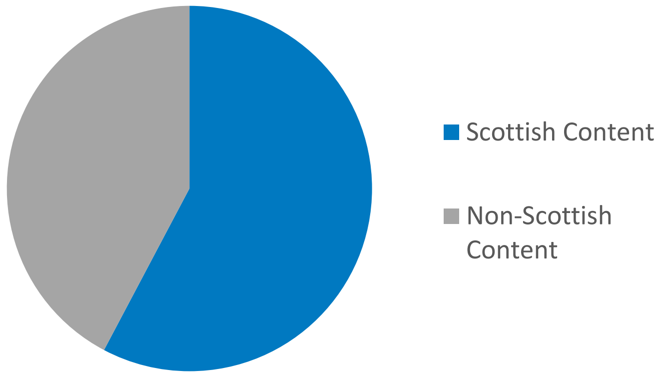
Scottish content	85%
Scottish Value	£32.1 million
Non-Scottish content	15%
Non-Scottish Value	£5.7 million
Component Value	£37.8 million
Component 12.0% of Total Value	

3.8 Summary of Scottish Content

A summary of the estimated content in Scottish wastewater treatment projects is provided below:

Table 3.8: Estimated Scottish Content: Summary

Estimated Scottish Content - SUMMARY



Scottish content	56.4%
Scottish Value	£177.5 million
Non-Scottish content	43.6%
Non-Scottish Value	£129.9 million
Total Value	£307.4 million

It can be seen that this estimation of content attributes slightly over half of the content in Scottish wastewater treatment projects to Scottish registered or Scottish based organisations. This results in a value to these Scottish companies of around £177.5 million.

It should be noted that this exercise does not consider Scottish content in non-Scottish wastewater treatment, therefore, it is anticipated that the value of wastewater treatment to Scottish companies would exceed this value.

The estimated Scottish content in wastewater treatment varies widely across each component. A strong correlation between Scottish content and geographically linked components is observed. Geographically linked components refer to those components for which locality to a treatment plant strongly impact the ability to provide a cost effective and reliable service. For example, plant operation requires a level of on-site presence. Although the future of this component may allow for more external support due to increased automation and remote control (see Section 4.7), the presence of a site-based individual will always be required in some capacity.

A breakdown of the estimated content is shown in the following charts, broadly categorising components as on-going cost components and capital cost components.

Figure 3.2: Indicative Scottish Content in Wastewater Treatment by On-going Component

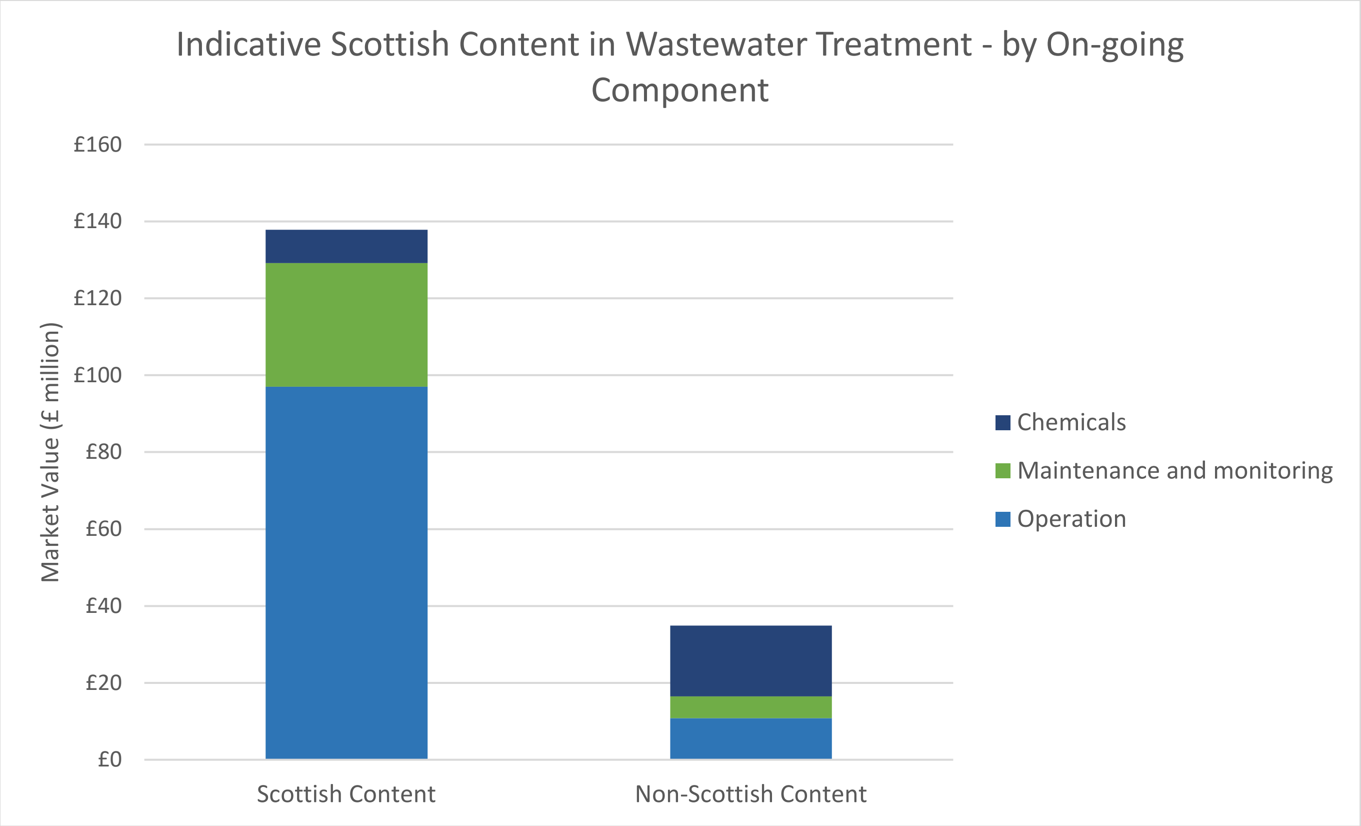
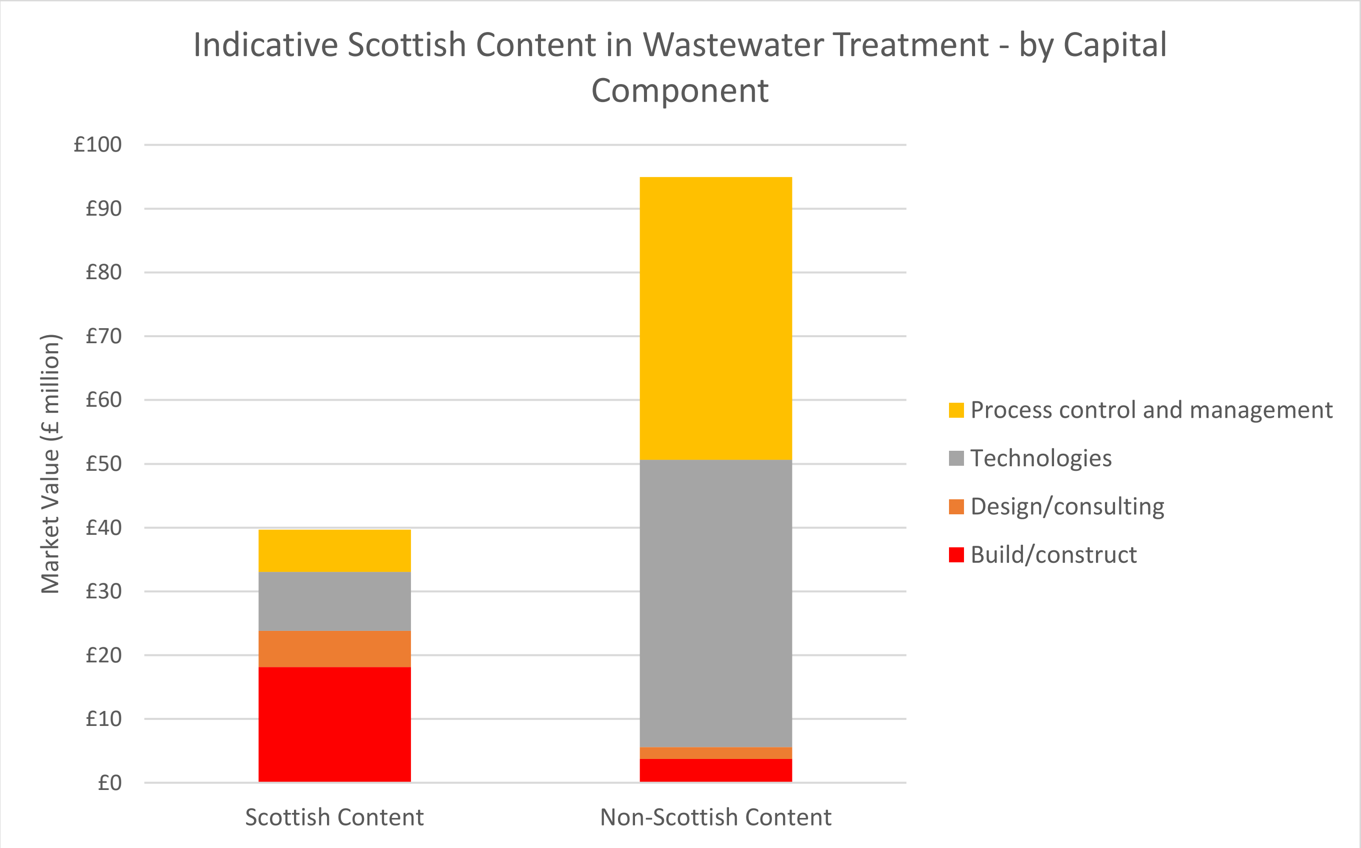


Figure 3.3: Indicative Scottish Content in Wastewater Treatment by Capital Component



It is clear from this breakdown that Scottish involvement in a Scottish wastewater treatment project is more likely to occur once the treatment system is already in place. The Scottish content of ongoing costs is estimated at almost 90% of costs (it should be noted that this does not include the implementation of replacement technologies).

The Scottish content during the initial implementation of a project (illustrated by capital costs) is much lower, at around 30% of the total content.

Based on the analyses above, it is shown that:

- Scottish content is strong where local contribution is favoured and during the ongoing operation of a wastewater treatment project.
- There is room for Scotland to develop in components where there is no traditional geographic link and those typically associated with initial project capital spend.

Section 4.0: Market Drivers

As with any other market, the Scottish industrial wastewater treatment market has a number of bespoke drivers and barriers that help to form the market and its potential for growth. This section provides an overview of the drivers for market growth.

4.1 Reduction in Discharge Costs

The discharge or uplift of wastewater from a site, whether treated or untreated, almost always has an associated cost. It is not uncommon for the quality or strength of contaminants in the wastewater to have an impact on these costs. Therefore, the onsite treatment of industrial wastewater can result in cost savings at an industrial site.

The main mechanisms by which wastewater would leave a site are as follows:

- A trade effluent consent for sewer discharge regulated by Scottish Water.
- An environmental discharge regulated by the Scottish Environment Protection Agency (SEPA).
- Uplift by an accredited waste contractor.

Improving wastewater quality via the introduction or improvement of treatment systems at industrial sites can result in cost savings due to improved performance relative to quality-based charging variables. This is most notable for sewer discharges (Mogden-based charging mechanisms apply - discussed in Section 4.1.1) and uplift by waste contractor (more heavily contaminated effluent will typically cost more to dispose of).

Savings can also be made by improving wastewater quality such that a more cost-effective discharge mechanism can be employed. For example, discharge of wastewater to the environment is typically the most cost-effective approach, however, this mechanism typically has the most stringent discharge quality requirements.

4.1.1 Trade Effluent Discharge (Mogden Formula)

Trade effluent is legally defined as any liquid waste 'produced in the course of any trade or industry' which is discharged to the wastewater system[8]. In Scotland, the wastewater system is operated by Scottish Water, a publicly owned organisation who own, operate and maintain wastewater assets across the country.

In 2008, the Scottish commercial water market was deregulated[9]. As a result, businesses in Scotland no longer purchase water and wastewater services from Scottish Water directly, rather they must do so via an approved water retailer. Scottish Water operate as the market wholesaler, selling services to water retailers (prior to their sale to end users). This deregulation did not impact the physical means of water and wastewater services (i.e. trade effluent is still discharged to the same treatment works), rather it changed the method of how services are acquired and introduced competition into the market.

Trade effluent is charged based on both the quality and the quantity of effluent. The quality factor allows consideration to be made for the further processing required to be undertaken by Scottish Water and also allows for improved discharge qualities to be financially rewarded.

Prior to the discharge of trade effluent from an industrial site, a trade effluent consent must be acquired via a water retailer from Scottish Water. This consent provides the limits imposed on the discharge, including parameters such as:

- Wastewater flow rates;
- Wastewater quality concentrations of select substances.

[8] https://www.scottishwater.co.uk/business/our-services/compliance/trade-effluent
[9] https://www.scotlandontap.gov.uk/

The consented limits for each site are determined based on a combination of the site's requirements and Scottish Water's capacity to treat the discharged wastewater. Where the Scottish Water asset downstream of the site is constrained in some way (e.g. hydraulically, or with respect to contaminant loading), tighter consent limits may be imposed than were initially requested by the industrial site.

Charging of trade effluent is calculated using the Mogden Formula. This formula combines quantity and a number of quality factors to determine trade effluent charges. In Scotland, the Mogden Formula is broken down into Availability Charges and Operational Charges.

Trade Effluent - Availability Charges

Availability Charges are in place to account for the availability of the service being made to the site and is based on the limits laid out in the site's trade effluent consent. The following equation is used for this item:

Availability Charge = [CDV x (Ra + Va)] + (Ba x sBODl) + (Sa x TSSl)

The parameters highlighted in green represent factors that are site specific and based on the site's trade effluent consent, where:

CDV	Chargeable daily volume (in m^3)
sBODl	Settled biochemical oxygen demand load (in kg)
TSSl	Total suspended solids load (in kg)

The parameters highlighted in red represent factors that are fixed as charging parameters and used to bill the site by the water retailer, as described below:

Ra	Reception charge
Va	Volumetric/primary charge
Ba	Biological capacity charge
Sa	Sludge capacity charge

Trade Effluent - Operational Charges

Operational charges are based on the actual trade effluent generated by the site. On a periodic basis Scottish Water will take samples of effluent for analysis against consented levels and chargeable parameters. These chargeable parameters are averaged over a period of one year and fixed for the following year.

The volume of trade effluent generated is also recorded or estimated to be included as scaling factor in the operational charging equation. Estimates are made where a trade effluent meter has not been installed at a site and are based on calculations provided by the site and approved by Scottish Water.

The following equation is used to calculate the operational charge:

Operational Charge = AVD x [Ro + Vo + (Bo x Ot / Os) + (So x St / Ss)

The parameters highlighted in green represent factors that are site specific and based on routine effluent samples taken, where:

AVD	Actual volume discharged (in m^3)
Ot	Fixed strength (settled chemical oxygen demand) of the effluent (in mg/l)
St	Fixed strength (settleable solids) of the effluent (in mg/l)

The parameters highlighted in red represent factors that are fixed as charging parameters and used to bill the site by the water retailer, as described below:

Ro	Reception charge
Vo	Volumetric/primary charge
Bo	Secondary treatment charge
So	Sludge treatment charge

As shown above, the site-specific variables (which are highlighted in green) are utilised to calculate total trade effluent charges. In the case these variables can be improved (and, for availability charges, consent limits reduced), cost savings can be made. The following key quality parameters are used to determine charges:

- Chemical oxygen demand (COD) covers Ot charging parameter;
- Biochemical oxygen demand (BOD) covers sBODl charging parameter;
- Suspended solids (SS) covers both St and TSSl charging parameters.

It should be noted, although samples will be analysed for all consented parameters, only the parameters above are utilised for the purpose of charging. The remaining parameters are utilised for determining compliance with the issued trade effluent consent.

Therefore, the reduction of the concentration of these three quality variables via treatment of the wastewater prior to discharge can result in cost savings for a site. Additionally, treatment to recycle wastewater would reduce the chargeable volume. Over the last 10 years (since deregulation of the water market), wholesale trade effluent charging values as determined by Scottish Water have risen by 3.13% per year on average (31.3 % in total). It is anticipated that cost of charging variables will continue to rise for the following reasons:

- For Scottish Water to continue running their treatment works as at present, inflationary increases can be reasonably expected (e.g. operational staff salaries, chemical supplies).
- Scottish Water has an established, wide-ranging wastewater treatment network. However, this asset portfolio has a constant requirement for maintenance and, due to increasing age, may require more wholesale renovations in due course.
- One of the main costs associated with the operation of a wastewater treatment plant is electricity, used for pumping, mixing, dosing, heating, etc. Over the last 8 years, the cost of electricity in Scotland has risen by an average of 5.6% per annum. However, it should be noted that Scottish Water have made large investments in technologies for the generation of renewable energy, which may offset this increasing cost.
- As Scottish Water wastewater treatment plants are typically end of line measures, these plants will discharge to the environment. As discussed in Section 4.2, the discharge of wastewater to the environment typically has more stringent quality requirements than the discharge of trade effluent (as trade effluent first goes via Scottish Water plants). Additionally, it is anticipated that environmental discharge quality requirements are going to become more stringent in the coming years, as SEPA are tasked with improving the quality of Scotland's water environment. Therefore, many Scottish Water treatment plants may have to be upgraded in order to meet newer standards, a cost which may be passed on in trade effluent charges.

In addition to improving the quality of wastewater discharged by a site, the implementation of a wastewater treatment facility can allow for the use of a trade effluent meter if one is not already installed. It is not uncommon for existing estimations of trade effluent volumes to exclude some variables that result in incoming water not being returned to drain. Therefore, the installation of a trade effluent meter (as a result of installing a wastewater treatment plant), can result in more accurate discharge volumes being reported to Scottish Water - in many cases, these may be lower volumes than would have been estimated (resulting in a reduction in ongoing costs).

Case Study 1

A large bakery had been experiencing large trade effluent bills for a number of years and were therefore assessing the potential for implementing a wastewater treatment solution in order to reduce associated charges. In total, charges of £173,000 per annum were experienced by the site. In addition to these charges, the effluent quality was typically close to the site's consented discharge limits, causing concern of regulatory non-compliance.

A breakdown of typical charges and associated quality parameters is shown below:

sBODl	TSSl	Ot	St
510 kg	85 kg	12,000 mg/l	730 mg/l
Annual Availability Charges		Annual Operational Charges	
£60,000		£113,000	

A wastewater treatment plant inclusive of a pre-filter, balancing tank, dissolved air flotation unit and v-notch weir was installed. As a result of this, effluent quality parameters were notably reduced, and the site's trade effluent consent was revised to reflect this improvement in quality - this resulted in a decrease in the site's trade effluent availability charges.

A breakdown of the typical charges and associated quality parameters following the implementation of the treatment system is shown below:

sBODl	TSSl	Ot	St
255 kg	60 kg	5,000 mg/l	450 mg/l
Annual Availability Charges		Annual Operational Charges	
£34,000		£52,000	

As can be seen, this treatment solution reduced annual trade effluent charges to around £86,000, a reduction of around £87,000 per annum.

The treatment plant came at a capital cost of £375,000, giving the project a simple payback of **4.3 years** and a net present value of **£617,000**.

4.1.2 Discharge to the Environment

Discharging of water to the environment will require authorisation from SEPA under The Water Environment (Controlled Activities) Scotland Regulations 2011 (as amended) (CAR), which for larger sites will typically be via a licence. This allows a site to discharge to the water environment (water courses, water bodies, ground water, etc.) in line with licence conditions. This licence includes a number of consent limits that are based on the characteristics of the wastewater to be discharged and the requirements of the receiving environment.

SEPA require payment for the administration of an application to discharge and, thereafter, will levy an annual charge for the discharge. Annual charging for discharges to the environment from industrial sites are charged as per The Environmental Regulation (Scotland) Charging Scheme 2018, as published by SEPA. For discharges to environment from an industrial site, there will typically be two main components to annual charging:

- An activity charge - a fixed fee as published in the charging scheme. Charge banding for this is determined by the type and scale of activity at a site.
- An environmental component - This charge allows SEPA to charge based on the quality of effluent discharged from a site and is variable. This charge involves the multiplication of a financial factor by an environmental score.

- Financial factor - This is a fixed value as reported in the charging scheme. For 2018, this is set at £275.14.
- Environmental score - This is a more complex value that is derived based on wastewater quality data as analysed at a site. Mass pollutant emissions are compared to set water pollutant thresholds (which are derived from Environmental Quality Standards) and then summed up.

It is common that the charges levied by SEPA are notably lower than those associated with discharge of trade effluent or uplift of wastewater by an approved contractor. However, this lower cost can be offset by the following factors:

- As wastewater is to be discharged to the environment, the quality limits associated with a CAR licence tend to be stringent. These limits are likely to differ depending on a range of factors such as discharge location, local ecosystems, potential impact on the environment, etc.

  The table below shows an illustration of a site that were applying for both a trade effluent consent and a licence to discharge to the environment to compare associated requirements:

  Table 4.1: Example Wastewater Discharge Comparison

Example Discharge Comparison			
Parameter	**Environmental Discharge**	**Trade Effluent Discharge**	**% Difference**
BOD	25 mg/l	375 mg/l	1,500%
COD	125 mg/l	450 mg/l	300%
Suspended Solids	50 mg/l	150 mg/l	300%
pH	6-9	6-9	-
Free Oil and Grease	10 mg/l	N/A	-
Nitrogen	10 mg/l	N/A	-
Phosphorous	10 mg/l	100 mg/l	1,000%
Coliform Bacteria	150,000 MPN/100 ml	N/A	-

  The environmental discharge limits are more stringent and also includes additional parameters.

  As a result of more stringent limits, the costs associated with wastewater treatment tends to rise. In many cases, the required limits are so low that the benefit of the lower discharge costs may be outweighed.

- The application and maintenance requirements associated with a CAR licence are typically notably more robust than those required for a trade effluent consent. The industrial site will have to demonstrate environmental controls and assurances that consent limits will not be breached. SEPA are typically more reactive to consent limit breaches than Scottish Water.

- SEPA's main role is as an environmental protection regulator, not as a provider of wastewater services like Scottish Water. Therefore, SEPA may be less inclined to allow for discharges to the environment, especially if the area is served by Scottish Water, and may reject an application for discharge.

- Depending on the discharge, regulations beyond CAR may be required to be complied with - the Aquatic Animal Health (Scotland) Regulations 2009, as regulated by the Scottish Government's Animal Health department could be relevant.

Case Study 2

With a view to determining the most cost-effective approach to wastewater treatment across a full life cycle, an industrial site in the aquaculture industry commissioned an assessment into options available to them prior to the construction of a new site. The following options were assessed:

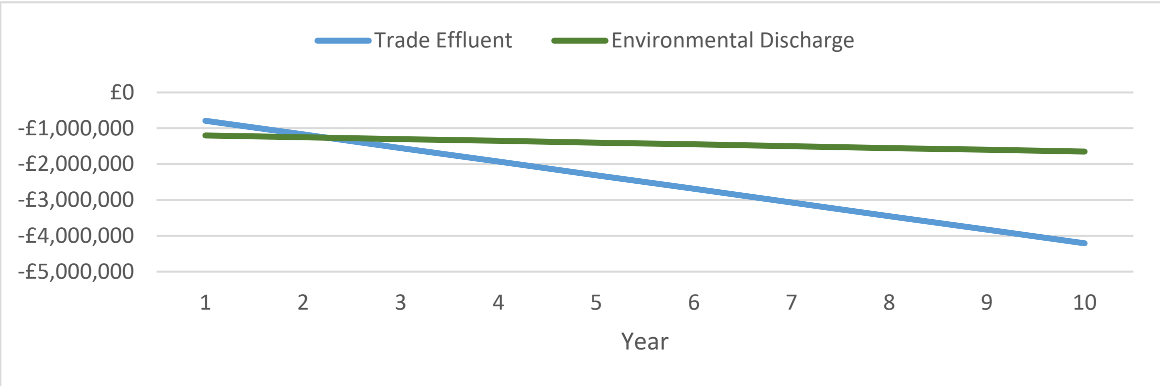
1. Treatment of wastewater to allow for discharge to a local Scottish Water sewer.
2. Treatment of wastewater to allow for discharge to local water body.

Through liaison with regulators, equipment providers and industry experts, appropriate treatment systems for each option were identified and evaluated. Additionally, discharge costs, maintenance costs, operational costs and discharge routes were identified.

As a result of this exercise, the following comparative business cases were determined:

	Sewer Discharge	Environmental Discharge
Total Capital Cost	£790,000	£1,200,000
On-going Costs	£380,000	£50,000

The indicative costs are charted over a period of 10 years below:



As can clearly be seen, this identified that, although initial capital costs were higher, the lifecycle costs of a discharge to the environment were more favourable. Therefore, this option, with higher treatment requirements, was preferred by the site.

4.1.3 Uplift of Wastewater by an Accredited Contractor

In some cases, sites will choose for wastewater to be uplifted from their site by an accredited waste contractor for disposal off-site. Relative to discharge as trade effluent or discharge to the environment, this approach typically has notably higher associated operational costs on a £/m^3 basis. This can be attributed to the requirement to transport wastewater and the additional manual involvement in filling and emptying tankers prior to discharge.

This approach is typically only utilised in the following scenarios:

- The quality of effluent, in such that treatment on site would not be cost effective due to high capital costs associated with relatively complex treatment. In this scenario, effluent quality would also mean that disposal as trade effluent or to the environment would not be consented by SEPA or Scottish Water. This low effluent quality would also be a factor in the high cost of uplift as contractors will typically include for charging based on quality.
- There is no possibility for the site to discharge as trade effluent as there is no local network available (due to location or the local Scottish Water plant is at capacity) and the option to discharge to environment is not available (due to strict discharge limits or no suitable discharge location is available).

- Only small volumes of industrial wastewater are generated; therefore, the total associated costs are low (although unit charges are high). Due to lower overall costs, alternative approaches may not have been considered.

In the case where a site can treat wastewater that was previously uplifted for off-site discharge, allowing for discharge as trade effluent or to environment, or even improving wastewater quality to reduce uplift charges, notable savings can often be made.

It is anticipated that costs associated with this method of wastewater disposal will continue to increase for similar reasons as those discussed in Section 4.1.1. This is due to the wastewater being uplifted is likely to pass through a treatment facility which will be subject to the same constraints and pressures that any other facility described will face.

Case Study 3

A large industrial site in the food and drink industry generated two distinct wastewater streams, broadly characterised as follows:

1. **High volume but of reasonable quality**. This wastewater stream was discharged to a local Scottish Water sewer as trade effluent, resulting in charging via the Mogden Formula, with a low quality component but large volumetric component. Volumetric unit charges were in the order of £0.34/m^3.
2. **Lower volume but of very low quality**. This wastewater stream was uplifted by tankers operated by a specialist contractor. This resulted in charges of around £6.70/m^3 of effluent uplifted. The client initially considered that the quality of this waste stream would prohibit discharge as trade effluent.

In total, combined wastewater charges of **£150,000** per annum were typically experienced at the site. Uplift by an accredited contractor accounted for £115,000 of these costs.

In order to address this, the two waste streams were combined and treated in an on-site effluent treatment plant consisting of a balancing tank, a dissolved air flotation (DAF) plant, a pH correction system and a v-notch weir discharge. This resulted in a wastewater stream that could be discharged to sewer.

Inclusive of maintenance, operation, chemical supply and key overheads, the annual charges associated with wastewater dropped to around **£60,000**, a decrease of **£90,000** per annum.

	Original Set-up	After Implementation of Wastewater Treatment	Difference
Trade Effluent	£35,000	£55,000	£20,000
Uplift by Accredited Contractor	£115,000	£5,000	-£110,000
TOTAL	**£150,000**	**£60,000**	**-£90,000**

The full treatment plant had an associated cost of around £240,000. This gave the project a simple payback of **under 3 years**, a key factor in the decision to install a plant on site.

4.2 Regulatory Compliance

As discussed in Section 4.1 above, discharge of wastewater from a site typically has associated consent limits implemented by a regulator (Scottish Water, SEPA). Therefore, to discharge wastewater from a site, these limits have to be met, which is a notable driver for businesses to implement technologies to treat wastewater.

This requirement from regulators has been identified as a driver behind many sites installing treatment facilities. It is common for wastewater generated in industry to be viewed only as a problem that needs to be dealt with rather than key site infrastructure that can be improved or developed. Therefore, meeting regulatory requirements (i.e. the minimum level of effort) can be considered the level that industry are happy to work towards.

The potential legal, financial and company reputational ramifications of not meeting regulatory compliance is deemed as a driver towards improvement. However, as discussed in Section 5.2.3, it is considered that enforcement by regulators is not always strong - and some sites will exploit this to avoid, delay or limit improvement action.

Discharge consents are not the only regulatory driver behind industrial wastewater treatment. Requirements of legislation such as The Pollution Prevention and Control (Scotland) Regulations 2012 (PPC), which is relevant to a large number of Scottish industrial sites, can be a driver towards improvement. These regulations, which involve a site wide assessment of pollution prevention and control, require sites to work towards the principles of Best Available Technique (BAT).

BAT holds specific regulatory meaning, as provided below:

"**Best**" - means the most effective techniques for achieving a high level of protection of the environment as a whole.

"**Available**" - means those techniques which have been developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the cost and advantages, whether or not the techniques are used or produced in the United Kingdom, as long as they are reasonably accessible to the operator.

"**Techniques**" - includes both the technology and the way the installation is designed, built, maintained, operated and decommissioned.

The concept of BAT are further described in detail in the BAT reference (BREF) notes. The BREF notes detail how BAT can be applied across a number of sectors and describes application across a range of technologies.

Often, technologies that represent BAT may have higher up-front capital costs but will have more favourable ongoing costs. Technologies specified under BAT tend to be of higher specifications than those that would normally be installed by an average industrial site.

Historically, the principles of BAT have not always been strictly enforced by SEPA (similar to those for discharge consents – as per Section 4.1). However, this appears to be changing with the industry reporting more cases of enforcement. The stricter the enforcements of concepts such as BAT, the more opportunity there is for the market to grow as regulation enforces change, rather than just encouraging it.

Across the market, it is reported that environmental regulations appear to be tightening, with stronger enforcement and stricter limits. For example, the BREF notes are currently undergoing a phased update, following the introduction of the Industrial Emissions Directive (IED) in 2012. Once a BREF note relevant to a permitted site has been updated, the site has up to 4 years to comply with revised BAT conclusions. Enforcement with regard to these updated standards has been reported in the market.

One of the notable developments over recent years regarding water management under BAT has been the move towards encouraging full or partial reuse of water on a site, rather than the disposal of wastewater. If aggressively enforced, this requirement could be a catalyst for growth in the industrial wastewater treatment market.

As all wastewater eventually works back to the water environment (either directly or via discharge to a Scottish Water plant that later discharges to the environment), the changes in regulations are anticipated to be a strong driver in the market in the coming years - both in terms of industry investment and market innovation.

Protection of Scotland's natural water resources is high on the agenda of SEPA as they implement their overarching One Planet Prosperity strategy[10].

It should be noted that the practical enforcement of regulations may not always be as robust as considered necessary by many companies working in the market. This is discussed further in Section 5.2.3.

Case Study 4

Due to an increase in production at a chemical handling site, the quality of wastewater being generated had dropped to a level that the regulator of the site's wastewater discharge, SEPA, had reported regular non-compliant sampling results.

The site had an existing effluent treatment plant that was aging and close to the end of its lifespan. However, due to the capital costs associated with the implementation of a new system, this had been delayed a number of times. Finally, due to a chemical spill at the site causing a pollution incident (untreated wastewater was discharged to the environment), SEPA provided the site with a written warning notifying them that failure to work toward compliance would result in legal action and the potential of a fine.

As the site was regulated under PPC, SEPA required that the principles of BAT be followed in the procurement of a wastewater treatment system. Therefore, the selected wastewater solution designer worked in tandem with a consultancy specialising in the principles of BAT to provide a suitable solution for presentation to SEPA. The BAT assessment considered the following:

- The technical applicability of the system to be installed;
- The capital investment required for design, procurement, installation and commissions of the proposed system;
- The anticipated ongoing costs of running the system;
- The system's anticipated environmental impact;
- Alternative options available to the site (alongside the assessment criteria noted above).

As a result of the assessment, SEPA confirmed that the approach to be taken represented BAT. The new system was installed at the site, inclusive of controls preventing any discharge of effluent in the event of a chemical spill on site.

This new system has resulted in regular compliance with the regulator's quality limits and also provided system running cost savings.

4.3 Operational Cost and Environmental Savings

In many cases, the implementation of new wastewater treatment technologies at an industrial site can be justified by potential operational cost savings that may be made. Technologies are being continually researched and refined as suppliers look to optimise in terms of treatment efficacy, capital costs and associated operating costs (as discussed in Section 8.1).

Many industrial sites will have environmental efficiency targets that they are required to meet e.g. those set by site management or corporate, environmental management systems (e.g. ISO 14001), supply chain pressures or regulatory requirements such as the energy savings opportunity scheme (ESOS - detailed further in the case study below)[11].

[10] https://www.sepa.org.uk/regulations/how-we-regulate/delivering-one-planet-prosperity/
[11] https://www.gov.uk/guidance/energy-savings-opportunity-scheme-esos

Therefore, as these environmental savings regularly have associated financial savings, there is the potential for operational cost savings due to the meeting of these targets.

Technologies may promote potential efficiencies in terms of:

- Energy demand (e.g. electricity or gas);
- Chemical consumption;
- Water consumption;
- Operator time savings;
- Maintenance cost reductions;
- Plant lifespan extension.

The advantage of focussing on operational cost savings as a driver for implementation is that business cases can be prepared to justify any investment. As one of the main barriers to investment in wastewater treatment is financial (discussed in Section 5.2.1), this can help to overcome the barrier, especially with those who view wastewater treatment solely as compliance-based investment.

It is common for wastewater plants to be viewed as outwith the scope of many site's continuous improvement cycles as they are not viewed as part of a site's core processes, rather as a compliance-based add-on. Therefore, wastewater treatment plants are often run with high environmental and economic inefficiencies. This provides a high level of potential for improvement by adopting modern technologies.

Case Study 5

With a view to improving energy efficiency at larger organisations, the UK government implemented ESOS, a mandatory energy assessment scheme. As part of this scheme, qualifying organisations are required to undertake assessments focussed on the identification of cost-effective energy efficiency opportunities. This is a key factor at wastewater treatment facilities as energy represents one of the largest operational costs.

As a qualifying organisation, a large pharmaceutical company commissioned an energy efficiency audit of a wastewater treatment facility that they operate.

Energy efficiency opportunities were identified for the site, with a total potential cost saving of over **£650,000 each year**. This equated to potential carbon savings of **1,650 tonnes per annum**.

Opportunities considered improvements around the following areas:

- Upgrade of existing sludge management technologies;
- Control measures associated with plant mixers and fans;
- Optimisation of aeration tank instrumentation and controls;
- Implementation of alternative, energy efficient treatment technologies;
- Improved plant maintenance measures and practices.

As each of these opportunities had associated business cases with attractive payback periods, a number of them were implemented at the plant. This resulted in both cost and environmental savings for the site.

4.4 Growth of Industrial Markets

Growth in the industrial wastewater treatment market can be, for obvious reasons, heavily linked to the growth of industrial markets. In the case where an industry that traditionally has a requirement for wastewater services is growing, this has a positive impact on the wastewater treatment market. Wastewater discharge characteristics vary across sectors, and their treatment requirements can vary also. Therefore, specialism in treatment of wastewater in growth markets is likely to have a positive impact on growth.

In Scotland, the main industrial growth markets likely to have an impact on the wastewater treatment market are described below[12]:

- **Food and Drink Sector** - Average growth of around 2.6% per annum. Notably, increased growth in the fishing and aquaculture sector (12.3%) and in the manufacture of food products sector (4.1%).
- **Life Sciences Sector** - Average growth of around 3.7% per annum. Notably, increased growth in the manufacture of basic pharmaceutical products and pharmaceutical preparations sector (7.8% average annual growth) and in the manufacture of medical and dental instruments and supplies sector (3.6% average annual growth).

Although sector growth figures are a good indication of potential impact on the wastewater treatment sector, these are indicative only. As the characteristics of wastewater generated by each sector varies (and hence the associated treatment requirements), slight fluctuations in a declining sector may have a larger impact than large fluctuations in a growing sector.

As discussed in Section 6.0, it is recommended that the Scottish wastewater treatment sector look to focus on these growth sectors, becoming global experts. This will allow for Scottish input on locally relevant processes.

4.5 Water Scarcity and Water Reuse

The issue of water scarcity is one that is of a growing concern across the world. This occurs where water resources are insufficient to satisfy long-term average requirements. Primarily, there are two factors that drive water scarcity:

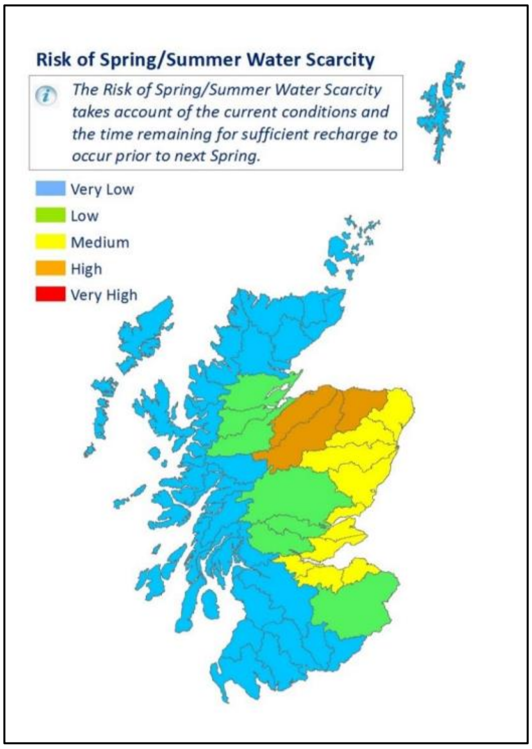
- Climate - controlling the availability of freshwater resources and seasonality of supply;
- Demand - this is largely controlled by population and industrial activities.

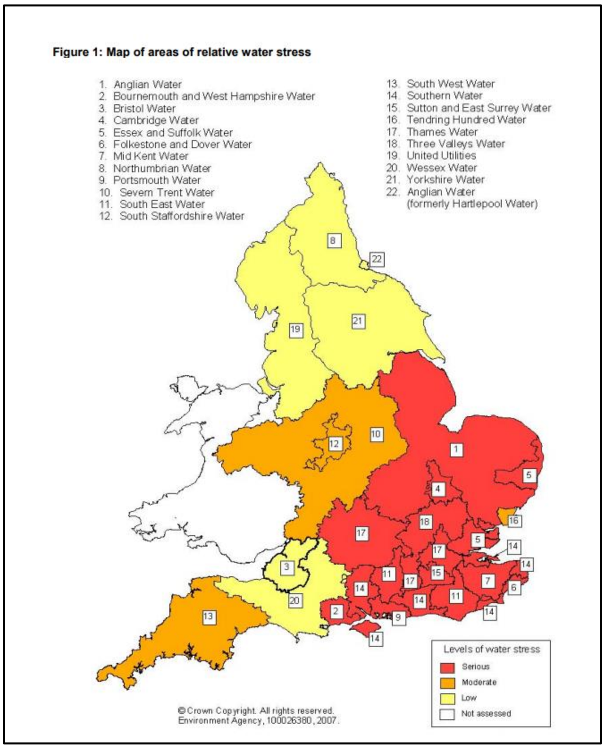
In order to address scarcity, adjusting and controlling demand can help to remediate the issue. As industry is a large consumer of water, reviewing how water is used at a site is an important factor. In particular, this can contribute towards a push on recycling of water at a site, instead of the discharging of wastewater. This therefore could act as a driver towards implementation of further wastewater treatment systems at industrial sites, which do not just treat water to a discharge standard but also allow for reuse.

[12] All growth figures refer to turnover growth between 2008 and 2016 as per the Scottish Governments Growth Sector Statistics Database (https://www2.gov.scot/Topics/Statistics/Browse/Business/Publications/GrowthSectors/Database)

As an indication of water scarcity in the UK, the figures below provide an overview of both Scotland and England provided by their associated environmental regulators:

Figure 4.1: Spring/Summer Water Scarcity in Scotland[13]
Figure 4.2: Map of Areas of Relative Water Stress in England[14]



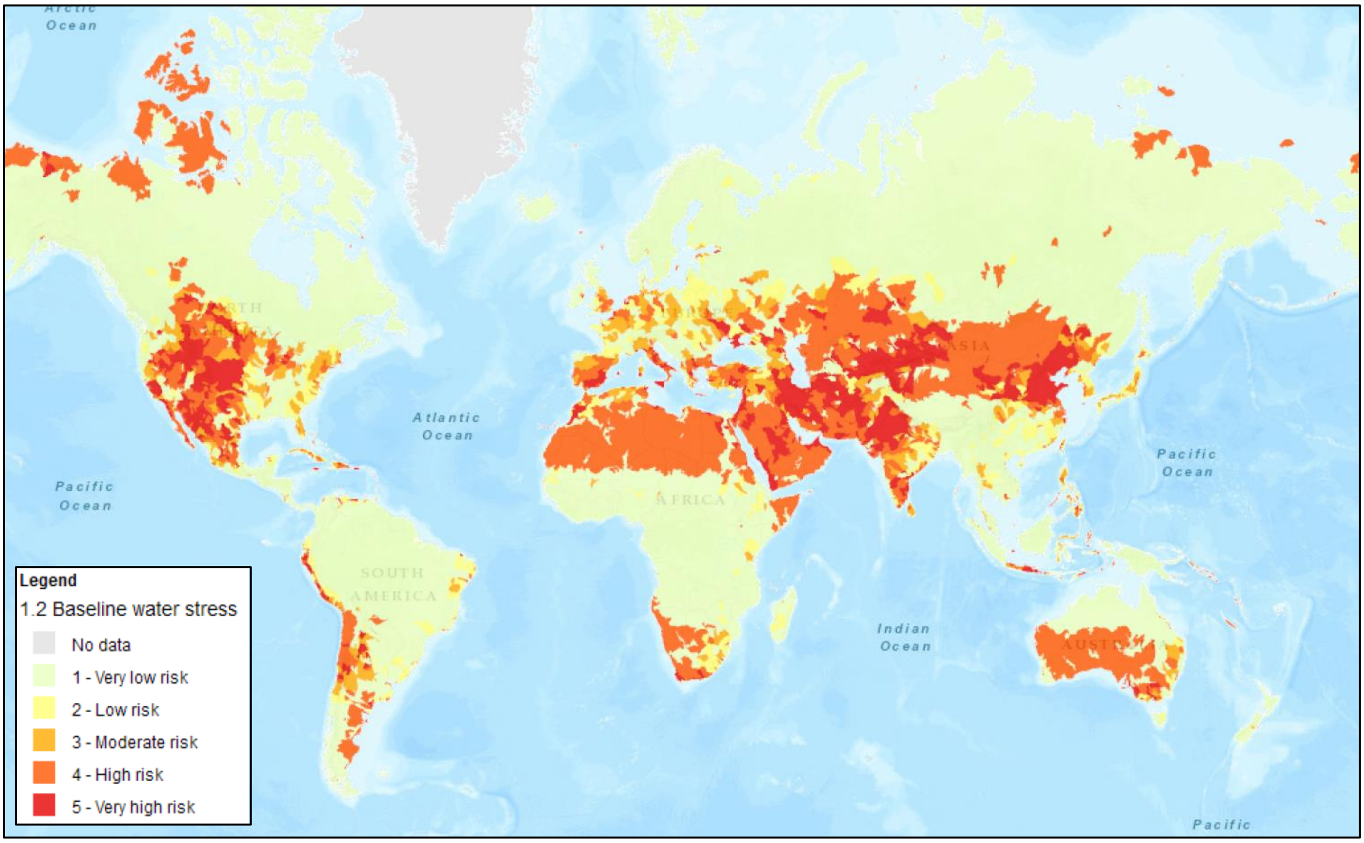


The majority of Scotland has little risk of water scarcity, apart from some of the East coast. In comparison, much of the South East of England has water stress categorised as severe. Although Scotland may currently have less of a requirement to reuse water due to water scarcity, issues in the rest of the UK could result in national measures or water distribution plans that could impact Scottish industry. The head of the Environment Agency (EA) in England has warned that within 25 years it is anticipated that England will not have enough water to meet demand[15].

[13] SEPA Water Scarcity Situation Report (28/02/19)
[14] Environment Agency - Areas of Water Stress: Final Classification
[15] https://www.bbc.co.uk/news/uk-47620228

The map below shows water stress across the globe.

Figure 4.3: World Map of Water Stress[16]



This clearly shows that water scarcity and stress on natural resources is prevalent across large parts of the world. Therefore, adaption of wastewater treatment allowing for reuse to help alleviate this stress may be a key feature of the market in the coming years.

4.6 Equipment Affordability Driven by Demand

As discussed in Section 8.0, R&D of wastewater treatment techniques is ongoing as the market looks to improve technologies. One of the areas in which R&D can support technologies is in improving affordability.

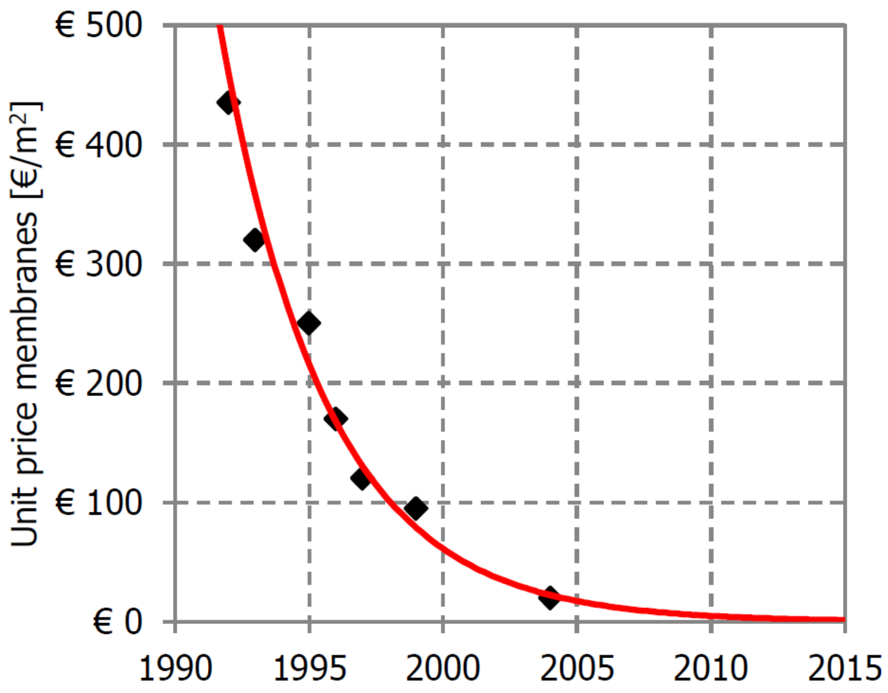
The affordability of a technology has a relatively strong correlation to its adoption by the industrial market. As demand for technology increases, so does the associated investment in R&D, potentially further improving affordability. Also, as production of a technology increases, the overheads associated with production may start to decrease, potentially passing further potential capital savings to the end users.

The advancement of membrane technologies is an example of where the affordability of wastewater treatment technology has been driven by demand. This technology has been developing steadily over the last few decades, showing advancements in terms of treatment efficacy, operating efficiency and, possibly most importantly, unit affordability.

The figure below provides an overview of membrane costs per m^2 over time.

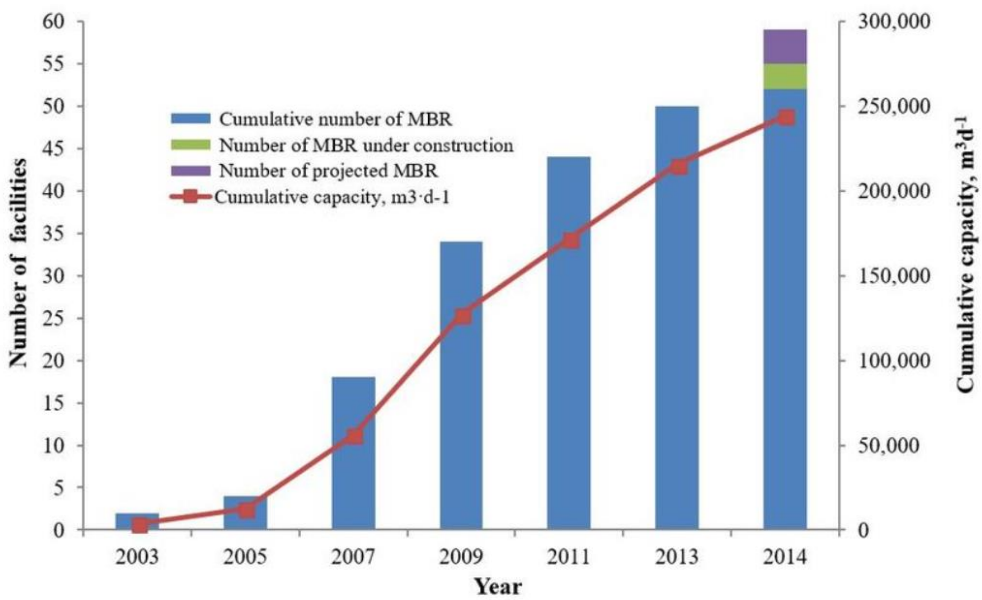
[16] World Wide Fund For Nature - Water Risk Filter (http://waterriskfilter.panda.org/en/Explore/Map)

Figure 4.4: Indicative Unit Cost of Membranes 1990 to 2015[17]



Affordability of membranes has improved considerably over time. As a result, the uptake of membranes in wastewater treatment facilities has also risen. The chart below provides an overview of the uptake of Membrane Bioreactors (MBRs) in Spain, a technology dependent on membranes.

Figure 4.5: Uptake of MBRs in Spain 2003 - 2014[18]



The adoption of a treatment technique that is dependent on membranes has risen as costs associated with membranes have dropped. Where affordability improves, this will start to encourage industrial sites to consider investing in ageing wastewater treatment equipment or will improve business cases associated with new treatment facilities.

[17] The Feasibility of a Commercial Osmotic Power Plant - R. Kleiterp
[18] Cost comparison of full-scale water reclamation technologies with an emphasis on membrane bioreactors - R Iglesias, et al.

4.7 Increased Automation and Remote Control

One of the trends in the industrial wastewater treatment market in recent years is the increase in automation and remote control/data analysis. These new capabilities have resulted in a number of operational benefits being available in wastewater treatment - potentially allowing for a more consistent quality of discharge.

This trend is strongly linked to the development in communication technologies such as low-power wide-area network (LPWAN) and in instrumentation. The move towards remote data collection, exchange and analysis being used to impact control or automation (sometimes referred to as the internet of things - IOT) is growing in influence across a multitude of sectors, development which has benefitted the wastewater treatment sector.

These advancements have allowed treatment plant operators to access real time data on the running of a treatment facility. The data available depends on the instrumentation made available at the plant. Systems may simply monitor discharge quality/flow rates or allow for analysis of plant operation across a number of stages.

Increased automation and remote control of wastewater treatment plants can be a real driver for growth as it could represent a notable change in how the sector operates, proving a disruptive influence. Advances in treatment technologies are not always readily understood or adopted by industry, however, the IOT is becoming recognisable across various sectors and its benefits are therefore becoming better understood. As industrial sites observe the benefits of similar intelligent systems across other parts of their business, this could help to encourage adoption of similar systems at wastewater plants.

Implementation of an effective intelligent control system can help to highlight existing inefficiencies (if the data is suitably analysed – this is not always the case as noted in Section 5.2.6). This in turn could help industry focus on their treatment technologies and better quantify the benefits of alteration. Benefits are also available for industrial sites who would prefer remote control or plant performance analysis by a specialist third party to offer a level of assurance on the running of a plant.

It should be noted however that during cost engineering in later stages of any design project (undertaken prior to the installation of a wastewater treatment plant), automation, instrumentation and remote control are typically the first elements to be removed, as they may be viewed as non-essential. This barrier may start to lower as the IOT approach is adopted more widely but is a key consideration at present.

4.8 Increased Adoption of Environmental Controls - Export Markets

In many cases, when a developing country first becomes industrialised, the ethos of the nation can be to grow at all costs in order to make the most of the opportunity afforded. It is common that, once industry is established, maturity/necessity can start adapting the ethos to one of growing sustainably.

As this trend continues, authorities typically start to impose stricter limits on the acceptable quality and quantities of wastewater that can be discharged by industry. Many developing countries are currently at this point where sustainable development is being adopted and associated controls are being enforced.

As Scotland is a nation with well-developed regulations and therefore experience of compliance with these strict regulations, there may be opportunity for the Scottish market to support those developing a sustainable ethos.

For example, there is potential opportunity for the Scottish market to support industry in India as industry develops and sustainability becomes a factor. India is the worlds fasted growing large economy[19] and it is reported that there is good opportunity for Scotland to support in water and wastewater treatment sector. Scottish Enterprise have identified India as a key emerging market.

[19] https://www.scottish-enterprise.com/learning-zone/business-guides/components-folder/business-guides-listing/explore-emerging-markets

Scottish support in this is not limited to developing countries. The priority example of this is Ireland. Whilst it is a clearly a developed country, its regulation of water quality (via implementation of the Water Framework Directive) is relatively poor. In recent years it has started to put significant additional resource towards administration and enforcement of associated legislation, via the Environment Protection Agency (EPA), and also via the creation of Irish Water (a Scottish Water equivalent). Representatives from Scottish Water are currently in the process of assisting Irish Water to set up a similar administrative framework as exists for Scotland, and many sites can expect large increases in trade effluent costs. Likewise, the EPA are currently reviewing/auditing sites with no authorisation for natural discharges, or where compliance of existing authorisations is not being enforced.

As a result, there will be a significant number of new or upgraded wastewater treatment installed in Ireland in the coming years, and Scotland is well placed to assist.

Section 5.0: Market Barriers

This section provides an overview of the

- Barriers to new entrants in the market.
- Barriers to industry investment in the market.

Comment is also provided on the potential impact of Great Britain and Northern Ireland's exit from the European Union (Brexit) on the Scottish industrial wastewater market.

5.1 Barriers to New Entrants

5.1.1 Reputation

In entering the wastewater treatment market, one of the main barriers faced by new entrants is having little or no brand reputation. This barrier impacts different parts of the market in differing ways:

- **Professional Services**

  For professional services (e.g. designers and consultants) entering the industrial wastewater treatment market, although their company may not have a reputation, it is likely that individuals working for the company will do. Having peer recognition through relevant professional institutions or demonstrable experience in the sector can help alleviate concerns that industrial clients may have.

  The difficulty for these companies will be in the form of identifying, or being notified of, new opportunities. Without a reputation, the supply chain may not be aware of the company, restricting opportunities to bid/quote for services for which they may be suited.

- **Product Manufacturers/Vendors**

  In the case where a product is being sold, reputation is very important. Where a company does not have a reputation, it is more likely that claims on technology performance will be challenged or doubted, even if verified data is available. This can result in companies having to offer free product trials for installations as they look to build up a robust reputation.

  It is not uncommon for a technology vendor to be chosen based purely on reputation, whether founded or not. This is typically weighted towards the larger companies involved in the market, who have wider brand recognition.

  A manufacturer may look to mitigate some of the risk associated with lack of reputation by accessing relevant registrations or approvals. However, in some cases, the end purchaser may not be familiar with or place weight on these registrations and approvals. This may be required simply to compete with the competition on an equal basis.

The development of a strong reputation can be a lengthy process taking a number of years. However, once formed, this can be a key factor in the success of a company or technology.

This is a common potential barrier across sectors and, as such some other sectors have identified solutions to remove this barrier. For example, in the oil and gas sector, the First Point Assessment (FPAL) database allows for independently verified suppliers to be introduced to buyers. This effectively allows suppliers to rely on the reputation of the established and controlled database, giving buyers confidence. This is an approach that could be implemented in the water and wastewater treatment market.

It should be noted that the impact of a bad reputation from one source can be much stronger than a good one from a number of sources. Depending on the source, the weight of an opinion can make a notable difference to the likely success of a technology.

In some cases, a technology's reputation may not be something within a company's control. One company reported that, as a result of poor imitations of their product, the whole technology was given a negative reputation for a period of time.

5.1.2 Proof of Technology Efficacy

In order for an industrial client to purchase a technology, they will first look to determine the efficacy of the technology proposed. As discussed in Section 5.2.4, the industrial sector has a reputation of being risk averse, especially when considering processes that they have less familiarity with. This aversion to risk is not necessarily unfounded, therefore the burden of proof typically lies with those producing the technology. Industrial companies will rely on a strong track record to demonstrate capabilities, and an industrial site is unlikely to want to be a company's first customer.

It is therefore important that appropriate technology testing has been undertaken that can show efficacy in realistic and representative situations. The utilisation of wastewater test facilities is likely to be beneficial to a new entrant seeking to demonstrate practical technology efficacy (additional detail on test facilities is available in Section 8.3). In many cases, technology manufacturers (especially if SMEs) often offer technologies to sites at discounted rates (or sometimes free of charge) as they look to build up a bank of evidence/reputation. This puts further pressure on company start-up costs (as discussed in Section 5.1.3).

However, even with robust evidence of technology efficacy, a fear of new technologies and the unknown can still remain. The path to demonstrating that a technology is appropriate is not common for all technologies and all industrial clients. Some may require proof beyond what is currently available for a new entrant, while others may more readily accept the available proof. There is currently no widely adopted/recognised standard testing methodology used to approve technology efficacy, resulting in some developers having to undertake a number of similar tests and demonstrations to prove the technology to different potential clients.

In some cases, designers will look to provide process guarantees when finalising a treatment system design. This guarantee is typically based on proposed effluent discharge quality based on defined influent parameters and can help to encourage buy-in from reticent industrial sites by passing the risk on to the designer (and away from the site).

5.1.3 Start-up Costs

When entering a market as a new business or an existing business with new products, the costs associated with start-up can be significant and can act as a notable barrier to progression. Often, prohibitive spend will be required prior to a company being in a position to start recouping the spend through sale of services or technology (or even having a technology at a point where sale would be possible). It's reported that a technology can typically take 7 to 10 years to get to market, therefore, this start-up period can be a key factor in a technology's likely success.

Typical start-up costs to be considered can include:

- **Business overhead costs** - this would include items such as staff costs, office rental, utility bills, IT systems, etc. These are unavoidable costs across all businesses and can be significant.
- **Insurances** - a range of different insurances may be required by a business at inception. For example, professional liability insurance, workers compensation insurance, business interruption insurance, product liability insurance, property insurance, etc. Depending on the nature of the business and the scale of associated investments required, insurance values can range.
- **Legal costs** - in setting up a registered company, legal advice and support is typically required. Also, in the case a technology is being developed, patents may be required, which again have an associated legal cost implication.
- **Research and development (R&D)** - the process of research and development for a new technology can be long and costly. Start-ups may need to purchase raw materials, commission independent reviews, pay for access to specialised R&D sites (e.g. test centres), etc.
- **Registrations/approvals** - to provide credibility or sell a product legally, registrations or approvals may need to be sought, e.g. Drinking Water Inspectorate (DWI) approval, EU Biocidal products regulations (EU BPR) registration, Control of Pesticides Regulations (COPR) registration, etc.
- **Management systems** - In order for a company to be included on potentially lucrative client frameworks, lengthy demonstrations of commitment to quality, the environment, health and safety, etc. are often requested. In many cases, it can therefore be deemed appropriate for the developer to develop expensive registered management systems (e.g. ISO 9001, ISO 14001, OHSAS 18001) to readily demonstrate these commitments.

Due to the required investment that a business or individual may need to make in advance of receiving any income, this barrier can stop innovators from entering the market. Even in the case all start-up costs are believed to be accounted for, some things cannot be planned for or anticipated.

Case Study 6
A Scottish wastewater treatment technology start-up had developed and patented their innovative new technology. The process undertaken to that stage had been costly due to standard business start-up costs and extensive R&D. A version of the developed technology was then found being used, inclusive of the patented product name, by a large wastewater treatment company in mainland Europe. No legal permissions had been sought for the use of the name or attempted duplication of the product. This led to lengthy and costly legal proceedings for the developer. Even though the case was decided in their favour and compensation provided, it was considered that this resulted in a notable financial loss for the start-up. In addition to this, the copycat technology had sold a number of units. As the replication was not considered to offer the same benefits to industry as the original technology, this resulted in the company's reputation being negatively impacted.

5.1.4 Short Term Planning from Industry

In many cases, industry can take a short-term view with regards to investment in wastewater treatment (as further discussed in Section 5.2.2), favouring low capital costs above low operating costs. Many new products entering the market are not new technologies, rather adaptions or advancements to existing technologies, but with improved operational performance (e.g. treatment potential, running costs, maintenance time, etc.). Therefore, a longer-term approach to investment is important.

The implementation of a product with improved operational efficiency can often require a customer to invest based on the lifetime savings associated with the technology rather than an improved purchase cost. Therefore, unless industry adopts a longer-term view with regard to wastewater treatment, this can be a notable barrier to new products.

5.1.5 Client Technical Understanding

Understanding the wastewater treatment market can require a strong grounding in the technical aspects of a wastewater treatment facility. In the case a new technology is on offer that offers gains on existing technology, it is important to know how this will impact costs, plant operation and (potentially most importantly) wastewater discharge compliance.

In the majority of cases, decision makers regarding wastewater treatment at an industrial site will not have a background in wastewater treatment, rather, it is likely that they will specialise in services associated with the site's core operations. Additionally, non-technical senior management or accountancy staff may have significant influence. Although many of the key concepts employed in the assessment of technologies may be similar across disciplines, in some cases, specific technical knowledge is required.

Without fully understanding how a technology would be beneficial to a site, the potential for industry implementation is low. This knowledge gap is one that some industrial sites look to bridge via the employment of sector specialists or active investigation by motivated employees. However, it is a gap that others do not bridge, remaining with technologies and concepts with which they are more familiar and comfortable.

Many larger companies restrict procurement of technologies to pre-defined and approved framework contractors. Where an innovative new technology is proposed to be included on a framework, it is reported that this can be rejected due to being too similar to a product already in the framework - even when this is not the case. Unless those involved in procurement have sufficient technical understanding, differentiating factors between new and existing products can be misunderstood.

In the case of a new technology type with an innovative technical operating concept being proposed, understanding of the core technical concepts of how the product operates may be required. Reliance on textbooks and publically available descriptions of common technologies may prove to be outdated, causing a lack of industry confidence in the product.

As discussed further in Section 9.8, this lack of technical understanding could be potentially bridged by the employment of qualified and informed operators at a site's wastewater treatment facility.

5.1.6 Marketing Capabilities

There is a difference in skill sets required by an individual to develop a technology or service and the skill set to effectively market a new technology. In some cases, the same individual may have both of these skill sets, however, in many instances this is not the case.

Therefore, a new entrant may have developed a revolutionary technology that has a number of demonstrable advantages/improvements relative to existing products, however, if they cannot effectively market the product, sales may not reflect potential. New entrants often have a technical background, which can become the focus of marketing presentations, regardless of the receiving audience.

Although technical personnel at an industrial site may be involved in investment decision making, it is common that non-technical personnel may also be involved (e.g. finance directors, managing directors, etc.). Therefore, knowing how to effectively market can be as important as the technical make-up of a technology or service. In many cases, the success of a technology is down to an ability and knowledge of how to sell it rather than technical benefits.

Case Study 7
One technology manufacturer reported that, upon discussion of the technology with key stakeholders in an industrial company, there was an aversion towards discussing compliance of the site's wastewater treatment plant. The company did not want to consider that the plant may not be compliant and did not want to install any technology that could potentially impact compliance (even if positively). Therefore, the manufacturer's marketing team posed the technology as purely a solution to assist in the optimisation of the treatment facility. Although the product would also assist with compliance, the understanding of how best to present the benefits that the stakeholders were more focused on allowed for a sale of the technology.

5.1.7 Cost Engineering

As discussed further in Section 5.2.1, the lack of available capital for investment can be a notable barrier to the implementation of wastewater treatment technologies at industrial sites. This lack of investment potential often results in rigorous cost engineering being undertaken prior to a project being approved. Cost engineering typically results in the removal of elements not considered to be essential to the basic operation of a system.

Elements such as controls, instrumentation, telemetry and plant automation (typically items that fall into the process control and management component) are removed from a proposed design. For technology suppliers who specialise in technologies often in the "non-essential" category, cost engineering can be a significant challenge.

Cost engineering holds an important role in industry, helping to control investment costs and manage site capital budgets. However, cost engineering does not necessarily allow for a longer-term outlook and has a focus on capital investment rather than lifetime costs. In many cases, the technologies engineered out of a design could have longer term benefits that would outweigh their initial investment costs.

Case Study 8
In order to address the issue of discharging wastewater that was acidic in nature, and often outwith compliance parameters, an industrial site in the heavy manufacturing industry commissioned a consultant/designer to provide the cost for a fully automated pH correction system. In order to avoid operator time being spent at the treatment facility, telemetry was to be scoped that would allow for remote analysis and control. The system was provisionally designed and sent to the market place for vendors to provide competitive quotations. This resulted in a quotation that met the site's requirements being returned at a cost of around **£48,000**. Upon review of the quotation provided, the client looked to reduce costs due to budget constraints placed on them by the company's financial officer. As a result, a cost engineering exercise was undertaken which removed any non-essential automation, instrumentation and telemetry. As a result, the system was re-tendered and the site's basic requirements were met for **£32,000**. The revised system, although technically viable, had the following impacts relative to the original design: ▪ Lower energy efficiency (equivalent to around £1,230/annum); ▪ Additional staff time demand; ▪ Higher potential chemical demand (equivalent to around £870/annum); ▪ Absence of safety features in the event of system failure.

5.1.8 Access to Funding

In Scotland, new businesses can be supported by a range of funding options open to them. These can be in the form of grant funding for regional growth, support for R&D, start-up loans, technology verification support, etc.

However, the world of funding, grants and loans can be complex. Funding options can have stipulations regarding:

- Company location;
- Company size;
- Industries to be supported;
- Potential company benefits;
- Background of company owner;
- etc.

The success that a business may have in accessing funding could depend on the timing of an application, the current focus of the grant organisation or the way in which they have prepared their application.

With a range of funding opportunities available to small businesses operated by a number of organisations, finding the correct opportunity can be difficult or confusing. These important funding channels, which are in place to encourage innovation and entrepreneurship, can often be missed by those who meet the requirements of the intended recipients.

To overcome this barrier, Scottish Enterprise, Business Gateway and other economic development agencies, can provide advice to businesses on access to funding and research and innovation. Specifically for water, there is the Hydro Nation Water Innovation Service (HNWIS) to help accelerate the development of new water related technologies to commercialisation.

5.2 Barriers to Industry Investment

5.2.1 Availability of Capital for Investment

One of the main barriers to an industrial site investing in the wastewater treatment is the availability of capital to invest. Wastewater treatment plants can have significant capital and installation costs and industries do not typically prioritise investment in non-production related areas (if capital is available at all).

A wastewater treatment facility is a long-term investment. Therefore, factors such as longer term company stability may come into account when factoring in investment. It is common for on-site treatment facilities to be run well beyond their design life as industry looks to avoid capital investment in what is typically considered an overhead cost, until such time as investment becomes critical e.g. due to regulatory pressures.

The benefits associated with the installation of a new system aren't always fully grasped, causing the business case associated with investment to be based only on compliance or cost and not on the additional benefits that could be realised.

As discussed in Section 5.2.5, it is not uncommon for a treatment plant to be only monitored against compliance. Other inputs such as electricity, chemicals, water and maintenance costs are not as closely assessed. Therefore, this is a notable barrier to an accurate business case being prepared for the investment in a new plant (or plant upgrades) based on the operational cost savings that could be made.

To aid in overcoming this barrier, alternative payment models have been made available by some system suppliers. These can be an effective approach to support industry. In these models there are typically two parties. The industrial site looking to install a wastewater treatment system and a supplier who will operate the payment model, generally with the backing of investors. A number of these models are described below.

- Build-Operate-Transfer (BOT)

  In this scenario, the supplier builds (including financing) the wastewater treatment facility to designed specifications, operates the facility for an agreed period of time and finally transfers the system over to the industrial site at the end of a contracted time period. Over the period of the contract, the industrial site will pay a predetermined periodic fee to the supplier.

- Build-Own-Operate-Transfer (BOOT)

  This is similar to BOT, apart from the supplier owns the asset for the contract duration.

- Build-Lease-Transfer (BLT)

  This approach differs from BOT in that no operation is provided by the supplier. This is similar to a loan arrangement.

- Design-Build-Operate-Transfer (DBOT)

  In some cases, the supplier may also be required to design the treatment plant. This is common in cases where the efficacy of the plant is tied into the ongoing contract.

There are other models that have been developed, however they are commonly slight variations of the models described above:

- An initial capital investment (e.g. a percentage of capital costs) may be required from the industrial site;
- Ongoing costs to the industrial client may not always be fixed, in some schemes, this may involve both fixed and variable elements;
- Some schemes may extend to include elements such as acquisition, maintenance and payment of discharge consents.
- At the end of scheme (i.e. once system has been transferred to the industrial client), the supplier may offer an operation contract to continue running the plant.
- Some models do not include the transfer of the system at contract completion although this is not typical for wastewater treatment.
- Industrial site payments are typically inflation adjusted as projects are usually long term.

5.2.2 Lack of Plant Lifetime Cost Consideration

As noted previously, industrial sites can view wastewater treatment facilities only as overhead investments, with business cases being built solely on regulatory compliance. However, in upgrading a treatment facility, there is potential for discharge and operational cost savings (Sections 4.1 and 4.3).

In many cases, wastewater treatment plant operating costs are not effectively monitored. Therefore, the basis for preparing an investment case based on cost savings is not readily available. This may be due to a lack of effective monitoring data being generated or these costs not being deemed as important enough to fully understand. However, until appropriate business cases demonstrating improvement can be generated, lifetime costs may not be considered.

With large capital costs associated with wastewater treatment, it is common that industrial clients will undertake cost engineering exercises prior to investment. At this stage, it is common for technologies that are not crucial to operation but offer lifetime cost savings to be removed from the design. It is reported that, even when clear and positive business cases demonstrating benefit are presented, these can be ignored as total capital investment costs have to be reduced.

In industry, it is often considered that water (and by association wastewater) is the poor relation of gas and electricity. The reasoning for this comes from the water and wastewater expenses typically being lower than those for gas and electricity. As a result of this relationship, the prioritisation of water and wastewater can be lowered, with the true cost of wastewater at a site not being fully understood.

Case Study 9

When purchasing pumps for an on-site wastewater treatment facility, a Scottish industrial site was reported to have been made aware that the pumps available from their preferred technology supplier would require replacement every 3-4 years.

The preferred technology supplier provided details for an alternative pump type that would better match the site's pumping requirements. This alternative unit had a higher capital cost, however would be expected to have a lifespan roughly three times longer and have a lower energy demand. Although the benefits were clearly presented and understood by the client, they opted for the cheaper unit with a shorter lifespan and higher running costs.

Drivers for taking this approach may be the way that budgets are allocated within a company (e.g. annual budgets) encouraging short term thinking, or an internal long term uncertainty causing a short term approach to taken.

5.2.3 Regulatory Enforcement

The presence of a regulated wastewater discharge can be a driving factor for many industrial sites. However, regulatory enforcement often does not result in penalties that are sufficiently large to dissuade non-compliance. Therefore, for sites that are not concerned with the potential of negative publicity or their environmental impact, enforcement may not be enough to encourage compliance with associated regulations.

The SEPA Enforcement Report 2016-17[20] stated that total fines across all of their regulated activities of £92,575 were levied in 2016-17. £28,150 of that total was associated with water regulations. This was spread over 5 different incidents, resulting in an average fine of £5,630.

As the cost of an effective wastewater treatment plant can commonly be into 100s of thousands of pounds, fines in this range would not cause an economic reason for an industrial site to change. However, these fines only represent cases where SEPA have proceeded to a prosecution. SEPA will typically offer a site a number of opportunities to avoid this outcome before prosecution is pursued - it is understood that SEPA prefer the approach of working with companies to remediate non-compliance issues wherever possible.

[20] https://www.sepa.org.uk/media/340366/sepa-enforcement-report-2016-17-final-hi-res.pdf

SEPA report that, through the Regulatory Reform (Scotland) Act 2014, they are now able to enforce fines up to £40,000 for certain environmental offences[21]. However, there have been no reported changes in regulatory enforcement.

It is reported that Scottish Water, as the other key wastewater regulator in Scotland, often operate in a similar manner to SEPA in the event of compliance breaches, with strong financial penalties not being typical.

Common sense enforcement of regulations is a sensible approach, avoiding prosecution where possible. However, for persistent offenders who do not seek to alter approach, stricter enforcement with stronger potential consequences may act as a driver for upgrading wastewater treatment plants.

5.2.4 Industry Risk Aversion

Risk aversion in industry is common. As well as impacting new entrants to the market, it is a barrier to industry investment.

Even where a new entrant to the market is not involved, industry can be reticent to implement any change that is perceived as risk. The attitude of "if it isn't broken, don't fix it" is common with regard to wastewater treatment.

Wastewater treatment can be an area that that is overlooked, even in companies with a positive attitude to continuous improvement and who practice that ethos throughout the rest of their facility. This is typically due to the fear of potentially impacting compliance. Any alteration to a plant that is currently operating to a satisfactory level (or what is deemed to be satisfactory) can be treated with a level of trepidation.

Additionally, although proposed implementations may be common place in the wastewater treatment market, if an industrial site does not have knowledge of the market, technologies can be viewed as new, causing the same barriers as discussed in Section 5.0.

Often fears are rooted in a lack of technical knowledge regarding wastewater treatment at a site, with the plant only being in place for compliance reasons. Wastewater discharge regulations are not the only regulations an industrial site is likely to be operating under. However, if other regulations are associated with operations that the site has more technical understanding of, a less risk averse approach is typically employed. This approach could potentially be adopted for wastewater treatment if increased technical knowledge was available.

5.2.5 Prioritisation of Wastewater Treatment

In most cases across industry, wastewater treatment can be viewed as an unfortunate by-product of the site's production that must be dealt with to a defined level of compliance, and no further. In the case that capital is available, this is preferentially allocated to production related projects, not to the improvement of existing wastewater facilities.

By focussing too much on wastewater treatment, some companies fear that they would be moving too far from their specialism ("core business") into the territory of "being a wastewater treatment company". Although opportunities may be available for the site to make financial, environmental and time savings through the improvement of wastewater facilities, these are not made. The facility is considered as a relatively fixed cost that is only addressed if/when regulatory compliance is at stake. As treatment plants can often be robust systems, that can run effectively relative to compliance long beyond their design life, this can result in plant upgrades not being considered for long time periods.

Although many concepts that are prioritised on the production side of a site (e.g. energy efficiency or waste optimisation) are relevant on the wastewater side, the plant can become detached and is not fully considered. It is common that wastewater treatment facilities may not be included in site wide continual improvement plans.

[21] https://consultation.sepa.org.uk/communications/determining-the-amount-of-a-variable-monetary-pena/

As a result, at industrial sites with this approach towards wastewater treatment, plants can be run inefficiently without performance being properly challenged. In the case that due consideration is made to wastewater treatment, potential savings can be made, which could be used to further support the key function of the site, the production side. Although wastewater treatment is not a direct production activity, it can have an impact on production. These savings could include:

- Financial savings from reducing running costs, optimising maintenance costs or decreasing discharge costs. These savings could be used to further invest in the wastewater facility or in the site's production operations.
- Operator time savings could be made. Where the operation and maintenance of the treatment plant is provided by on-site staff, this time saved could be reapportioned to tasks more directly related to production.
- By investing in a wastewater treatment plant, it is likely that downtime due to plant failures associated with the treatment plant will be reduced. As most sites cannot run without an operational wastewater treatment plant, this also helps to reduce production downtime.
- In some cases, the optimisation/replacement of a treatment plant could allow for greater throughput. Where a site's operations are constrained by their treatment plant, this could lead to an opportunity for increased production.

Case Study 10
Operations at a company in the dairy sector were resulting in the generation of wastewater that exceeded trade effluent consent limits, even after passing through a treatment plant. As a result, the site's production was constrained in order to ensure wastewater discharge remained compliant. The wastewater treatment facility proved to be a limiting factor on production, causing the site to work within its potential capacity. Until the wastewater treatment plant had impacted the site's production, it was not considered by the site to be part of production, rather as an add-on facility which had had little investment made into it since original installation. As a result of the impact on production, the dairy invested in additional treatment technology and an upgrade of existing infrastructure to improve the performance on the treatment facility. Following on from this the site were able to increase production without being limited by their trade effluent consent.

5.2.6 Performance Indicators for Operation and Maintenance

For many industrial sites, the performance of a wastewater treatment facility is based solely on whether compliance with regulator set discharge limits are met. Where the facility consistently treats wastewater within consented levels, no other aspects of the running of the plant are questioned or addressed.

In the case where external operation and maintenance operators are employed, contracts are commonly written up to consider only compliance. Other performance indicators, which can drive improvement, are not always included.

However, a wastewater treatment plant should be subject to continual improvement. To do so, it is important that other key metrics are tracked and benchmarked for improvement. A treatment plant can have a significant energy, resource, cost and water demand, which should be built into improvement metrics.

Common key performance indicators that can be monitored include:

- Energy efficiency
  - kWh per m^3 of wastewater treated
  - kWh per mass of contaminant (e.g. kg COD) reduced

- Raw material consumption efficiency
  - kg of chemical dosed per m^3 of wastewater treated
  - kg of chemical dosed per mass of contaminant (e.g. kg COD) reduced

- Maintenance frequency
    - Cost of maintenance per m^3 of wastewater treated
    - Cost of maintenance per mass of contaminant (e.g. kg COD) reduced

- Water efficiency
    - m^3 of water consumed per m^3 of wastewater treated
    - m^3 of water consumed per mass of contaminant (e.g. kg COD) reduced

A wastewater treatment facility's performance can be masked by excessive resource use. For example, a treatment plant could have a notable water demand due to operators heavily diluting wastewater at a significant cost that is out of specification. This currently occurs to a significant degree at one of the largest private treatment plants in Scotland.

By monitoring and understanding more than just compliance, improvement projects at a wastewater treatment plant are more likely to be identified and benefits more clearly demonstrated. If environmental and cost based targets for operators are implemented, this can help to encourage the continual improvement ethos.

Unless an industrial site is monitored and measured, there is little opportunity to understand where processes require improvement or to demonstrate the impact of improvements. Where a technology is being trialled at a site, the potential for investment is likely to be based on the improvements observed. However, without a benchmark of performance, no robust improvement can be shown.

5.2.7 Fear of Job Losses

As discussed in Section 4.7, the opportunities for wastewater treatment plant automation and remote control are increasing. Although these advancements will be welcomed by some areas of industry, there will be others that will fear the ramification of these advances i.e. the loss of jobs for on-site treatment plant operators.

It is natural that operators have a strong influence on whether treatment facilities are upgraded or replaced. Additionally, in the case where an upgrade or replacement project is undertaken, it is likely that the existing operator would be included in the design and specification stages of the project. With site specific knowledge of the wastewater generated (its strength, flow rate, likely variations, daily patterns, etc.), operator's input should be encouraged.

However, in the case where this fear of job loss is influencing an existing operator's input, this could be a barrier to industry investment.

These fears are not unfounded. In the case where a plant is replaced by a new, heavily automated and more efficient system, it is not uncommon for operator hours or the number of required operators to decrease.

5.3 Potential Impact of Brexit

At the time of writing, Great Britain and Northern Ireland are in the process of negotiating their exit from the EU. With no deal surrounding the exit currently in place, the potential impacts of Brexit are unknown. However, the following considerations are made:

- As discussed in Section 3.0, much of the content in Scottish wastewater treatment facilities, notably in terms of technologies, does not originate in Scotland. A large proportion of content does not originate from the rest of the UK either. The EU is a major contributor to content in Scottish industrial wastewater treatment plants.

  Therefore, the impact that Brexit has on the import of technologies, chemicals and services from the EU could have a knock-on impact on our wastewater treatment sector. This could leave Scottish industry having to pay more for technologies than they had previously.

  On the other hand, this could help to catalyse the Scottish manufacture of wastewater treatment technology in order to meet a need.

- The Scottish industrial wastewater treatment market is dependent on activity in the Scottish industrial sector. Therefore, if Brexit negatively impacts Scottish industry, this is likely to have similar impacts on the industrial wastewater treatment market.

- As an EU member state, the UK's (and hence Scotland's) environmental legislation is derived from EU legislation. Upon exit from the EU, it is unclear how the UK will impose environmental legislation. As this is a major driver to the industrial wastewater market, weakening of regulations could weaken the market, while strengthening them could have the opposite effect. Weakening is considered more likely than strengthening.

Section 6.0: Scottish Supply Chain

6.1 Scottish Supply Chain Database

A database of companies in the Scottish industrial wastewater treatment supply chain has been developed and is available in Appendix C. This database provides a list of companies with capabilities to support Scottish industry with wastewater treatment.

This database contains 102 companies working in the Scottish industrial wastewater treatment market, denoting where companies have a Scottish base or where they are registered in Scotland. This includes a range of businesses, working across industrial sectors. The database is broken into two main lists:

1. Those with a Scottish base actively working in Scotland - Appendix C1.
2. Those without a Scottish base but are active in the Scottish Market - Appendix C2.

Notes:

- Database includes companies that reportedly work in Scotland. It provides a further filter option by those that are registered in Scotland and those that have a Scottish base.
- Initially, companies with Scottish bases were included based on assessment of information provided by Companies House[22] that are categorised under the following SIC codes:
  - 36000 - Water collection, treatment and supply
  - 37000 - Sewerage
  - 42910 - Construction of water projects
  - 74901 - Environmental consulting activities
- Additions were then made to the database via consultation with industry, existing industry experience, existing online database, information provided by Scottish Enterprise and available publications;
- Database is not considered to be exhaustive and is also designed to be readily amended as the market changes.

This database includes categorisation of companies in the following categories of industrial wastewater treatment:

- Design;
- Technology manufacture/construction;
- Operation/maintenance;
- Chemicals;
- Process control and management.

From the supply chain database, a pattern similar to the one discussed in Section 3.0 is observed. Therefore, similar geographically linked strengths are observed in the Scottish market. These trends are discussed under each of the categorisations below:

- **Design**

  In keeping with Section 3.0, there are a number of companies with Scottish bases that are included in this category. Notably, this includes some of the larger companies on the database (e.g. Veolia and Suez) who have Scottish design offices. Although sometimes supported from out with Scotland, it is reported that Scottish projects are generally led from the Scottish bases.

- **Technology Manufacture/Construction**

  The database shows a large number of companies with Scottish bases involved in this component, which appears to contradict the findings of Section 3.0. However, it is important to note that it is not necessarily common for these companies to be involved in the manufacture of technologies from their inception, rather they are more often to be involved in final assembly or in adapting technologies. The main exception to this is in the manufacture of tanks, for which the Scottish market has Scottish based manufacturers.

[22] https://www.gov.uk/government/organisations/companies-house

- **Operation/Maintenance**

  The database only includes nine companies with a Scottish base involved in operation/maintenance. Again, this appears to contradict the findings of Section 3.0, which indicated a strong Scottish involvement. However, the following should be considered:

  - Those companies identified are typically large (e.g. Business Stream, Veolia, H&E and Suez). The external operation/maintenance market is made up of a smaller number of large organisations.
  - Many industrial sites undertake operation/maintenance internally. These sites are not included on the supply chain database as this is not a service they undertake commercially, rather done to support an internal need.

- **Chemicals**

  The database is broadly in line with the description provided in Section 3.0. There are examples of manufacturers, handlers and vendors on the database.

- **Process Control and Management**

  A number of Scottish based companies are provided in this area. Similar to the technology manufacture/construction category, a number of companies are involved only in final installation, assembly or as vendors. Some companies offer solutions that are designed are manufactured in Scotland, however these companies are relatively small on the global market scale.

6.2 Inward Investment Opportunities

In order to assess the potential of advancing the Scottish industrial wastewater treatment market, the potential of inward investment opportunities was considered. Inward investment is the investment into an area (in this case Scotland) from an external source looking to develop a presence or get involved in a growing market.

This section considers the potential factors and opportunities that may motivate an external organisation to invest in Scotland.

- The Scottish food and drink sector is a thriving and growing part of our economy. The entire industry is worth a reported £14 billion[23] and accounts for 29.7% of the Scottish manufacturing sector's value added (£3.8 billion)[24]. In 2017, exports had increased by 11% to a total of around £6 billion and the market aims to grow to £30 billion by 2030[25].

  The continued success of this sector in Scotland represents an opportunity to attract inward investment, by focussing on Scottish strengths. As the sector continues to grow, there is a corresponding investment in the sector, one which often has a link to wastewater treatment systems. The presence of a market into which a business can sell is a key component when identifying where a business is to be based. Therefore, promotion of the opportunities in the sector could be a strong motivation for wastewater treatment service providers looking to fill a market gap.

  Wastewater treatment in the food and drink industry can require relatively niche technologies as waste streams from each sector show differing characteristics. Promoting Scotland as a leader in the food and drink industry could motivate organisations' investment in the country. One industrial wastewater treatment technology company that recently invested in Scotland highlighted this sector as currently being underserved and an opportunity for growth in their business.

- The oil and gas and life sciences industries are also important sectors in which Scotland has a global presence. Water is a large player in both industries, for example, it is estimated that, for every barrel of oil produced, 5 barrels of water is required[26]. Therefore, the opportunities for investment into these sectors should be encouraged.

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[23] https://www.scotlandfoodanddrink.org/about-the-industry/
[24] http://www.fdfscotland.org.uk/sfdf/sfdf_comp.aspx
[25] https://interface-online.org.uk/news/scottish-food-drink-industry-unveils-new-vision-double-size-industry-30-billion-2030
[26] https://www.ediweekly.com/five-barrels-water-produced-per-barrel-oil/

The life sciences sector in Scotland can also provide good insight into effective promotion of inward investment. Scotland invested in enabling infrastructure, funding and centres of excellence that stimulated inward investment which helped to boost the sector's Gross Value Added (GVA) by around 16% per annum from 2007 to 2016[27]. Using this sector as a blueprint can help to map out opportunities for the industrial wastewater treatment sector.

- As discussed in Section 8.3.1, Scottish Water Horizons operate two full scale water and wastewater test facilities. These facilities offer developers the opportunity to test and verify technologies against realistic water and wastewater scenarios. Access to these facilities could prove to be a draw for organisations looking to be based in an area where R&D is encouraged and enabled. The building of infrastructure in support of the wastewater treatment sector can help catalyse investment.

  These test facilities are part of the Water Test Network (WTN), a network of test centres in North-West Europe. This network has access to European funding to help support SMEs when testing. This will facilitate Scottish test facilities to be utilised by a range of organisations from across North-West Europe, potentially attracting companies to invest in Scotland. This is further supported by the HNWIS programme operated by Scottish Enterprise with the aim of assisting companies bring innovative water and wastewater technologies to market.

Inward investment is an evolution of a sector that takes a period of time to show the full benefit. This can be held back or catalysed by external factors outwith Scottish control e.g. investment in the sector by other countries.

6.3 Scottish Export Capabilities

The industrial wastewater treatment market is one that operates globally, with treatment plants typically having worldwide representation when broken down into component parts. Therefore, the potential factors that may motivate export are considered below:

- As discussed in Section 3.8, much of Scotland's involvement in the industrial wastewater treatment market is in components that are traditionally supported locally (e.g. operation, maintenance, building/construction, etc.). Therefore, to export these services would likely require relocation of personnel or hiring of locals. These services in their current form are not traditionally suited for export - this would typically be limited to technologies, process control, chemicals, etc.

  However, there is potential that these services could be coordinated from a non-local, Scottish hub, providing support to non-local contractors. Scotland has been operating under relatively strict wastewater regulations (when compared globally) for a number of years, therefore, the experience gained may be readily applied elsewhere. Export of this knowledge may benefit countries that are currently imposing/enforcing similar regulatory levels in their wastewater sector. Developing countries with growing industrial bases, such as India, could offer potential opportunity for the export of Scottish knowledge and experience. As such Scottish Enterprise have identified India as a key emerging market.

  On the other hand, as discussed in Section 4.8, as Irish Water are in the process of consolidating the implementation of the WFD, there is opportunity for the Scottish market to assist. As regulation at Irish industrial sites has not been to the level enforced in Scotland, there is opportunity for the Scottish experience and knowledge base to be utilised. This is considered likely to require technical knowledge on industrial wastewater, the supply and installation of technologies as well as subsequent operation and maintenance. Due to the proximity of Scotland to Ireland, many Scottish based companies could be well placed to support.

- Given the relatively small scale nature of the market, it is reported that where technologies are developed in Scotland, export is required to make a commercial return. Although the Scottish industrial wastewater treatment market is large (£307 million), it is not generally considered to be a large enough market for a particular technology to be solely focussed on. This is due to treatment plant technology costs being potentially large, but also relatively infrequent (with a reported typical lifespan of around 20 years[28]).

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[27] https://www2.gov.scot/Topics/Statistics/Browse/Economy/QNAS2018Q1
[28] "A comparative life cycle assessment of a wastewater treatment technology considering two inflow scales"

Therefore, to successfully operate in a market that is large enough to support the production and sale of technologies at scale, export is required. One of the most common approaches for smaller developers to export effectively is by forming partnerships with larger or local companies, and this is common in Scottish developers.

Companies with an innovative technology that meets a growing need tend to be those most attractive to foreign partnership. Technologies that are easily replicable or entering a saturated market, for obvious reasons, hold less export potential.

- The technologies that are best suited to export from the Scottish market are those that offer improvements/advancements relative to existing available technologies, those showing a high level of growth potential (e.g. membranes, digestion, etc.), those with low transportation costs and those developed to meet a Scottish need which is also common elsewhere.

  If these criteria are not met, the technology may be one that would be aiming to replace an incumbent, typically a larger company if the technology is well established, which would tend to be able to operate more cost effectively due to lower overhead costs. The wastewater treatment market is relatively mature, therefore, for established technologies, it is likely that these are already produced at a scale that would prohibit a small company cost-effectively building up a business.

- In the UK manufacture is often quality rather than quantity driven. Research reports that around 78% of UK manufacturers focus on quality to drive business growth[29]. As this has been an operating principle in other sectors in the UK, resulting in the country having a strong reputation for quality worldwide, this may be a differentiating factor that could allow for increase Scottish export in the industrial wastewater treatment market. One of the key purchasing criteria that industry use is reliability[30], therefore this can help meet those requirements.

[29] https://www.manufacturingglobal.com/people-and-skills/uk-manufacturers-are-prioritising-product-quality
[30] Technavio - Global Industrial Wastewater Treatment Equipment Market (2015-2019)

Section 7.0: Technology Overview

The industrial wastewater treatment market utilises a wide range of technologies that can be applied depending on the industry subsector, quality of wastewater, contaminants to be removed, volume of wastewater flow, etc.

7.1 Overview of Existing Technologies

In order to provide a high-level understanding of common technologies, a number of technology descriptions are provided in Appendix D (technologies D1 to D14).

Technologies described are categorised as follows:

Table 7.1: Technology Overview Summary

<table>
<tr><th>Category</th><th>Category Description</th><th>Technology Overviews Included</th></tr>
<tr><td rowspan="3">Primary Treatment</td><td rowspan="3">First stage of wastewater treatment utilising physical procedures.</td><td>D5: Wastewater Balancing</td></tr>
<tr><td>D9: Wastewater Pre-treatment</td></tr>
<tr><td>D14: Other Filtration</td></tr>
<tr><td rowspan="5">Secondary Treatment</td><td rowspan="5">Following primary, the removal of smaller particles already dissolved or suspended in the wastewater.</td><td>D1: Membrane Bioreactor (MBR)</td></tr>
<tr><td>D6: Anaerobic Digestion (AD)</td></tr>
<tr><td>D7: Chemical Clarification</td></tr>
<tr><td>D8: Activated Sludge</td></tr>
<tr><td>D13: Other Biological Wastewater Treatment</td></tr>
<tr><td rowspan="5">Tertiary Treatment</td><td rowspan="5">A final cleaning stage prior to the release or recycling of wastewater. Often focussed on key chemical constituents.</td><td>D2: Nano-filtration (NF)/Reverse Osmosis (RO) Membranes</td></tr>
<tr><td>D3: Ultra-filtration (UF)/Micro-filtration (MF) Membranes</td></tr>
<tr><td>D10: Chemical Oxidation</td></tr>
<tr><td>D11: Ion Exchange</td></tr>
<tr><td>D4: pH Neutralisation</td></tr>
<tr><td>Other</td><td>Technologies not falling directly into the categories above.</td><td>D12: Sludge Treatment;</td></tr>
</table>

The descriptions include the following:

- An overview of the technology and how it operates;
- Technology advantages;
- Technology disadvantages;
- Overview of contaminant removal efficiency;
- Growth outlook; and
- Typical sectors of industry in which the technology would be utilised.

For further information on all of the technologies considered the Best Available Technique (BAT) Reference documents are recommended for consideration - http://eippcb.jrc.ec.europa.eu/reference/.

7.2 Emerging and Developing Technologies

The industrial wastewater treatment market is one that is continually evolving, with the emergence of new technologies and development of existing technologies to help meet tighter discharge limits, improve operational efficiencies and respond to changing industrial requirements. Appendix D provides comment on the growth outlook of the common technologies described.

Below provides an overview of some advances in the wastewater treatment market, both in terms of further development of existing technologies and utilisation of new technologies.

7.2.1 Membranes

The use of membranes is commonplace in the industrial wastewater treatment market. They have developed over the past few decades to become more affordable whilst being able to serve a wider range of applications. They are a technology which is still developing as additional applications are explored and the technology further optimised. Many recent developments in the industrial wastewater treatment market have been as a result of membrane advancements or cross-pollination. For example, membranes were applied to the common activated sludge process to develop the MBR process. MBRs now represent the fastest growing advanced wastewater treatment technology[31] and it is considered that they will continue to be a growth area in the market.

Greater membrane adoption and technology development is anticipated over the coming years, with the technology's predicted global CAGR of 9.09% between 2017 and 2022[32] (relative to a market CAGR of 4.5%). Key technology developments are anticipated to include:

- Optimisation of system efficiencies for use in specific applications (e.g. selective uptake/removal of specific pollutants);
- Membrane material selection, such as the utilisation of graphene due to its beneficial properties (e.g. thin, strong, light, hydrophobia, etc.);
- Design optimisation to reduce energy consumption and associated carbon impact;
- Development of technology to improve affordability;
- Use of membranes for material recovery;
- Combination of membranes with other treatment techniques (e.g. alongside photocatalysts, in the place of clarification, etc.);
- Optimisation of membrane backwash to improve system efficacy and extend lifespan.

The utilisation of membranes in new areas and to treat wastewater to higher levels is anticipated to be a continuing trend in the coming years. Factors such as water scarcity are expected to aid development of the technology as a greater demand for water re-use and desalination will be required. The University of Glasgow, University of Edinburgh and Heriot Watt University all report research into this technology.

7.2.2 Biological Treatment

The biological treatment of industrial wastewater, using microorganisms as oxidising agents to degrade organic substances, is a wide treatment categorisation including a number of techniques. This has been commonly applied at industrial sites for decades, however it still represents an area of potential development as the market continues to develop a better understanding of treatment microorganisms and a changing industrial market.

For example, this could include the technique of naturally improving microorganisms to treat specific wastewater flows. This would include selection of a microorganism (e.g. bacteria, yeasts, microalgae, etc.) and the generation/encouragement of variants suited to specific wastewater treatment applications. This can allow for the offset of techniques such as chemical oxidation or incineration, representing a more sustainable treatment method.

As the properties and potential functions of microorganisms are better understood, applicability in the industrial wastewater treatment sector can be identified.

[31] https://gtr.ukri.org/projects?ref=EP%2FK010360%2F1
[32] Technavio: Global RO Membrane Market 2018-2022

For example, this could be ammox bacteria that turn ammonia into nitrogen gas, chitosans that allow for ion-exchange interactions with anionic compounds or phototropic bacteria converting wastewater into hydrogen gas. It is anticipated that further biological research into the properties of microorganisms could have a significant impact on the industrial wastewater treatment market.

As this technology continues to evolve, developments could include:

- Use of biological treatment to assist in the recovery of metals in wastewater flows;
- Recovery of nutrients and energy from wastewater;
- Enhanced removal of micro pollutants from wastewater;
- Generation of wastewater treatment by-products with a commercial value (as opposed to sludge generation);
- Adaption of the method by which microorganisms are added to a biological treatment process;
- Utilisation of microorganisms to refine wastewaters and sludges into products that are less hazardous or are beneficial products;
- Optimisation of the mechanics associated with biological treatment systems;
- Improved energy and resource efficiency.

7.2.3 Photocatalytic Oxidation with Titanium Dioxide

This process utilises titanium dioxide (TiO_2) as a catalyst in the generation of hydroxyl radicals in the presence of light leading to the degradation of organic compounds and microorganisms. It requires the presence of the catalyst and exposure to light (often generated UV light). There is potential for the process to be utilised in the treatment of industrial wastewaters for:

- Destruction of organic pollutants;
- Specific pollutant degradation;
- Reduction of toxicity;
- COD/BOD removal;
- Odour and colour improvement.

There are currently two approaches to this technique, suspension of the catalyst and immobilisation of the catalyst.

Suspension of the catalyst involves dosing it into the wastewater flow, passing through light for reaction and subsequent catalyst removal. This is reported to provide a higher level of pollutant removal relative to immobilisation, however removal/recovery of the catalyst from suspension can have a cost impact.

Immobilisation of the catalyst requires it to be impregnated onto a surface, which the wastewater could come into contact with. In some cases, this may be a membrane, effectively combining filtration and photocatalysis.

The technique has potential to be a relatively financially favourable, environmentally friendly and sustainable approach to treatment and the technology has made a small impact on the industrial wastewater treatment market already. However, it is considered that this technology has development potential and optimisation could allow a wider uptake. Current barriers reported include:

- The capital costs associated with UV light generation;
- Recovery of catalysts if in suspension;
- Efficiency of the technique;
- Optimisation of set-up.

Development of this technique may involve considering factors such as the use of alternative catalysts, utilisation of a broader light spectrum, impregnation media for immobilised systems, integration into other systems (typically membrane-based systems), selective pollutant removal, etc.

Photocatalysis is an area in which the University of Edinburgh, Strathclyde University and the University of Aberdeen all report active research.

7.2.4 Anaerobic Digestion (AD)

The utilisation of AD as a wastewater treatment technology is one that has grown in recent years, with development of the technology ensuring it is a relatively common option. This technology is especially favourable in terms of sustainability and longer-term economic benefit, with value being derived from waste. With Scotland being at the forefront of the circular economy[33], technologies such as AD may benefit. In addition to being an effective method for the treatment of wastewater, AD can be utilised to treat and extract value from wastewater sludge which would otherwise be disposed of.

The food and drink sector is one in which AD has a high potential. As discussed in Section 6.2, Scotland has a thriving food and drink sector, which provides opportunity for increased Scottish uptake of the technology. Reported research and development of the technology includes:

- Broadening of operational parameters, such as application of systems at a smaller scale (to include a focus on brewery and distillery wastewater);
- Operation of AD at lower temperatures;
- Optimisation of biogas production and purification;
- Opportunities for the utilisation of biogas produced (e.g. as a fuel for vehicles);
- Wastewater pre-treatment to catalyse hydrolysis stage and decrease system residency;
- Control of specific biological growth to selectively focus pollutant removal (e.g. sulphate removal);
- Feedstock manipulation and adaption to optimise system treatment and biogas potential;
- Exploration into microbial mutations and variations with enhanced treatment capabilities;
- System development in order to improve affordability, both in terms of capital and ongoing costs.

Scottish higher education facilities reportedly proactively researching this area include Glasgow Caledonian University, Aberdeen University, Abertay University and Heriot Watt University.

7.2.5 Ion Exchange

As discussed in Appendix D, ion exchange is a method of removing undesired or hazardous ionic constituents from wastewater. The ions are replaced with more acceptable ions from a resin. Development and research into the technology and associated resins has been reported.

For example, the use of new ion exchange technology in water/wastewater decolouration has shown improvements relative to traditional techniques. With many wastewater discharge consents (especially those discharging directly to the environment) also including a visual condition, this is could to be an important development in the technology. This development has leading input from the Scottish market via a Scottish registered treatment technology designer.

In addition, development of the technology has considered:

- The optimisation of resins to allow for the removal of more contaminants;
- Improved energy efficiency;
- Size and portability of a typical system (with a focus on the system being modular).

It is anticipated that these developments could result in ion exchange technologies becoming a more common industrial wastewater treatment technology.

7.2.6 Ultrasonic Reactors

An ultrasonic reactor can act as an advanced oxidation process, utilising the amplitude and power of ultrasonic vibrations to catalyse reactions and assist in pollutant removal. Within an ultrasonic reactor, the reaction chemistry and kinetics can be altered to offer required contaminant removal levels. For example, this method can be utilised in the precipitation of sulphate from a wastewater.

The filtrate that is generated as a result of this technique reportedly has a lower moisture content than sludges from alternative processes. Additionally, it is often non-hazardous allowing for reuse in applications such as a raw material in cement production, waste stabilisation and treatment of contaminated soils.

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[33] https://www.gov.scot/publications/making-things-last-circular-economy-strategy-scotland/

At present, capital costs associated with the technology are relatively high and would require the offset of an expensive discharge route (e.g. tankering of wastewater from site) to justify investment. Additionally, the precipitate formed is typically fine and therefore slow to settle, requiring a specially designed clarifier (or membrane).

The technology has been shown to remove the following contaminants from wastewater flows:

- Sulphate;
- COD;
- Phosphate;
- Heavy metals.

Development of this technology is anticipated to focus on increasing affordability, improving precipitate settlement rate and increasing treatment efficacy.

Section 8.0: Industrial Wastewater R&D

8.1 Overview of Current R&D

With a view to understanding the themes in current wastewater treatment related R&D, data regarding publicly funded research and innovation was evaluated. This data was provided by the Gateway to Research (GtR) website, a website developed by the UK Research and Innovation (UKRI).

The full database of publicly funded projects was assessed in order to consolidate the list to those associated with wastewater treatment. These projects were then categorised by type.

The graphs below provide an overview of this evaluation considering the breakdown in terms of both number of projects (out of a total of 203 projects) and value of awards (out of a total of over £40 million):

Figure 8.1: Number of UK Wastewater Research Projects by Type (as Reported by GtR)

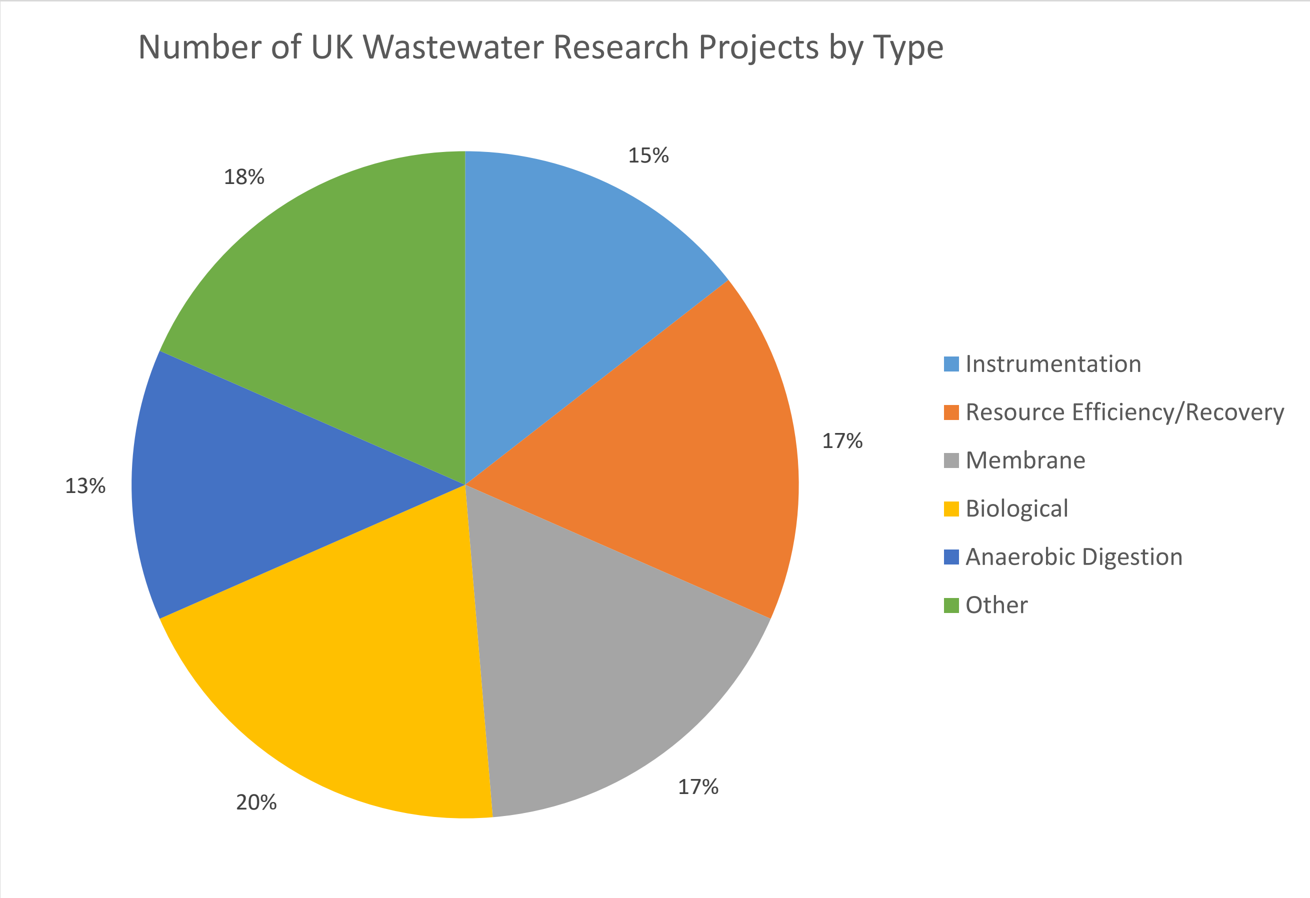
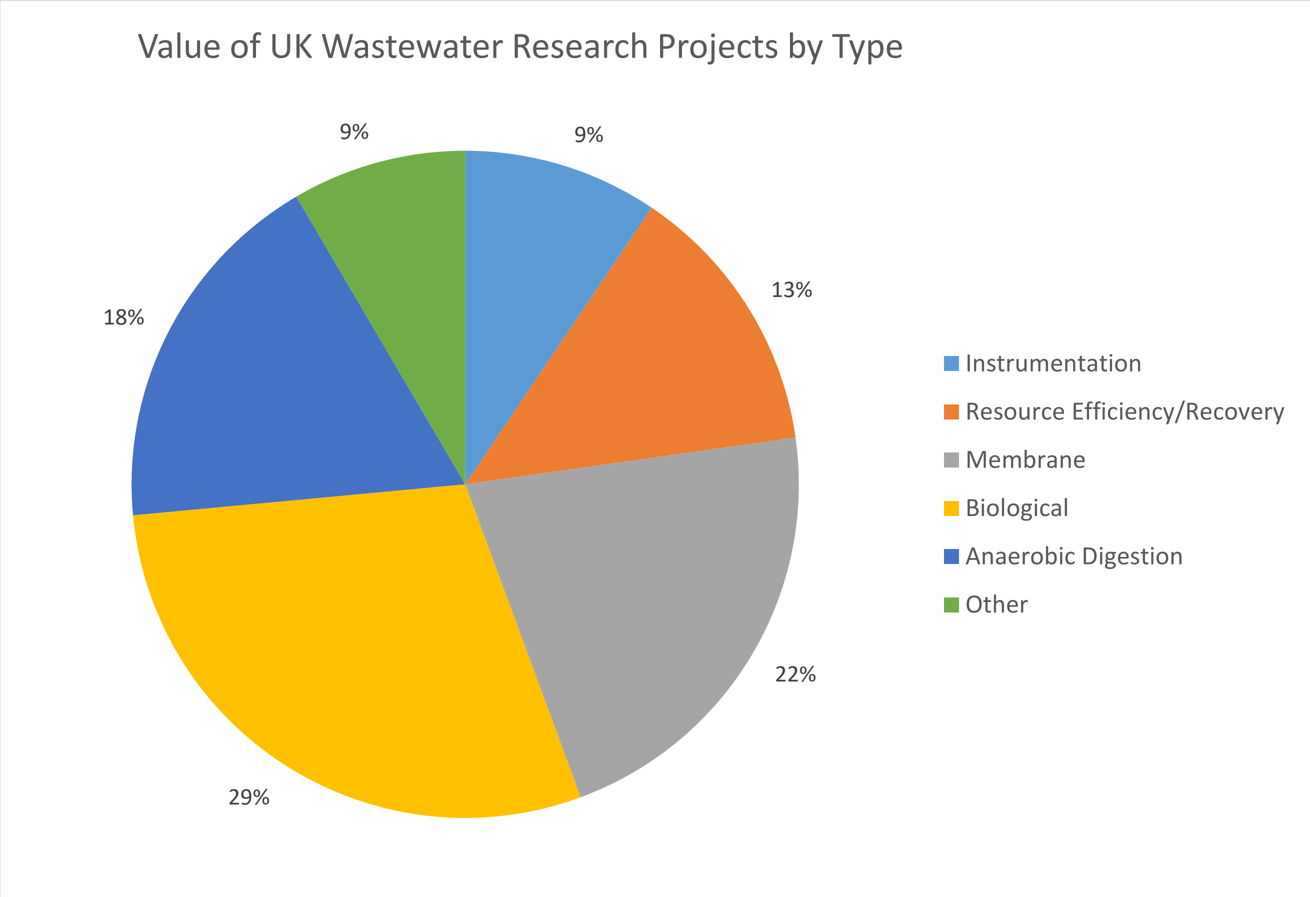


Figure 8.2: Value of UK Wastewater Research Projects by Type (as Reported by GtR)



As can be seen above, current research appears to be dominated by the five sub-categories of biological, membrane, resource efficiency/recovery, anaerobic digestion and instrumentation. In terms of value, these types account for around 91% of all funding.

From this pattern of research, it is shown that the wastewater treatment market is in a phase where optimisation and extended utilisation of existing technologies is dominant. This conclusion is one that is reflected and supported by those in industry.

Rather than a focus being on the development or identification of technologies with new technical concepts, advancement and adaption of existing technological concepts is a key trend. Research of existing technologies typically considers the following:

- Optimisation of contaminant removal;
- Resource efficiency (e.g. energy efficiency of technology);
- Technology affordability;
- Adaption of technologies to allow for removal of alternative contaminants or a wider range of contaminants;
- Cross pollination of technologies across industries (i.e. utilisation of a technology in an industry or process that it had not previously been used in);
- Incorporation of technologies into unit operations to enhance performance.

Research into existing technologies has allowed for technology advances in recent years (notably membranes and biological treatment). For example, the utilisation of membranes in MBRs has effectively allowed for the replacement of traditional clarification after biological treatment. This has led to a number of operational and cost benefits and has led to MBRs having one of the strongest predicated growth outlooks of all technologies. This focus appears to be warranted as it allows for tried and tested technologies to be explored and implemented to realise their full potential.

Although the trend reportedly appears to be focussed on development of existing technological concepts, the R&D sector is highly adaptive and are likely to embrace any new concepts if/when they are identified.

One of the areas that R&D is looking to advance existing technologies is in cross pollination. It should be noted that cross pollination is not necessarily limited to a sector or process type. Rather, cross-pollination can be applied well beyond a technology's original intended use. For example, bubble wrap was initially conceived as a wallpaper prior to it being an effective protective wrapping. Therefore, there may be on-going R&D that could impact the wastewater treatment market that has not currently been captured due to current proposed use.

Additionally, the Scottish government has openly embraced the circular economy and, as a country, Scotland are at the forefront of its adoption. This has a resultant impact on the advancement of existing technologies and their cross-pollination.

One area of R&D that is not being developed solely for the wastewater treatment market but is expected to have a notable impact on it, is the IOT (and associated areas). Data on the GtR website shows that the funding awarded to IOT associated R&D is almost six times that awarded to R&D of wastewater treatment technologies.

To support Scottish R&D and companies (especially SMEs) on the innovation path, The Scottish Government, through SE and HIE, has established the Hydro Nation Water Innovation Service (HNWIS - https://www.hnwis.scot/). This service is a single point of access that can provide businesses involved in water related technologies with specialist support as well as linking them up with existing research, development and testing networks.

The service is designed to work with businesses to encourage technology innovations, with the aim of supporting the development of new products and services as well as identifying market opportunities. The service offers access to wide range of innovation services including the following technical support:

- Product readiness assessment - aimed at supporting companies to assess their technology and provide advice on a route and time to market.
- Product trial support - funded consultancy to support the independent testing and verification of technologies.

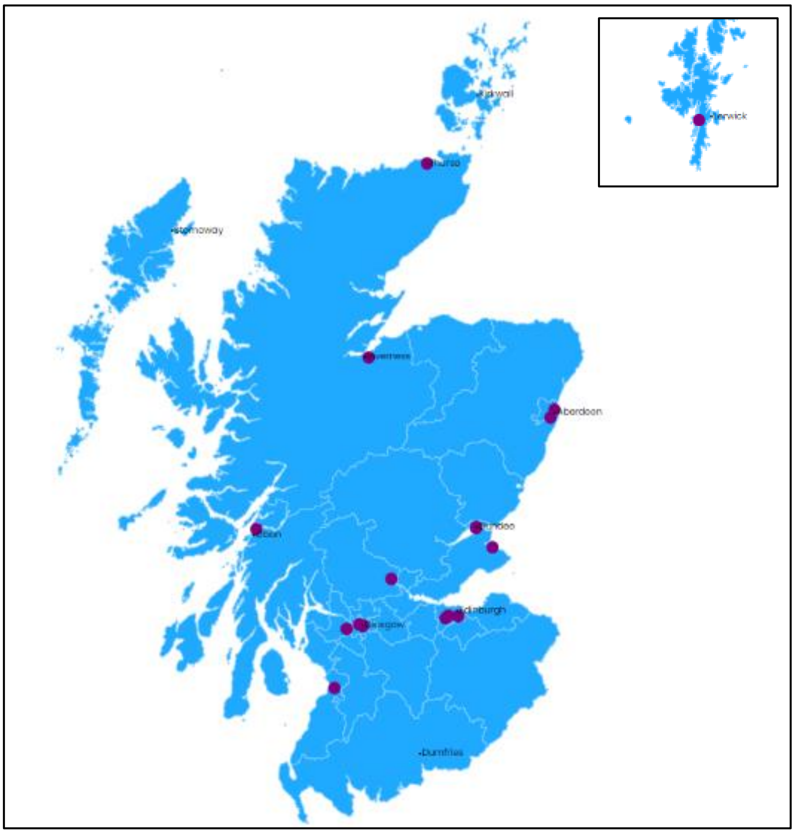
8.2 Higher Education R&D

Scotland's R&D commitment in higher education facilities is strong, with Scottish expenditure in this area consistently exceeding the EU average.

As an overview of Scotland's R&D capabilities in higher education facilities, The University of Abertay have developed an interactive online map[34] showing some of Scotland's capabilities in the water and wastewater markets. The screenshot below shows Scottish higher education establishments with expertise and facilities in water supply and treatment.

[34] https://save.abertay.ac.uk/abertay_watermaps_2017/watermap2017/

Figure 8.3: Map of Reported Scottish Higher Education Establishments with Expertise in Water Supply and Treatment



As can be seen, there is a widespread knowledge base in this area. In particular, the following higher education facilities were reported to have focussed expertise in water treatment: Aberdeen University, The James Hutton Institute, Abertay University, Edinburgh University, Heriot Watt University, Glasgow University, Glasgow Caledonian University and Strathclyde University.

Areas of expertise varies across these facilities, covering a range of topics and wastewater treatment technologies. The table below provides a high-level overview of a selection of the areas of expertise or involvement that Scottish higher education facilities report.

Table 8.1: Scottish Higher Education Facilities' Areas of Reported Expertise/Involvement

Higher Education Facility	Areas of Reported Expertise/Involvement	
Aberdeen University	▪ Biological wastewater treatment ▪ Anaerobic digestion ▪ Biorefinery	▪ Resource recovery from wastewater ▪ Photocatalytic oxidation
Abertay University	▪ Resource recovery from wastewater ▪ Phosphorous reduction in wastewater ▪ Anaerobic digestion	▪ Phosphate removal ▪ Wastewater reuse
Edinburgh University	▪ Biological wastewater treatment ▪ Nanomaterial use in water treatment ▪ Photocatalytic oxidation	▪ Chemical oxidation of wastewater ▪ Bioremediation from algae ▪ Membrane optimisation
Heriot Watt University	▪ Resource recovery from wastewater ▪ Chemical clarification ▪ Anaerobic digestion	▪ Wastewater sludge management ▪ Treatment using micro algae ▪ Membrane optimisation

Higher Education Facility	Areas of Reported Expertise/Involvement	
Glasgow University	▪ Biological wastewater treatment ▪ Membrane optimisation	▪ Photocatalytic oxidation ▪ Anaerobic digestion
Glasgow Caledonian University	▪ Resource recovery from wastewater ▪ Advanced wastewater treatment ▪ Anaerobic digestion	▪ Biological wastewater treatment ▪ Membrane optimisation
Strathclyde University	▪ Photocatalytic oxidation ▪ Membrane optimisation	▪ On-site treatment management ▪ Wastewater treatment design
James Hutton Institute	▪ Biological wastewater treatment ▪ Anaerobic digestion	▪ Wastewater recycling ▪ Phosphorus removal

It should be noted that this overview is not exhaustive and does not include all areas of expertise/involvement a facility may have.

From the table above, it can be seen that Scottish higher education R&D in the field of industrial wastewater treatment is broad, covering a wide range of potential applications.

8.3 R&D Test Facilities

In order to adequately develop technologies so that they can effectively perform as required, the use of appropriate technology test facilities is crucial. Test facilities should allow technologies to be tested in representative and realistic situations. With this as a focus, the UK Water Partnership (UKWP) have developed a searchable facilities register which gives users an overview of available facilities (and associated services) in the UK.

The database, which can be set-up on a map for geographical context (as shown below) or as a contact database, provides the following information:

- Organisation name;
- Facility name;
- Facility location;
- Contact details;
- Facility/company website.

Figure 8.4: UKWP Mapped Database

At present, the database has 23 facilities recorded that specialise in "Industrial Effluents and Leachates". This can be found at https://www.theukwaterpartnership.org/facilities-register/.

Another resource that can be used to identify test facilities is the Water Test Network (WTN) which has established a network of testing facilities, which can be used by SMEs, across North-West Europe for the development, testing and demonstration of new products approaching entry to the water sector.

The WTN aims to support SMEs in getting technologies to market over a shorter time period than traditionally observed. By connecting facilities across North-West Europe, SMEs will be able to test across a variety of water types, settings and applications. This network has been granted EU funding of €3.63 million (£3.10 million) and has a total budget of €6.10 million (£5.19 million).

The European market is a key player in the global industrial wastewater treatment technologies sector, with notable contributions from the Netherlands, France, Switzerland and Germany. Involvement of Scottish companies and Scottish test facilities with these countries could help to develop key partnerships with those more experienced in the technologies market.

Further details on the WTN can be found at http://www.nweurope.eu/projects/project-search/water-test-network/.

8.3.1 Scottish Water Test Facilities

In 2015, in order to support R&D in the wastewater treatment market, Scottish Water's commercial subsidiary, Scottish Water Horizons, developed Scotland's full-scale water and wastewater technology test facilities. These facilities allow developers to test their technologies against realistic conditions that may be found in industrial or municipal applications - addressing a need highlighted by the market. The facilities are set-up so that users can test technologies at different stages of the treatment process, allowing for access to varying quality parameters.

The two facilities are:

- **Gorthleck Development Centre** - designed to support the innovation of potable water treatment. The facility was repurposed from a former water treatment works and has its own supply of raw (borehole) water.
- **Bo'ness Development Centre** - designed to support the innovation of wastewater treatment. This facility is located adjacent to an existing Scottish water wastewater treatment works and so allows for the intake and disposal of authentic wastewater at multiple stages of the treatment process. The wastewater is a mix of trade effluent and domestic wastewater (sewage), with sewage dominating. Additionally, if required, developers can safely supply their own industrial wastewater to be utilised at the centre due to appropriate licencing/permits being in place.

There are fees associated with use of the test centres, which include an option for limited resource support from local Scottish Water Horizons staff. The fees are reported by Scottish Water to be relatively low, though could act as a potential barrier for longer term trials.

These facilities allow Scottish developers to test technologies at specialised facilities and could also be used to attract developers from other countries (further discussed in Section 6.2).

8.3.2 Industrial Testing/Innovation

From discussions with those who have been involved in R&D of technical products, many utilised existing industrial contacts to access wastewater treatment facilities in which to test technologies. These industrial facilities are not registered test facilities but do offer the benefit of testing in a realistic and representative environment.

Industrial partnerships can allow technology suppliers to develop their systems using industry specific wastewater parameters and conditions.

As part of their One Planet Prosperity strategy, SEPA have committed to helping companies implement successful innovation. In some cases, SEPA report that this could include amending site permits for a limited time period to trial innovative techniques/technologies. This option could enable industrial sites otherwise concerned about the impact of innovation on compliance to consider trialling new technology.

Section 9.0: Conclusions and Recommendations

Following the research documented above, a number of recommendations are made below regarding the Scottish industrial wastewater treatment market.

Each of these recommendations provide comment on the potential benefit for industrial sites, potential benefit for the industrial wastewater treatment market and potential ways that SE could support the recommendations.

9.1 Realising Cost Saving Potential

In Scotland, it is considered that there is a good level of cost saving potential in the operation of wastewater treatment facilities. It is reported that numerous treatment plants are not operated in an efficient manner. Root causes for this include:

- Wastewater treatment facilities are often viewed only as vehicles to maintain a wastewater discharge compliance rather than as part of a site's wider operations. Therefore, plants are often excluded from routine continual improvement undertaken elsewhere at a site.
- At many sites, wastewater treatment is beyond the technical comfort zone of site personnel. In a number of cases, it is also beyond the comfort zone of the plant operator who follows, but does not necessarily fully understand, an operation process. Therefore, sites lack the knowledge to undertake improvement projects and often approach wastewater treatment with a level of apprehension due to it being an unknown.
- Sites can view a treatment plant as a one-off fixed investment that should only be reviewed when the plant requires replacement. Given the typical lifespan of a treatment plant is 20 years, this represents a missed opportunity.
- As many treatment plants are only targeted against compliance, there is often little indication of the level of efficiency a plant is working towards. Where other performance statistics are not considered, efficiency can drop without any visible repercussions.

It is therefore recommended that there is an industry drive towards realising cost savings in effluent treatment. This could begin with benchmarking of current performance to provide a baseline for improvement and understand the costs behind the operation of a wastewater treatment plant.

From this, business cases for system optimisations, technological improvements or even full plant replacements can be formed. This could help to support industry investing in technologies with higher capital costs, but lower on-going costs.

Benefit to Industry	▪ Realisation of cost savings; ▪ Improved financial and environmental performance.
Benefit to market	▪ Increased industry focus on performance related drivers. ▪ Investment in solutions with lifetime savings.
Potential support from SE	▪ Provide industry support as they baseline performance. ▪ Highlight loans or grants for investment in new technologies. ▪ Develop case studies of successful examples of realising costs savings. ▪ Support for the assessment of technical and financial feasibility. ▪ Support for identification of opportunities to adopt Industry 4.0 principles through diagnostic review and road mapping.

9.2 Employment of Alternative Capital Payment Models

In many cases, the availability of capital can be a barrier to industrial sites investing in wastewater treatment facilities. To aid in overcoming this barrier, some system suppliers offer alternative payment models (see Section 5.2.1). These approaches are recommended, especially where available capital funding is low.

Benefit to Industry	▪ Lower financial risk in terms of borrowing investment capital. ▪ Variable approaches to fit site requirements.
Benefit to market	▪ Overcomes industry barrier of lack of investment. ▪ Models are typically more financially favourable to market.
Potential support from SE	▪ Support development of business cases and identify alternative approaches.

9.3 Marketing Support for New Entrants

The marketing of a product typically requires different skill sets from those required to develop a product. In many cases, developers who are newly entering the market take on the responsibility for marketing the product. Due to the potential skill gap, this could result in new products struggling to enter the market, not due to poor technical efficacy, but due to ineffective marketing.

SE already offer a level of marketing support (via their marketing expert support framework), which is reportedly well utilised. However, this support does not typically extend to new market entrants. It is therefore recommended that this support is extended to selected new market entrants.

Benefit to Industry	▪ Helps to ensure that good developments are not lost due to poor marketing. ▪ Puts opportunities into market language.
Benefit to market	▪ Helps to overcome the barrier of being able to effectively communicate with the market.
Potential support from SE	▪ Provide marketing support for new entrants to the market as well as established organisations. ▪ Clearly signpost support available.

9.4 Promotion of New Technologies

In order to encourage the uptake of new technologies, it is recommended that Scottish Enterprise provide support with the promotion of these technologies. This could be via events such as workshops or showcases, with industry or those in the wider wastewater treatment market (such as designers) in attendance. Any promoted technologies could first be screened by Scottish Enterprise to ensure events are reputable and offer benefits to industry.

This promotion could also be connected to the HNWIS programme, encouraging the uptake of innovative technologies. After businesses have been provided with technical support through the programme, they will be able to present independently verified performance details.

Benefit to Industry	▪ Potential to utilise new technologies with improved treatment performance, utility consumption, associated operational requirements, etc.
Benefit to market	▪ An opportunity to showcase verified technologies to potential buyers.
Potential support from SE	▪ Awareness raising of new technologies within industry (e.g. via workshops or showcases).

9.5 Performance Targets in Operation Contracts

Many industrial sites do not fully operate their own wastewater treatment plant. Rather they rely on externally contracted operators.

As wastewater treatment is commonly viewed only as a compliance exercise, where targets are included in operation contracts, these tend to focus only on compliance. It is recommended that contracted targets are extended to include operational performance criteria such as energy use, chemical use, maintenance costs, etc.

This will aid in understanding of how efficiently a wastewater treatment facility is being run and could help operators to feel greater ownership over plants. This in turn could encourage optimisation and upgrade of facilities as operators look to meet targets.

Benefit to Industry	▪ Control of plant operating costs. ▪ Improved environmental performance. ▪ Early identification of plant inefficiency.
Benefit to market	▪ Increased appetite for upgraded technologies. ▪ Industry focussed on plant performance.
Potential support from SE	▪ Encourage adoption of performance targets (on a case by case basis).

9.6 Scottish Support of Irish Market

In Scotland, implementation and enforcement around the Water Framework Directive is well established and has been in place for a number of years. However, this has not been the case in Ireland, where integration of the directive and associated enforcement is being strengthened.

Therefore, there is an opportunity for Scottish industrial wastewater treatment companies to support the Irish market as it becomes established. Due to the relative locality of Ireland to Scotland, services such as consultancy, design and technology assembly, which are well established in Scotland, could be exported to Ireland. Where local support is required (i.e. Irish based), service providers from the Scottish market could be in a position to coordinate support and act as a knowledge base (e.g. for provision and support of treatment plant operators.

Benefit to Industry	▪ Strong Scottish market could benefit Scottish industry.
Benefit to market	▪ Potential for growth into new market. ▪ Relatively locality suits Scotland's strengths in the market.
Potential support from SE	▪ Make the Scottish market aware of the opportunity. ▪ Support Scottish companies as they look to export products and services to Ireland

9.7 Adoption of Internet of Things (IOT)

Across all sectors there is a movement towards data collection, exchange and analysis used to impact control or automation. This approach has potential to provide a number of benefits in the industrial wastewater treatment market as industry look to optimise, control/analyse remotely, understand treatment facilities and automate operation.

Early Scottish adoption of this approach and associated technologies could allow for Scotland to become a market leader in this area. The IOT is gathering a lot of interest across sectors and is developing at a rapid pace. By adapting this to suit wastewater treatment facilities, Scotland could carve a niche in an area that is anticipated to have large growth potential (a reported high demand is to be expected in the next 5 years).

Benefit to Industry	▪ Increased understanding of operational performance of plants ▪ Potential to use technology to reduce operating costs.
Benefit to market	▪ Early adoption could make Scotland a global market leader.
Potential support from SE	▪ Support the market in their development of the technology for wastewater treatment applications ▪ Highlight opportunity of WWT to Scottish data companies ▪ Scottish Manufacturing Advisory Scheme may support industry using their Industry 4.0 diagnostic tool.

9.8 Wastewater Treatment Plant Operator Qualifications

In the UK, the operation of a privately run wastewater treatment plant is currently a profession that does not require any qualifications or certifications. An industrial site can elect any individual who they consider appropriate to operate the facility.

In other industries, various levels of certification are required for the operation of different plant types and various plant scales. It is recommended that Scotland considers the implementation of mandatory wastewater treatment certifications.

Benefits of this approach include:

- Improved health and safety management as operators understand the risks associated with wastewater, dosing chemicals, treatment technologies, etc.
- Additional environmental protection arising from reduced potential of non-compliant discharges as operators understand technical details of how to operate a plant.
- One of the root causes for risk aversion with regard to investment in wastewater treatment comes from a lack of technical understanding of the process or new technologies. This would help to alleviate these concerns.
- A qualified/certified operator with technical understanding is more likely to take ownership of a plant, driving improvement and optimisation in a plant. This could lead to proactive adoption of innovative technologies.

Benefit to Industry	▪ Confidence in treatment plant operation. ▪ Improved health and safety and environmental performance.
Benefit to market	▪ An industry knowledge base. ▪ Reduced risk aversion from industry for investment.
Potential support from SE	▪ Raise this issue with industry and public sector representatives to understand if, and who, could take this forward.

9.9 Use of Industrial Sites for Technology Testing

The development of effective wastewater treatment technologies requires testing of technologies in representative wastewater. This can help to refine technologies, understand real-world requirements and develop the verification required when selling equipment. Scottish Water have developed full-scale test facilities that can support with this however, they are geared to municipal technologies more than industrial focussed technologies.

Therefore, it is recommended that developers and industries are connected in order to allow for testing of technologies at industrial sites. Industries could be encouraged to support via funding or through an agreement with the developer regarding purchase of the refined technology. In some cases, there may be mutual benefit to the testing as the industrial site benefits from the optimisation of the existing treatment facility.

This may act as a catalyst in the development of technologies for use in the pharmaceutical sector, a sector in which wastewater treatment may soon become a key focus.

Benefit to Industry	▪ Company shown to support Scottish R&D. ▪ Access to latest technology and operational improvements
Benefit to market	▪ Testing and development of technology in a real-world scenario. ▪ Industrial case study of technology efficacy.
Potential support from SE	▪ Connect technology developers with industrial sites. ▪ Support additional verification activities required (e.g. wastewater analysis, development of appropriate verification programmes, etc.).

9.10 Standardisation of Technology Testing

One of the barriers reported by wastewater treatment technology developers is in proving the efficacy of a new technology. This can result in the developer undertaking a number of technology verification tests and multiple providing technology demonstrations, just to demonstrate something that had already been demonstrated.

Therefore, it is recommended that adoption and recognition of standardised testing is encouraged. This would allow a developer to provide testing results from a verified independent source. Although this would not completely eradicate the requirement from industry to prove the technology, this could become a commonly accepted certification for technology designers or vendors or as an accepted route onto procurement frameworks.

The environmental management standard ISO14034:2016 for environmental technology verification currently appears to be the most applicable standard and has started to be adopted. For example, the Scottish Water test facility in Bo'ness has been designed to support this standard and the WTN operates to this standard (as well as others). However, it is considered that its adoption could go further.

In the case this ISO14034:2016 was widely recognised, this could allow developers to dedicate time and effort to undertaking robust testing in line with the standard that could then be provided to evidence performance of technologies. Rather than undertaking repeated verification tests for new clients, a verified and recognised evidence package could be provided.

Benefit to Industry	▪ Confidence in data due to independent verification.
Benefit to market	▪ Clearer route to market. ▪ Reduced expenditure associated with verification.
Potential support from SE	▪ Support developers through testing (e.g. wastewater analysis, development of appropriate verification programmes, etc.).

Appendix A: Glossary of Terms

BAT	Best Available Techniques
BERD	Business Enterprise R&D
BLT	Build-Lease-Transfer
BOD	Biochemical Oxygen Demand
BOOT	Build-Operate-Own-Transfer
BOT	Build-Operate-Transfer
BREF	BAT Reference
CAGR	Compound Annual Growth Rate
CAR	The Water (Controlled Activities) Scotland Regulations 2011
COD	Chemical Oxygen Demand
COPR	Control of Pesticides Regulations
DAF	Dissolved Air Flotation
DBOT	Design-Build-Operate-Transfer
DWI	Drinking Water Inspectorate
EPA	Environment Protection Agency
ESOS	Energy Savings Opportunity Scheme
EU	European Union
EU BPR	EU Biocidal Products Regulations
GBP	Great British Pound
GDP	Gross Domestic Profit
GERD	Gross Expenditure on R&D
GtR	Gateway to Research
GVA	Gross Value Added
HIE	Highlands and Islands Enterprise
HNWIS	Hydro Nation Water Innovation Service
IED	Industrial Emissions Directive
IOT	Internet of Things
LPWAN	Low-Power Wide-Area Network
MBR	Membrane Bioreactor
OCED	Organisation for Economic Development
ONS	Office of National Statistics
PPC	Pollution Prevention and Control
R&D	Research and Development
SE	Scottish Enterprise
SEPA	Scottish Environment Protection Agency
SMEs	Small and Medium Enterprises
SS	Suspended Solids
UK	United Kingdom
UKRI	UK Research and Innovation
UKWP	UK Water Partnership
USD	United States Dollar
WETS	Water Efficient Technology Scotland
WFD	Water Framework Directive
WTN	Water Test Network

Appendix B: List of Interviewees by Company Name

- Business Stream Ltd;
- Barr and Wray Ltd;
- Veolia Water Technologies Ltd;
- Scottish Enterprise;
- Dryden Aqua Ltd;
- Clearfleau Ltd;
- EnviroChemie;
- Haeger and Elsasser;
- General Electric;
- ProcessPlus Ltd;
- Strathkelvin Instruments Ltd;
- Vector Aerospace;
- Mabbett and Associates Ltd;
- HydroFloTech.

Appendix C1: Scottish Supply Chain Database - Scottish Based

Mabbett

SUPPLY CHAIN DATABASE - SCOTTISH BASED

Company	Scottish Registered?	Scottish Base?	Website	Categories				
				Design/ Consulting	Technology Manufacture/ Construction	Operation/ Maintenance	Chemicals	Process Control & Management
AA Enviro Ltd	Yes	Yes	http://aaenviro.com/	Yes	No	No	No	No
Advanced Microwave Technologies Ltd	Yes	Yes	https://www.advancedmicrowavetechnologies.com/	No	Yes	No	No	No
AL-2 Teknik UK Ltd	Yes	Yes	http://www.al-2.dk/en/solutions/	Yes	Yes	No	No	Yes
Aquabio Ltd	No	Yes	https://www.aquabio.co.uk/	Yes	Yes	No	No	No
Avista Technologies UK Ltd	Yes	Yes	https://www.avistatech.com/	No	Yes	No	Yes	No
Balmoral Group Holdings Ltd	Yes	Yes	http://www.balmoral-group.com/	Yes	Yes	No	No	No
Barr and Wray Ltd	Yes	Yes	http://www.barrandwray.com/	Yes	Yes	No	Yes	Yes
Booth Welsh Automation Ltd	Yes	Yes	https://boothwelsh.co.uk/	No	No	No	No	Yes
Brenntag UK Ltd	No	Yes	https://www.brenntag.com	No	No	No	Yes	No
Business Stream Ltd	Yes	Yes	https://www.business-stream.co.uk/	Yes	Yes	Yes	Yes	Yes
Centri-Force Ltd	Yes	Yes	http://www.centri-force.co.uk/	No	Yes	No	No	No
Centrifuges Un-Limited	Yes	Yes	http://www.centrifuges-unlimited.co.uk/	No	Yes	No	No	No
CETCO	No	Yes	http://www.cetco.co.uk/	No	No	No	Yes	No
Charles Tennant & Co LTD	Yes	Yes	https://www.tennantsdistribution.com/	No	No	No	Yes	No
Chemviron (Calgon Carbon Corporation)	No	Yes	https://www.chemviron.eu/	No	No	No	Yes	No
Clearfleau Ltd	No	Yes	https://clearfleau.com/	Yes	Yes	Yes	No	Yes
Clearwater Controls Ltd	Yes	Yes	https://clearwatercontrols.co.uk/	No	No	No	No	Yes
Clyde Union Ltd	Yes	Yes	https://www.spxflow.com/en/clydeunion-pumps/	No	Yes	No	No	No
DHMO Ltd	Yes	Yes	https://www.dhmo.co.uk/	No	Yes	No	No	No
Dryden Aqua Ltd	Yes	Yes	https://www.drydenaqua.com/	No	Yes	No	No	No
Forbes Group Ltd	No	Yes	https://www.forbesgroup.eu/	Yes	Yes	No	No	No
George Leslie Ltd	Yes	Yes	http://www.georgeleslie.co.uk/	No	Yes	No	No	No
Greenthread Ltd	Yes	Yes	https://www.greenthreadsolutions.com/	No	Yes	No	No	No
H2 Oil and Gas Ltd	Yes	Yes	http://www.h2oilandgas.com/	Yes	Yes	Yes	No	Yes
Haeger and Elsasser	No	Yes	https://he-water.co.uk/	Yes	Yes	Yes	Yes	Yes
Hanley Technology Ltd	Yes	Yes	https://www.hanleytechnology.com/	No	No	No	No	Yes
HORIBA Europe GmbH	No	Yes	https://www.horiba.com/en_en/	Yes	Yes	No	No	No
Hydroflotech	No	Yes	http://www.hydroflotech.com/	Yes	Yes	No	No	Yes
Hydroklear Services Ltd	Yes	Yes	http://hydroklear.co.uk/	Yes	Yes	Yes	Yes	Yes
I & C Process Solutions Ltd	Yes	Yes	https://www.iandc.org.uk	Yes	No	No	No	No
IDS Systems UK Ltd	Yes	Yes	https://idsystemsuk.co.uk/	No	Yes	No	No	Yes
Ineos Group Ltd	No	Yes	https://www.ineos.com/	No	No	No	Yes	No
Living Water Ecosystems Ltd	Yes	Yes	https://www.livingwater.org.uk/	Yes	No	No	No	No
Mabbett & Associates Ltd	Yes	Yes	https://www.mabbett.eu/	Yes	No	Yes	No	Yes
Multi-Valve Technology Ltd	Yes	Yes	http://www.multivalve.com/	Yes	Yes	No	No	No
Omni Instruments Ltd	Yes	Yes	https://www.omniinstruments.co.uk/	No	No	No	No	Yes
Process Instruments (UK) Ltd	No	Yes	http://www.processinstruments.co.uk/	Yes	Yes	No	No	No
ProcessPlus Ltd	Yes	Yes	https://www.processplus.co.uk/	Yes	No	No	No	Yes
Quatraflow Ltd	Yes	Yes	http://quatra-flow.com/	Yes	Yes	No	No	No
Ross-shire Engineering Ltd	Yes	Yes	http://www.ross-eng.com/	Yes	Yes	Yes	Yes	Yes
Scotmas Ltd	Yes	Yes	https://www.scotmas.com/	Yes	Yes	No	No	Yes
SEM Energy Ltd	Yes	Yes	https://www.s-e-m-group.com/	Yes	Yes	No	No	No
STEM Drive Ltd	Yes	Yes	http://www.stemdrive.com/	No	Yes	No	No	No
Strathearn Water Ltd	Yes	Yes	https://www.strathearnwater.com/wastewater-treatment	Yes	No	No	No	No
Strathkelvin Instruments Ltd	Yes	Yes	http://www.strathkelvin.com/	Yes	Yes	No	No	Yes
SUEZ Advanced Solutions UK	No	Yes	https://www.suezwater.co.uk/	Yes	Yes	Yes	No	No
Tech Sure (UK) Ltd	Yes	Yes	https://www.techsureuk.com/	Yes	Yes	No	No	No
UK Water Ltd	Yes	Yes	http://uk-water.com/	Yes	No	No	No	No
Uniting Ltd	Yes	Yes	https://www.unitingltd.co.uk/	Yes	No	No	No	No
VBTM Associates Ltd	Yes	Yes	http://www.vbtmgroup.com/services	Yes	No	No	No	No
Veolia Water Technologies Ltd	No	Yes	https://www.veolia.co.uk/	Yes	Yes	Yes	Yes	Yes
Wastewater Wizard Ltd	Yes	Yes	http://www.wastewaterwizard.co.uk	No	Yes	No	No	No
Weir Group PLC	Yes	Yes	https://www.global.weir/	No	No	No	No	Yes
WGM (Engineering) Ltd	Yes	Yes	https://wgmengineering.co.uk/	Yes	Yes	No	No	No

Appendix C2: Scottish Supply Chain Database - Scottish Interest

Scottish Enterprise Mabbett™

SUPPLY CHAIN DATABASE - SCOTTISH INTEREST

Company	Scottish Registered?	Scottish Base?	Website	Categories				
				Design/ Consulting	Technology Manufacture/ Construction	Operation/ Maintenance	Chemicals	Process Control & Management
Advanced Bioprocess Development Limited	No	No	http://www.bioprocesses.co.uk/	Yes	Yes	No	No	No
Alpha-Purify	No	No	https://www.alpha-purify.com/	Yes	Yes	No	No	No
Amiad Filtration Systems Ltd	No	No	https://www.amiad.com/	Yes	Yes	No	No	No
Andritz Separation	No	No	https://www.andritz.com/separation-en	Yes	Yes	No	No	No
Aquaread Limited	No	No	https://www.aquaread.com/	Yes	Yes	No	No	No
ATG UV Technology	No	No	https://atguv.com/	Yes	Yes	No	No	No
Bio-bubble technologies ltd	No	No	http://www.bio-bubble.com/	Yes	Yes	No	No	No
Bio-Systems Corporation Ltd	No	No	http://www.biosystemsbio.com/	Yes	Yes	No	Yes	No
Bowman Stor Ltd	No	No	https://www.bowmanstor.com/	Yes	Yes	No	No	No
C&G Depurazione Industriale srl	No	No	http://www.cgdepur.it/	Yes	Yes	No	No	No
Chelsea Technologies Group	No	No	https://www.chelsea.co.uk/	Yes	Yes	No	No	No
COMET SpA	No	No	https://www.comet-spa.com/	Yes	Yes	No	No	No
De Nora	No	No	http://www.denora.com/	Yes	Yes	No	No	No
Eco-tech Systems Environmental Ltd	No	No	http://www.ecotechsystems.co.uk/	No	No	No	No	Yes
ECS Engineering Services Lyd	No	No	http://www.ecsengineeringservices.com/	No	Yes	No	No	No
Eliquo Hydrok	No	No	https://www.eliquohydrok.co.uk/en/	Yes	Yes	No	No	Yes
Envitech Ltd	No	No	http://envitech.co.uk/	No	No	No	No	Yes
ESCO International (EI)	No	No	http://www.escouk.com/	Yes	Yes	No	No	No
Euro-Matic UK Ltd	No	No	https://www.euro-matic.co.uk/	Yes	Yes	No	No	No
Flottweg SE	No	No	https://www.flottweg.com/	Yes	Yes	No	No	No
Genesys International Ltd	No	No	http://www.genesysro.com/	Yes	Yes	No	No	No
Hiller GmbH	No	No	https://www.hillerzentri.de/index-en.html	Yes	Yes	No	No	No
Hydroflux Industrial Pty Ltd	No	No	https://www.hydroflux.com.au/	Yes	Yes	No	No	No
Industrial Textiles & Plastics Ltd	No	No	https://www.itpltd.com/en/products	Yes	Yes	No	No	No
In-Situ	No	No	https://in-situ.com/	Yes	Yes	No	No	No
Kelda Water Services	No	No	http://www.keldagroup.com/	Yes	Yes	Yes	No	No
Landustrie Sneek BV	No	No	https://www.landustrie.nl/nl/home.html	Yes	Yes	No	No	No
Mantec Technical Ceramics Ltd	No	No	https://mantecfiltration.com/	No	Yes	No	No	No
Markland Specialty Engineering Ltd	No	No	http://www.sludgecontrols.com/	Yes	Yes	No	No	No
MeasurIT Technologies Ltd	No	No	https://www.measurit.com/	Yes	Yes	No	No	No
Medora Corporation	No	No	https://www.medoraco.com/	No	Yes	No	No	No
MGA Controls Ltd	No	No	https://www.mgacontrols.com/	No	No	No	No	Yes
Modern Water Plc (Monitoring division)	No	No	https://www.modernwater.com/	Yes	Yes	No	No	No
Myron L Company	No	No	http://www.myronl.com/	Yes	Yes	No	No	No
Process Instruments (UK) Ltd	No	Yes	http://www.processinstruments.co.uk/	Yes	Yes	No	No	No
Prominent	No	No	https://www.prominent.com/	Yes	Yes	No	No	No
Pure Water Group	No	No	http://purewatergroup.com/	Yes	Yes	Yes	No	No
R2M LTD	No	No	https://www.r2mltd.co.uk/	Yes	Yes	No	No	No
RainCatcher Products and Services Ltd	No	No	http://raincatcher.co.uk/	Yes	Yes	No	No	No
Real Tech Inc.	No	No	https://realtechwater.com/	Yes	Yes	No	No	No
Richard Alan Group	No	No	https://www.richardalan.co.uk/	Yes	Yes	No	No	No
Scale Buster - Ion Enterprises Ltd	No	No	http://scalebuster.com/	Yes	Yes	No	No	No
STS Great Britain Ltd	No	No	https://www.stssensors.com/	Yes	Yes	No	No	No
Sucris SL	No	No	http://www.surcis.com/en	Yes	Yes	No	No	No
Tethys Instruments SAS	No	No	http://www.tethys-instruments.com/	Yes	Yes	No	No	No
Trace2o ltd	No	No	https://www.trace2o.com/	Yes	Yes	No	No	No
Van Remmem UV Technology	No	No	https://vanremmen.nl/en/	Yes	Yes	No	No	No
Warden Biomedia (Warden Plastics Ltd)	No	No	https://www.wardenbiomedia.com/	Yes	Yes	No	No	No
Watson-Marlow Fluid Technology Group	No	No	https://www.watson-marlow.com/gb-en/	Yes	Yes	No	No	No

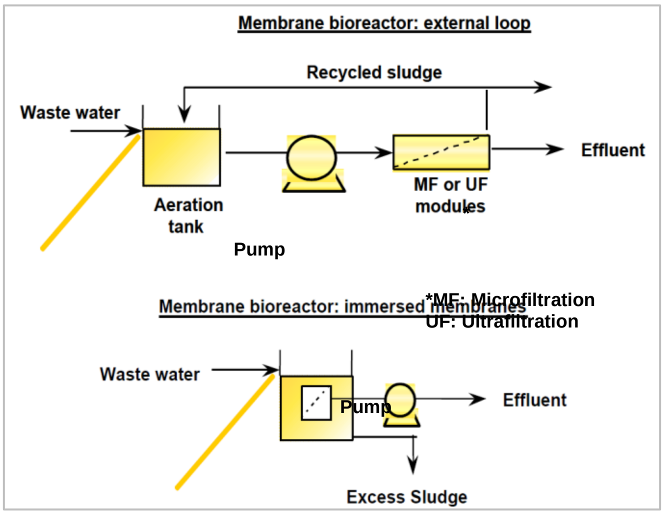
Appendix D: Technology Overviews

D1 - MEMBRANE BIO-REACTOR (MBR)

Technology Overview

The MBR process is a variation to conventional aerobic treatment processes (e.g. activated sludge) and can be utilised for a number of industrial applications. The system combines a growth bioreactor with a membrane process (e.g. microfiltration or ultrafiltration).

Effluent is supplied into the bioreactor via a screen (to remove large solids), where it passes through anoxic and aerobic zones. The flow is then drawn through a membrane, separating the treated effluent and sludge. The inclusion of the membrane negates the requirements for further clarification and filtration stages typically seen in conventional aerobic treatment processes. This results in a reduced technology footprint and can result in a higher contaminant reduction efficiency.



An MBR system is applicable for use after a level of mechanical pre-treatment to remove solids from incoming effluent. Typically, this technology will be applied where the removal of biodegradable compounds, suspended solids and microbial contaminants is required.

At present, MBR plants typically have a higher associated cost relative to similar processes (such as conventional aerobic treatment). However, MBR systems typically generate treated wastewater of a higher quality, resulting in a more favourable cost relative to quality. Additionally, it is anticipated that, due to a positive growth outlook for the technology and the continued advancement and adoption of membrane technologies, the economic differential may soon disappear. Due to process advantages of the technology, this could result in an increased uptake of the technology in the coming years.

Technology Advantages

- Smaller technology footprint.
- Reduced sludge volume generation (relative to common alternatives).
- Process can cope with relatively large COD variations, requiring smaller equalisation systems.
- MBR systems can act as physical barriers in periods of high contaminant loading.
- Ceramic membranes can have a constant performance without aging loss (in the case abrasion and pressure variations are controlled).

Technology Disadvantages

- High running costs (energy) due to pressure drop across the membrane and high air flushing rates required.
- Membranes are sensitive to abrasion, which can be a risk in retrofitted systems.
- Silicones must be removed from raw wastewater as they rapidly clog membranes.
- Pressure variations can break membranes so must be controlled.

Contaminant Removal Overview

MRB systems can show improved output quality in terms of organic loading and microbial contaminants. Reported removal efficiencies shown below:

BOD_5	~ >99%	COD	~ 95%
TP	~ 95%	TOC	~ 95%

Growth Outlook

The potential global growth outlook for this technology is high and it is anticipated that this will grow. This uptake is expected across both the industrial and municipal markets and the current 2.1% global market share will increase.

D2 - NANO-FILTRATION (NF)/REVERSE OSMOSIS (RO) MEMBRANES

Technology Overview

A membrane process involves the forced passing (permeation) of a liquid through a membrane. This results in the production of "clean" permeate and concentrated retentate.

There are a range of membrane options available (other options discussed elsewhere in this Appendix), however NF and RO represent the lower end of the membrane spectrum, offering the removal of finer particles and are typically used as final polishing stages in wastewater recycling or water treatment. Therefore, both NF (~0.001-0.01 µm) and RO (<0.002 µm) membranes have small pore sizes, to stop contaminant permeation.

NF and RO membranes are available in a range of materials and configurations. The optimum set-up for a particular application will be dependent on the nature of the incoming wastewater (and its associated contaminants) as the differing membrane materials have varying resistances to dissolved materials.

Membranes should be designed to in such a way that impurities can be removed (e.g. chemically or mechanically). It is common that membranes will foul and deteriorate, this impurity removal aids in the extension of a system's lifespan and improves efficacy.

Technology Advantages

- NF and RO have high separation efficiencies (i.e. separation of contaminants from wastewater);
- It is possible to recycle permeate and retentate (concentrate);
- Systems are typically modular allowing for flexible application;
- Typically have lower required operating temperatures;
- Systems can be automated.

Technology Disadvantages

- The clogging or fouling of membrane systems is a possibility;
- High pressures are required for the operation of systems to aid permeation of wastewater;
- Membrane technologies, especially those with smaller pores (e.g. NF and RO) can have high associated capital costs.

Contaminant Removal Overview

The typical potential removal efficiencies for NF and RO membranes are provided below:

Nano-filtration		Reverse Osmosis	
Mercury	>90%	DDT	100%
Cadmium	>90%	Aldrin	100%
TOC	80-90%	Dichlorvos	98%
TCB	96%	Malathion	99%

Growth Outlook

The potential global growth outlook associated with NF and RO membranes is high and it is anticipated that utilisation of these technologies will grow.

This is due to the application of membranes across new processes, the advancements in the technology, the encouragement from regulators towards water reuse, water scarcity, etc.

D3 - ULTRAFILTRATION (UF)/ MICROFILTRATION (MF) MEMBRANES

Technology Overview

A membrane process involves the forced passing (permeation) of a liquid through a membrane. This results in the production of "clean" permeate and concentrated retentate.

There are a range of membrane options available (other options discussed elsewhere in this Appendix), UF and MF represent a middle range of membrane treatment. These membranes do not offer as high a treatment level as other membranes, but do not require such high levels of pre-treatment. UF (~0.001 - 0.1 µm) and MF (~ 0.1 - 1 µm) membranes have relatively small pore sizes, to stop contaminant permeation and operate in a similar fashion to sieves, holding back contaminants.

UF and MF membranes are available in a range of materials and configurations. The optimum set-up for a particular application will be dependent on the nature of the incoming wastewater (and its associated contaminants) as the differing membrane materials have varying resistances to dissolved materials.

Membranes should be designed in such a way that impurities can be removed (e.g. chemically or mechanically). It is common that membranes will foul and deteriorate, this impurity removal aids in the extension of a system's lifespan and improves efficacy.

Technology Advantages

- UF and MF have high separation efficiencies (i.e. separation of contaminants from wastewater);
- Systems are typically modular allowing for flexible application;
- Lower levels of wastewater of pre-treatment is required relative to membranes with smaller pores;
- A relatively cost effective approach towards wastewater treatment.

Technology Disadvantages

- The clogging or fouling of membrane systems is a possibility;
- High pressures are required for the operation of systems to aid permeation of wastewater;
- Soluble materials will not be removed from waste streams;
- Waste water odour is not impacted by the processes.

Contaminant Removal Overview

UF and MF systems are designed for the removal of suspended solids from a waste water stream. The reported total suspended solids (TSS) abatement efficiency of these technologies is generally in excess of 99%.

Growth Outlook

The potential global growth outlook associated with UF and MF membranes is medium to high and it is anticipated that utilisation of these technologies will grow.

This is due to the application of membranes across new processes, the advancements in the technology, the encouragement from regulators towards water reuse, water scarcity, etc.

D4 - pH NEUTRALISATION

Technology Overview

Neutralisation is a common processing requirement at industrial sites, by which the pH of wastewater is adjusted to a required range. This treatment can be a stand-alone technology or built into a larger treatment plant. In some cases, pH correction is installed as a final stage prior to discharge and, in others, it is employed in earlier phases in order to enable or enhance the efficacy of further wastewater treatment phases.

The pH is adjusted by the addition of chemicals (an acid or an alkali) as required. Typically, pH monitoring is utilised to intelligently control chemical dosing pumps. The wastewater and added chemicals are mixed in a processing tank.

The neutralisation process results in the production of water and a salt (the composition of which is dependent on the acids and alkalis present). This technology is utilised across industry sectors and treatment plants that require the pH of wastewater to be adjusted. This is a commonly applied technology at sites using highly acidic or highly alkaline raw materials as part of processing.

Technology Advantages

- Common technology that is in use across industry with a number of examples of proven efficacy;
- Can be implemented as a module on a wastewater treatment facility, therefore relatively flexible application.

Technology Disadvantages

- Requires raw material input;
- Results in increased salt concentrations in wastewater.

Contaminant Removal Overview

pH neutralisation is a process utilised to neutralise wastewater rather than to remove contaminants. Therefore, there are no associated contaminant removal efficiencies to report.

Growth Outlook

Neutralisation is an established key component to a number of wastewater treatment processes, aiding effective further processing and in compliant discharge of wastewater.

Uptake for this technology is therefore already high and it is anticipated that utilisation of this technology will continue (typically as part of a larger system).

D5 - WASTEWATER BALANCING

Technology Overview

The majority of wastewater treatment technologies are most effective in relatively constant conditions in terms of flow and contaminant loading. In the case conditions were to vary, system efficacy could drop, systems could be overloaded and, in some cases, systems could fail (notably biological systems).

Wastewater balancing commonly involves the installation of an equalisation/balancing tank to be installed either in-line or as a side stream (to which flow can be diverted at peak periods or in the case of abnormal discharge).

Therefore, the application of wastewater balancing is a commonly applied technique utilised by the wastewater treatment market to equalise flows and loads and control feed into further processing stages. In some cases, wastewater balancing may be an effective technique on its own to help maintain compliance with discharge limits.

In addition to balancing flows and loads, this technique can be used in the detection and subsequent storage of abnormal discharges from a production facility. This can therefore be utilised to protect downstream processes.

This technique is used commonly across industrial sectors in wastewater treatment.

Technology Advantages

- Tried and tested technology for balancing of wastewater.
- Allows for wastewater quality and quantity peaks and troughs to be smoothed prior to further treatment.

Technology Disadvantages

- Typically has a large associated footprint - size is dependent on the hydraulic retention time required.

Contaminant Removal Overview

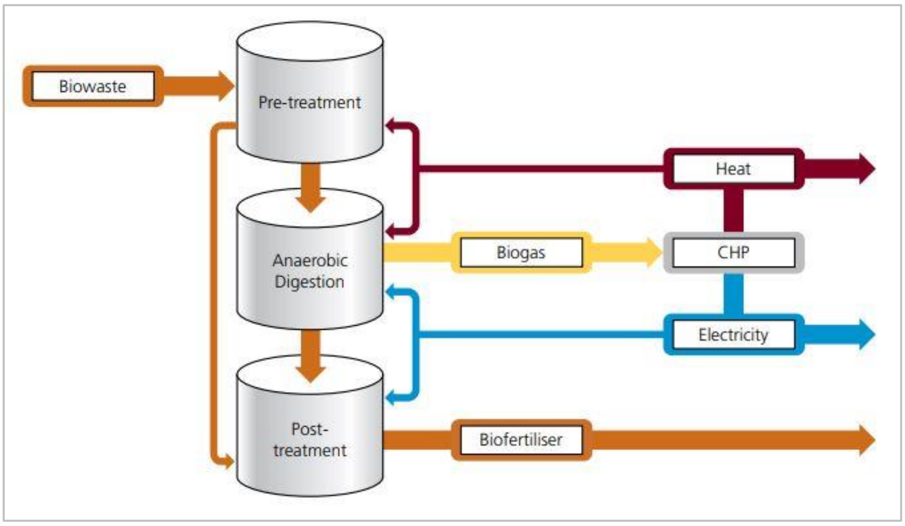
Wastewater balancing is a technique used to balance wastewater flows and loads rather than to remove contaminants. Therefore, there are no associated contaminant removal efficiencies to report.

Growth Outlook

The growth outlook associated with wastewater balancing is considered to be steady. This is a common technique and one that is expected to remain as an important process in the coming years.

D6 - ANAEROBIC DIGESTION (AD)

Technology Overview



The anaerobic treatment of a wastewater converts organic content, via the utilisation of microorganisms in an environment without oxygen, into a variety of products such as methane, carbon dioxide, sulphide, etc. (collectively known as biogas). The biogas consists of about 70% methane and 30% carbon dioxide, with smaller levels of other gases also present. Due to the methane levels in biogas, this product can be used in the generation of electricity or sold on for off-site utilisation. Therefore, this technology offers an income potential.

There are a variety of arrangements and configurations that can be utilised for anaerobic treatment, including an anaerobic contact reactor, an up-flow anaerobic sludge blanket, a fixed-bed reactor and an expanded-bed reactor. These configurations offer differing treatment capacities, waste water retention times, treatment efficiencies, resource consumption, footprints, etc. Application is dependent on on-site requirements and wastewater characteristics.

Anaerobic treatment is applicable at sites that generate wastewaters with high COD and BOD loadings. Additionally, there is a potential for companies who utilise this technique to benefit from government subsidies for the adoption of renewable technologies. This is a popular treatment technique in the food and drink sectors.

In some cases, anaerobic treatment may be installed in combination with a downstream aerobic treatment system to ensure treatment levels meet compliance standards (more common in the case that wastewater is to be discharged to the environment).

Technology Advantages

- Energy consumption is low relative to aerobic alternatives;
- Produces a gas by-product that has a high calorific content, amenable to further use for on-site use or sale as a fuel;
- Low levels of sludge generation relative to aerobic alternatives.

Technology Disadvantages

- Systems tend to be highly sensitive to toxic substances, potentially impacting microorganisms;
- Potential for the production of toxic, flammable and odorous gasses (beyond biogas);
- System start-up is slow;
- High initial investment costs.

Contaminant Removal Overview

The contaminant removal efficiency from anaerobic treatment is dependent on the configuration utilised. COD is typically reduced by between 75 and 90%.

Growth Outlook

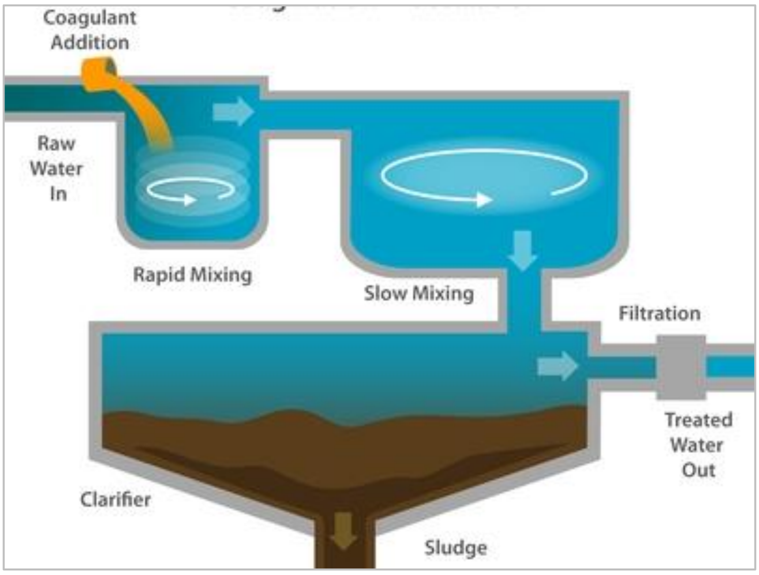
Due to the increased adoption of renewable technologies (and associated subsidies), the growth outlook for anaerobic treatment is currently positive. In the right application, an anaerobic system can be a financial asset with a long term payback on investment.

D7 - CHEMICAL CLARIFICATION

Technology Overview

Clarification of wastewater can take a number of forms and be included in a number of treatment systems. The first step in a typical chemical clarification system is the dosing of chemicals (and subsequent mixing) to take particles out of suspension. This would include the addition of a coagulant and a flocculant in the first case and have the following roles:

- Coagulant - Neutralises a particle's electrical surface charge allowing particles to group together as slightly larger particles.
- Flocculation - A stage aimed at grouping particles together into larger particles via collision so they can then be removed from the wastewater.



After this stage, particles can be removed via methods such as sedimentation or flotation. Sedimentation is the separation of particles and floating material from wastewater by gravitational settling. Solids settle and are then removed from the settlement vessel as a sludge for disposal, whereas floating material is skimmed from the water surface.

Flotation is a process for the removal of particles by attaching fine gas bubbles (usually air) and floating them to the top of a flotation tank. Floated materials are then typically removed by skimming of the water surface. Technologies such as dissolved air flotation (DAF) plants utilise flotation.

Relative to sedimentation, flotation tends to require smaller holding vessels, have a higher separation efficiency and be less impacted by flow rate changes. However, operating costs of a flotation system tend to exceed those for sedimentation.

Technology Advantages

- Installations are typically relatively simple so less likely to fail;
- Removal efficiency can be tailored to the wastewater via selection of dosing chemicals;
- Material recovery is a possibility.

Technology Disadvantages

- Potential for odour release;
- Valves can clog due to build-up of sludge;
- May not be effective for some fine materials and stable emulsions.

Contaminant Removal Overview

Clarification can show notable wastewater output quality improvements via contaminant removal. Although this can be for a range of differing contaminants, this can be summarised by considering the reduction of total suspended solids (TSS). Reported removal efficiencies are shown below:

	Sedimentation	Flotation
TSS	90-95%	90-98%

Growth Outlook

The potential global growth outlook for clarification technologies is predicted to be relatively steady.

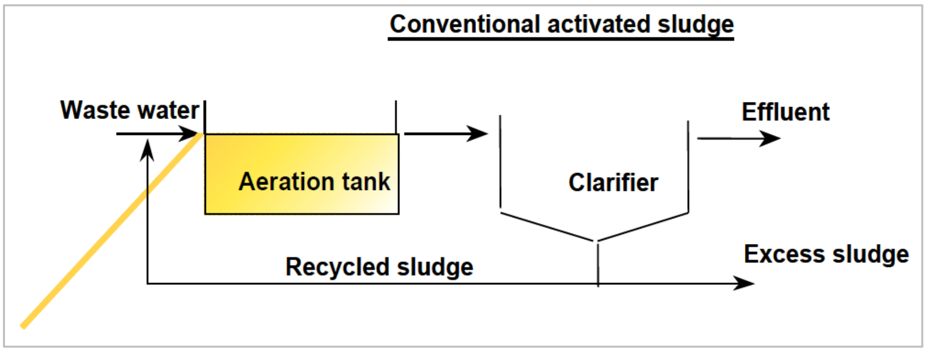
Clarification is expected to continue to be an important and widely utilised form of wastewater treatment. However, the development of membranes, could start to replace sedimentation and flotation.

D8 - ACTIVATED SLUDGE

Technology Overview

The activated sludge process is an aerobic process which enables the biological oxidation of dissolved organic substances in the presence of oxygen using microorganisms. This is a commonly applied technology across sectors and represents the largest single technology utilised across industrial and municipal wastewater treatment facilities globally.

Activated sludge systems can be scaled to meet processing needs. Where required, the system configuration can be adapted to meet site needs. Alternative aerobic systems working on similar principles to those utilised in activated sludge are also well used.



The conventional set-up of an activated sludge system involves wastewater, which has typically already been through a balancing tank and a screening, entering an aeration tank. The aeration tank is a reaction vessel containing microorganisms which are continually provided with oxygen (producing aerobic conditions). Wastewater leaves the aeration tank and enters a clarification tank in which sludge (containing microorganisms) settles to the bottom, allowing for a clarified wastewater to be discharged. The sludge can then be recirculated into the aeration tank or safely disposed of.

Due to space required for potentially large aeration and clarification tanks, these systems can require a large footprint. However, due to their wide application globally, they can represent a relatively cost-effective approach with a high level of technical assurance.

Technology Advantages

- Large volumes of wastewater can be treated.
- Relative to processes such as adsorption, incineration and wet oxidation, energy efficiency is high.
- A proven technology with a long track record of effective treatment.
- Typically degrades contaminants into less harmful compounds.

Technology Disadvantages

- The associated biological processes can be inhibited in the case contaminant levels or temperatures are too high.
- Technology has a large footprint.
- Generates a large volume of excess sludge which must be disposed of.
- The aeration process can result in the release of odour.

Contaminant Removal Overview

Activated sludge systems are a tried and tested technology with a wealth of data available to substantiate removal efficiencies. The technology can show improved output quality in terms of organic loading and microbial contaminants.

Reported removal efficiencies are shown below:

BOD_5	~>99%	COD	~95%
TP	~95%	TOC	~95%

Growth Outlook

The potential global growth outlook for activated sludge is closely linked to that of MBRs (as discussed above). MBRs are a variation on activated sludge plants and show certain advantages.

Therefore, growth potential is anticipated to be relatively low and the technology's market share (global across both industrial and municipal markets) of 10.6% is expected to decrease.

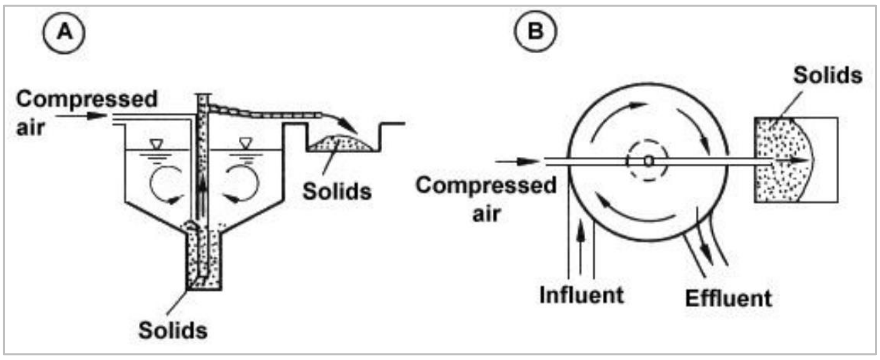
D9 - WASTEWATER PRE-TREATMENT

Technology Overview

The pre-treatment of industrial wastewater commonly includes the removal of insoluble contaminants prior to further treatment. In many cases, these substances are inert, but may also consist of hazardous materials depending on the site processes.

There are a number of potential pre-treatment options available, including:

- **Grit separators** - used primarily for the removal of larger solids that are in suspension when wastewater is flowing. Options for separators allow for sedimentation by slowing flows, use of centrifugal force to separate grit and aeration of wastewater to force separation.
- **Oil/grease interceptors** - installed as a primary oil or grease removal system, typically either by gravity separation or emulsification. Common pre-treatment would include separation of oil in a collection vessel prior to skimming oil from wastewater surface. Various interceptor configurations are available.
- **Primary settlement tanks** - in some cases, a primary settlement tank may be installed for the purposes of allowing solids to settle out of suspension prior to being removed from the system.
- **Wastewater screening** - a coarse screening stage to remove large solids in the wastewater flow from a facility. Commonly in the form of simple horizontal bars.
- **Straining** - a common first stage as wastewater enters a treatment facility in order to remove larger solids. Typically involves wastewater being passed through a porous rotating drum with solids being collected for disposal on the outside of the drum. This has the benefit of reducing ongoing maintenance costs and can also protect down steam treatment technologies such as pumps.



The requirements for pre-treatment techniques is dependent on the nature of the wastewater generated by an industrial facility. In some cases, the quality of wastewater means that pre-treatment is not required and wastewater is directed to further treatment stages.

Technology Advantages

- Proven technologies with high solid removal performance.
- Relatively simple technologies in terms of operation and maintenance.
- Offers protection to downstream treatment processes.

Technology Disadvantages

- Technologies offer little treatment of soluble contaminants.
- Additional levels of treatment typically required after pre-treatment.

Contaminant Removal Overview

The techniques above have differing contaminant removal efficiencies. These options are relatively widely used, and all offer a high level of large solids removal.

Growth Outlook

The growth outlook associated with the use of pre-treatment as a treatment process is considered to be steady.

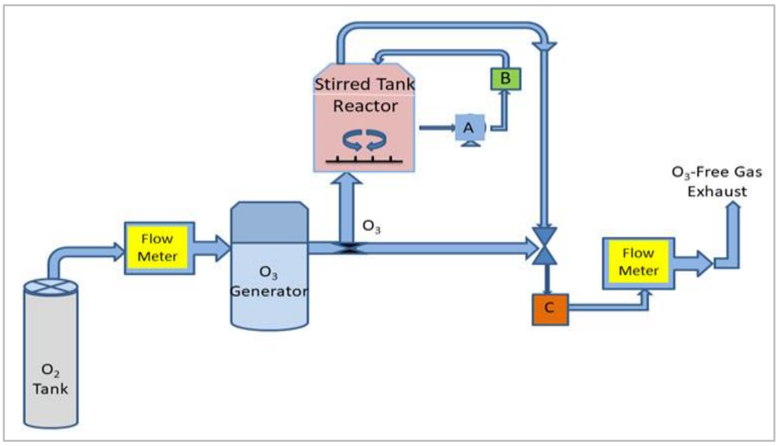
These techniques are widely-used and are cost-effective, therefore it is considered that their use will be maintained.

D10 - CHEMICAL OXIDATION

Chemical oxidation utilises chemical-oxidising agents to convert contaminants in wastewater (other than oxygen or bacteria) into similar, but less harmful/hazardous compounds or compounds that are more easily degradable/biodegradable. This process can also be used in the degradation of compounds that cause odour, taste, colour and for disinfection.

There are a number of chemicals that are utilised as chemical oxidising agents including chlorine, sodium hypochlorite, calcium hypochlorite, chlorine dioxide, permanganate, ozone and hydrogen peroxide. Hydrogen peroxide can also be used in advanced oxidation which uses hydroxyl radicals generated by the hydrogen peroxide in combination with ferrous salts, ozone, UV light, pressure or temperature.

Chemical oxidation is typically utilised in the case wastewater contains contaminants that are not readily biodegradable (or not biodegradable at all) which could disturb downstream wastewater treatment processes. In some cases, chemical oxidation is preferred, even when biological degradation is an effective approach. This is typically in the case that waste streams are small and would not warrant the implementation of a full biological treatment facility.



Due to it effectively removing inorganic compounds, chemical oxidation is used in sectors such as the chemical or heavy engineering sectors.

Technology Advantages

- Allows for the treatment of inorganic substances;
- Large fluctuations of effluent flow and load can be managed without negatively impacting treatment;
- Small residence times are required. Therefore, smaller holding tanks and associated system footprint;
- Process can be combined with others to optimise results.

Technology Disadvantages

- Can have a high energy demand (e.g. for ozone generation, UV generation, pressure, heating, etc.);
- High associated cost per unit removal;
- Can result in the formation of other, unwanted chemicals in some circumstances (e.g. halogenated organic compounds, chloramines, etc.).

Contaminant Removal Overview

Chemical oxidation of wastewater is an effective method by which to remove inorganic contaminants from a waste stream. Reported removal efficiencies are shown below:

TOC	>90%	Phenols	45-70%
Oil	75-90%	AOX	80%

Growth Outlook

The growth outlook associated with the use of chemical oxidation as a treatment process is considered to be steady.

This process is anticipated to remain important in the treatment of wastewater flows containing inorganic contaminants.

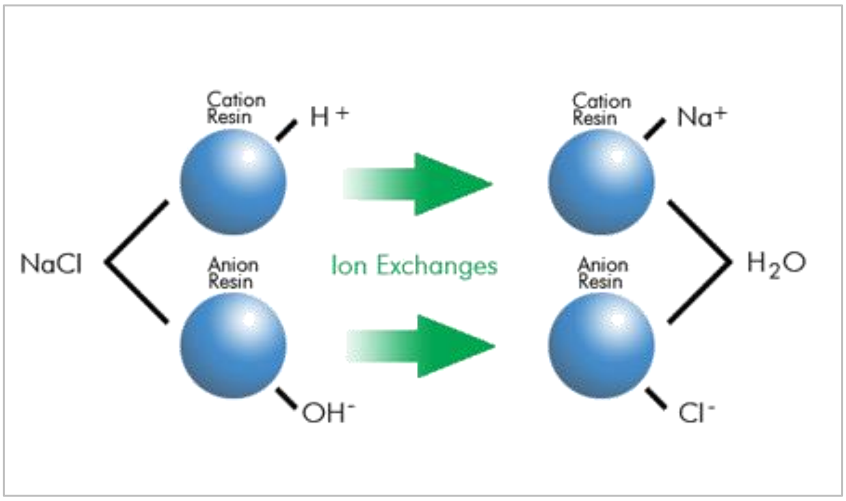
D11 - ION EXCHANGE

The ion exchange process is the removal of ionic constituents from a wastewater flow that are considered to be undesirable or hazardous. The ions are replaced by more acceptable ions from an ion exchange resin, where they are retained prior to release into a regeneration or backwash liquid (then termed as sludge or brine).

There are a number of resins available for use in an ion exchange system which are selected depending of the application. These resins require periodic replenishment as ions are exchanged as part of the process.

An ion exchange system typically consists of the following:

- A pressure vessel that contains the selected resin;
- Control values and piping;
- A resin regeneration system consisting of salt-dissolving and dilution control equipment.



Ion exchange can be utilised as an end-of-pipe treatment technology; however, it also offers the potential to recover materials. For example, it can be used as part of a wider treatment plant to recover water and process chemicals.

This technology is particularly applicable in the metals finishing sector as it allows for recovery of expensive process chemicals and in water treatment as it can have a high removal efficiency.

Technology Advantages

- Water recovery is possible.
- All ions and ionisable species can technically be removed.
- A large variety of resins for differing applications are available.

Technology Disadvantages

- Requires pre-filtration.
- Bacteria can grow on the surface of the resin resulting in performance deficiency.
- Results in the production of a brine and/or sludge which must be disposed.

Contaminant Removal Overview

Ion exchange of wastewater is an effective method by which to remove ionic constituents from a waste stream. Removal rates of between 80 and 99% are reported as typical.

Growth Outlook

The growth outlook associated with the use of ion exchange as a treatment process is considered medium to high as the technology and associated resins are better understood.

D12 - SLUDGE TREATMENT

Technology Overview

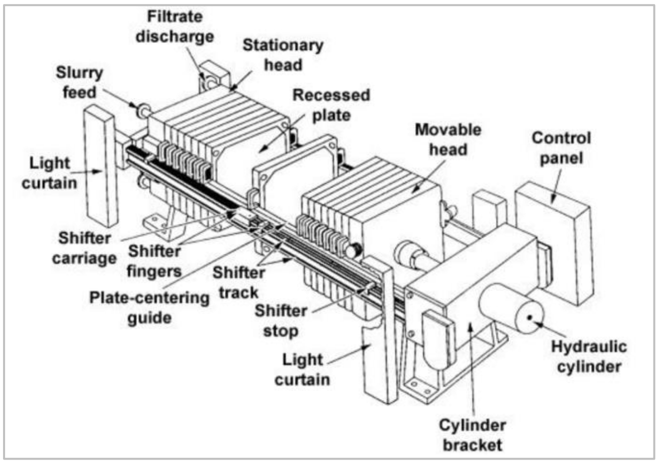
A number of wastewater treatment processes result in the production of a sludge as a waste product from treatment. Sludges are typically liquids with a semi-solid content containing pollutants removed from the wastewater and, in the case of biological treatment, excess microorganisms.

There are a number of sludge treatment techniques, with varying advantages and disadvantages and appropriate applications. The use of sludge treatment is one that is expected to see growth in the coming years as it can offer potential for resource recovery and cost savings. Common sludge treatment techniques include:

- Gravity thickening - use of gravity to settle out solid sludge from liquid;
- Centrifugal thickening - application of a screw press to separate solid sludge from liquid;
- Flotation thickening - flotation of solids using air prior to skimming of sludge;
- Belt filter press - forcing of sludge between two belts to separate solid sludge from liquid;
- Filter press - batch pressing of sludge between plates to separate solid sludge from liquid.

In some cases, stabilisation and conditioning techniques may be employed at a site to improve conditions prior to final thickening/drying using techniques noted above. This allows for the elimination of odours, reduction of pathogens, improved dewatering, etc. Stabilisation and conditioning can include:

- Chemical stabilisation - used to raise pH and kill pathogens;
- Thermal stabilisation - heating of sludge in a pressure vessel;
- Aerobic digestion - treatment of sludge in presence of oxygen;
- Anaerobic digestion - treatment of sludge in absence of oxygen.



	Technology Advantages	Technology Disadvantages
Gravity thickening	▪ Low energy demand ▪ Good for smaller plants	▪ Poor performance at large plants
Centrifuge thickening	▪ Small footprint ▪ Easy installation	▪ High energy demand ▪ Noise/vibration
Flotation thickening	▪ Good efficiency from biological sludges	▪ Can release odour ▪ Relatively poor dewatering
Belt filter press	▪ High dewatering efficiency ▪ Easy maintenance	▪ Sensitive to incoming sludge characteristics
Filter press	▪ High dewatering efficiency	▪ Batch operation

Contaminant Removal Overview

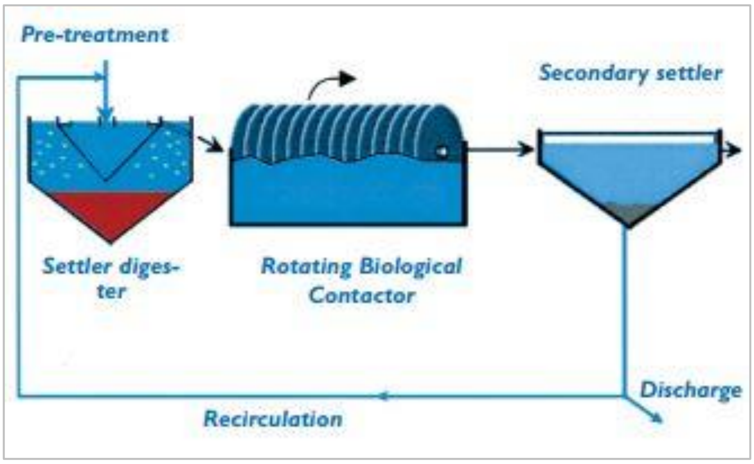
Sludge treatment processes are commonly utilised as a method to allow for the safe and efficient disposal of sludge. Therefore, there are no associated contaminant removal efficiencies to report.

Growth Outlook

The potential global growth outlook for this technology is medium to high and it is anticipated that this will see some growth.

D13 - OTHER BIOLOGICAL WASTEWATER TREATMENT

Technology Overview



The descriptions above provide an overview of some biological wastewater treatment options available (e.g. activated sludge, MBR and anaerobic digestion). However, there are a range of alternative biological treatment options available. Many of these are variations on common themes and use similar treatment principles to technologies already discussed.

Other technologies include:

- **Pure oxygen systems** - a variation of activated sludge in which pure oxygen is used to aerate rather than air. Typically shows improved contaminant removal efficiency relative to a conventional activated sludge process. Can be retrofitted to existing activated sludge systems.
- **Sequencing batch reactors (SBRs)** - a similar approach to wastewater treatment as activated sludge. However, all processing (reaction and clarification) is undertaken in a single tank with wastewater being processed in batches rather than continually.
- **Aerobic lagoon** - large basins constructed to allow for the treatment of wastewater by natural biological processes. These lagoons involve the use of algae, bacteria, sun and wind and are periodically mixed to allow for the introduction of oxygen and even treatment.
- **Trickling filters** - wastewater is evenly distributed over a filter media on which biomass grows as a film. Treated wastewater is then transferred to a clarification system.
- **Rotating biological contactors (RBCs)** - consists of a number of circular disks with biological growth on their surface being submerged in wastewater and rotated. Allows for constant mixing and aeration.
- **Anaerobic lagoons** - a similar process as that described for aerobic lagoons, but with the absence of oxygen.
- **Enhanced biological phosphorus removal** - utilises a combination of aerobic and anaerobic treatment to enrich polyphosphate accumulating microorganisms. These microorganisms uptake more phosphorus than is common.
- **Nitrification/denitrification** - the removal of ammonium by special biological treatment consisting of aerobic nitrification followed by anoxic denitrification. This process can typically be incorporated into a larger biological treatment plant.
- **Integrated constructed wetlands (ICW)** - utilisation of natural techniques for the treatment of wastewaters. A range of treatment options for varying contaminants can be found in nature. Requires a large footprint.

It should be noted that the list above is not exhaustive and there are other options available on the market. The references below provide an overview of the advantages and disadvantages associated with a number of biological wastewater treatment technologies.

Technology Advantages

- Commonly applied technological approach that shows effective BOD destruction.
- Large volumes of wastewater can be treated.

Technology Disadvantages

- Biological treatment typically has an associated sludge waste that requires disposal.
- Notable fluctuations in flow or load can 'shock' microorganisms.

Growth Outlook

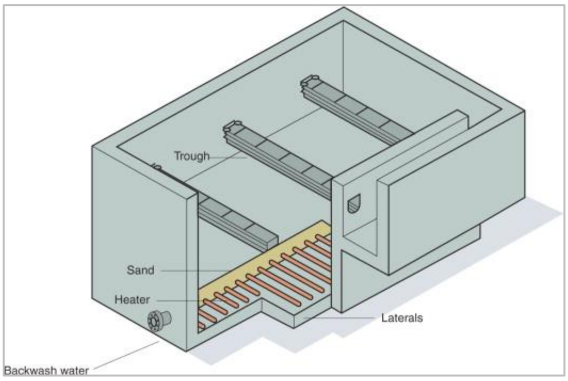
The anticipated global outlook for other biological wastewater treatment processes is expected to be steady. Although some processes may be developed and come to the fore, others may have a lower uptake over time.

D14 - OTHER FILTRATION

Technology Overview

Filtration is a process by which solids are separated from wastewater by passing through a porous medium. In many cases filtration is used as part of a wider wastewater treatment system to assist in the removal of contaminants.

There are a range of available filtration techniques with varying configurations and filter media porosity. This section considers filtration of coarse solids. Fine solid removal includes techniques such as reverse osmosis, nano-filtration, micro-filtration and ultra-filtration. Techniques include:



- **Granular-medium filter (or sand filter)** - a commonly used filtration method for the removal of contaminants. Wastewater is passed through a granular media, often (but not always) sand to separate contaminants. Filters are typically set-up for rapid treatment. Configurations vary depending on requirements with potential for wastewater upward flow, wastewater downward flow, semi-continuous operation, continuous operation, etc.
- **Fabric filter** - a relatively simple filter system by which water enters a casing under pressure which contains a fabric (or bag) filter. The fabric filter separates solids from the wastewater. Not typically used on large and heavily contaminated wastewater flows as bags can easily clog.
- **Gravity drum filter** - wastewater enters into a rotating drum with semi-permeable walls allowing wastewater egress but keeping contaminants internal to be separately removed. Drum walls are continually cleaned to avoid clogging of the system.
- **Rotary vacuum filter** - works using the opposing principle to a gravity drum filter. Instead of wastewater entering the drum, wastewater enters around a rotating drum and is drawn in through a semi-permeable wall via suction (filtered wastewater is then removed). Contaminants are then removed from the drum wall to avoid clogging of the system.
- **Belt press filter** - also used in the sludge dewatering process. Water is drawn in between two semi-permeable belts which are forced together, allowing filtrate to pass through and solids to be captured for removal.

Technology Advantages

- High separation efficiency of pollutants other than those in suspension;
- Can (in some circumstances) assist in the removal of pollutants other than suspended solids such as oil;
- Operational under a wide range of conditions.

Technology Disadvantages

- Filters are liable to clogging and fouling due to operation (dependent on filter media);
- Offers little treatment of soluble materials in wastewater.

Contaminant Removal Overview

The removal of contaminants using filtration is highly dependent on the nature of the incoming wastewater. Filtration can typically be an effective method for the removal of suspended solids from a wastewater flow.

Alternative filter media can be used that has demonstrated removal efficiencies for poly aromatic hydrocarbons (PAHs), semivolatile organic compounds (SVOCs), lipid soluble chemicals, hormones and micro-plastics.

Growth Outlook

The growth outlook associated with the use of filtration as a treatment process is considered to be steady.

Filtration is a robust, cost-effective and proven approach for the removal of coarse solids.