Developing a long-term strategy for **bioresources** in England

Full Report

Water UK | CIWEM | ATKINS Member of the SNC-Lavalin Group

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Foreword

As we look towards the future of the water industry, it is essential that we place a strong focus on bioresources. The sustainable management of these valuable resources will be critical in meeting the multiple societal and environmental challenges we face.

We commissioned the National Bioresources Strategy for England project to work collaboratively with regulators and stakeholders across the industry to develop a common understanding of the challenges and opportunities for bioresources. Working together enabled us to bring together the best minds and ideas from across the globe to drive progress towards a more sustainable future.

We would like to recognise and appreciate the efforts of all those who have contributed to the development of this strategy. This work sets out the future strategic pathways, so let us embrace this opportunity with enthusiasm and determination, and work together to build a brighter tomorrow for generations to come.

Dr Lu Gilfoyle
Water UK, Head of Environmental Strategy

Richard Brindle
United Utilities, Head of Bioresources Strategy

The creation of wastewater and resultant sewage and bioresources from our everyday lives is unavoidable. However, there are important choices we can make in how its managed. The water industry, its regulators and stakeholders need to make crucial decisions to capitalise on opportunities and overcome the challenges of managing bioresources.

There are many beneficial environmental outcomes that are achievable through effective, circular bioresources management. However, there are also several environmental and health impacts that must be carefully mitigated. The development of a long-term strategy for bioresources has enabled these considerations, alongside regulatory, technological and market considerations to be assessed within an adaptive pathway framework.

We have welcomed the opportunity to collaborate with Water UK and stakeholders across the water system on managing the development of the bioresources strategy. We are grateful to Atkins as technical advisors and those who have generously contributed time through engagement activities; whether through surveys, workshops, meetings, or governance groups.

CIWEM looks forward to supporting future collaboration on bioresource management to ensure it is put on the most sustainable footing possible.

Paul Shaffer
CIWEM, Director of Innovation and Delivery

This project marks a significant landmark of collaboration in the water industry, with companies regulators and stakeholders coming together to transform the way bioresources services are delivered.

Bioresources is positioned to play a major role in the transformation of the water industry; the potential to generate renewable energy, sequester carbon and provide a sustainable source for nutrients and other compounds is an exciting prospect. This will be essential for the UK to achieve its aims and goals. The opportunities detailed in this documents form a compelling narrative for bioresources to deliver on this potential.

Atkins has been proud to lend their support to this report as technical advisor, bringing world leading technical expertise from working across the asset lifecycle. The resulting output gives a strategic direction for bioresources that will aid delivery on national ambitions on net zero, self sufficiency and circularity by implementing technologies for tomorrows lived environment.

The engagement of this project across companies, regulators, stakeholders and the supply chain regarding bioresources has been an exemplar for future projects. We fully support Water UK's vision for this to continue so that bioresources can capitalise on the momentum generated to date.

Atkins would like to thank their collaborators on this project Cranfield University and Ken Shapland for their support.

Richard Lancaster
Atkins, Global Bioresources Director

Executive Summary

Industry background

The water industry is at a critical juncture globally; facing key challenges and uncertainty to existing bioresources strategies with emerging concerns regarding micropollutants, nutrient management, and emissions which impact upon the environmental protection of water, soil and air.

The challenges faced are surrounded by key industry sustainability challenges such as Net Zero Carbon, resilience and circularity. This has brought substantial focus on the sector, which encourages an unprecedented opportunity for collaboration.

Sharing of knowledge, development of a common understanding of the issues, further definition of regulatory frameworks, and development of innovation, technology and markets are all huge opportunities to be leveraged to enable key changes to help mitigate the challenges faced by the water industry. All of these, if handled optimally could lead to improved environmental outcomes, a least regrets strategic pathway for bioresources management and provide an opportunity for England to position itself as a global leader.

Bioresources opportunities

The solids extracted from wastewater treatment, both as untreated (sewage sludge), and after further treatment and stabilisation (biosolids), are collectively termed 'bioresources'.

Due to emerging risks, uncertainty regarding the sustainability of existing predominant strategies, potential opportunities, emerging technology and bioresources management trends, it was recognised that the English water sector needed to review the approach for current and future bioresources management, to ensure a positive, efficient response to new demands and possible future regulation changes. Water UK and its member water companies have been working with the Chartered Institution of Water and Environmental Management (CIWEM) and Atkins, CIWEM's technical advisor, alongside their regulators and other stakeholders.

Project aim

The aim of this collaboration was to bring together the English water industry, environmental and economic regulators and other key industry stakeholders to co-create a long-term framework for the safe, sustainable management of bioresources through to 2050. The work has been developing a collaborative long-term national bioresources strategy for England and a route-map to provide the sector with a view of the future direction of bioresources management.

This can only be achieved with a clear policy framework, a shared timeline of transformation and consideration of innovation and available technology. Whilst this is a complex challenge, it brings exciting opportunities which require collaboration.

Project approach

Four work packages (WP) formed the basis of the project, and included:

WP1: Mobilisation and establishing approach to stakeholder engagement.

WP2: Evaluate drivers for change (opportunities and challenges / risks).

WP3: Develop options for bioresources management and assessing influence of research and regulations.

WP4: Developing a strategy and route-map for managing bioresources.

As the first step of the project, a set of Critical Success Factors (CSFs) were developed. These high-level goals must be met for any bioresources strategy to be deemed a success.

A series of stakeholder workshops were held to define and prioritise the key CSFs of a future Bioresources Strategy. The stakeholders included water companies, regulators, the agricultural sector, end users, waste operators, industry experts and engineering organisations.

Using the CSFs as a filter, potential strategies were rationalised into four remaining viable options for bioresources management:

- incineration,
- thermal conversion,
- recovery to agriculture (food production) and
- resource production.

The majority of these (aside from recovery to agriculture) will generate residuals for which an end use/destination will need to be sought.

A suite of tests was used to identify the suitability of each option to address short, medium and long-term challenges faced by the sector.

Project findings

All four strategies had strengths and weaknesses in the short-term and all remained potentially viable options to some extent for companies to pursue in the medium or longer-term.

The work undertaken has highlighted that there is not one single 'ideal' strategy for the water industry to manage bioresources. This is due to several factors including:

- the level of uncertainty regarding the regulatory framework, (specifically with regards to emerging contaminants such as 'forever chemicals', microplastics, and anti-microbial resistance),
- the need for further research and development to enhance knowledge, markets for outputs and confidence in alternative strategies,
- the associated potential deployment lead time, and
- each company's local physical, economic, social and environmental context, individual asset base, and overall risk appetite.

Project output

The results of this work, provide direction for the English water sector on what the future for bioresources management may look like. These findings are captured in the route-map created as an output illustrating possible adaptive pathways. It shows the multi-faceted options available to the industry and provides flexibility to tailor to an individual Water and Sewerage Company's (WaSC's) circumstances.

There is no one single solution. It is a foundation to be used by WaSCs based on their own circumstances, in conjunction with their own strategy development mechanisms when determining when to invest, what strategic direction to take and the priority needed for resolution of the gaps in understanding to aid these decisions.

Future research needs were identified and categorised under four headings, Environmental, Economic, Regulator and Technological. These were developed into a timeline for implementation in line with business planning cycles. Further collaborative and regulatory work is required for their realisation.

Project conclusions

There are opportunities for wastewater and bioresources asset planning to be better aligned with signs that consensus is shifting towards alternative outlets instead of land application of biosolids.

Thermal conversion technology has potential for mitigation of emerging contaminants but is not yet sufficiently understood to make an informed decision on the implementation of such technology in AMP8. Resource recovery is not a stand-alone option and requires co-deployment with other pathways.

To maximise the opportunities arising from the developing markets for the new technology outputs, a continued collaborative approach is required where knowledge is shared, and scalability is enhanced. The UK should examine and critically assess technology in other countries where new technology such as advanced thermal conversion (ATC) and resource recovery has already been adopted in order to make the right decision for the UK's unique drivers and direction of travel. Detailed conclusions can be found in **Section 7.1**.

Project recommendations

An understanding of the integration of technologies, their combinations and interactions as a system of processes must be developed by the WaSCs.

A series of rapid responses need to be in place which can be supported by the establishment of a National Bioresources Strategy Governance Group to ensure ownership and delivery of this project's outputs and programme, and ongoing positive dialogue with key stakeholders continues. This will aid delivery of the prioritised research programme within the proposed timescales. Detailed recommendations on the critical next steps for the industry can be found in **Section 7.2.**

1 Introduction

1.1 History of bioresources in England

Sewage sludge is an inevitable, yet valuable, residual of municipal wastewater treatment: treatment processes vary, and therefore result in a varying quantity and quality of solids needing to be removed from the process stream as sewage sludge. Sewage sludge contains beneficial organic material and nutrients which gives it a central role within the circularity of our environment **(Figure 1)**. In fact, the management of sewage sludge and its subsequent use as source of organic matter has a long history, including the focus on maximising the utilisation of the benefits contained within it[1].

Recovery of biosolids to land as a soil improver and fertiliser is a long and well-established process which continues to be utilised across the world, with its beneficial use on land applications dating as far back as the middle ages. However, the step-change in approach to managing these beneficial properties in the UK came during the Victorian era when:

- The Great Stink in central London in 1858 highlighted the risks around inadequate sewage management to Government.
- In the early 1800s, Sir Humphry Davy discovered that methane gas (also known as biogas) was present from the treatment of sewage sludge. Biogas generated by a sewage treatment plant in Exeter was first used to light streetlamps. A similar invention was created by engineer Joseph Webb, who designed streetlamps in the 1860s to burn off the excess methane created in London's new sewerage system.

Sewage sludge treatment to produce biosolids and its use or disposal became more formally regulated in the late 20th Century, with the introduction of the EU Sludge Directive in 1986 and the Urban Wastewater Treatment Directive in 1991.

This gave greater focus to agricultural use of sewage sludge, controlling the possible effects of heavy metals and prohibited disposal to sea (which ceased in December 1998). This led to other developments including:

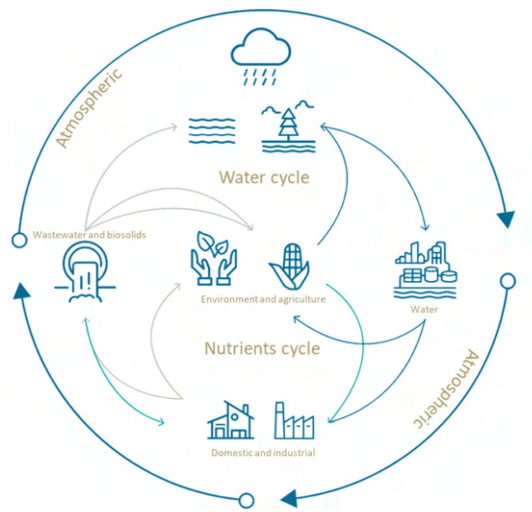
- The Sludge (Use in Agriculture) Regulations 1989 (as amended) and associated Code of Practice for Agricultural Use of Sewage Sludge. This importantly included limit values for metals in sewage sludge amended soil, effective sludge treatment controls and restrictions of the use of land after application.
- The decline in concentrations of heavy metals over the past 40 years with improved trade effluent control measures and changing industrial practices.
- The introduction of the voluntary Safe Sludge Matrix (1999) which sets out treatment required to remove harmful pathogens and the correct method of applying biosolids.
- Most recently the industry Biosolids Assurance Scheme (BAS) in 2017 that brought together current legislation under a single quality assurance scheme which is audited by a third party to give greater confidence to the wider sector and provide further stakeholder assurance.

The evolving use of biosolids has seen changes in discourse surrounding it: from seeing biosolids as a waste to be managed to a valuable resource which can be harnessed to deliver wider societal and economic benefits. Ofwat call wastewater sludge transport, treatment, recycling and disposal activities 'bioresources services.' As part of Ofwat's Periodic Review process, the water industry is required to demonstrate their long-term strategy around bioresources management.

The use of biosolids in agriculture, which reduces the reliance on artificial fertilisers and recycles phosphorus (a diminishing natural resource) was recognised by the UK Government and European Commission as the 'Best Practicable Environmental Option' (BPEO) for sewage sludge management in most circumstances. There is however a continuing balance to be struck between the benefits articulated above, and the environmental detriment that misapplication of biosolids can cause such as diffuse water pollution. This balance has formed the basis of the evolution of the regulatory framework to date.

We live in an evolving world, as populations grow, wastewater connectivity increases, and standards of living improve, we will see increased volumes of sewage sludge being produced. Improvements in wastewater treatment and tightening of discharge consent limits will also impact the quality and quantity of sewage sludge requiring management. It is, therefore, becoming more important to ensure that the connectivity between humanity and our environment is managed in a holistic and sustainable manner, balancing environmental protection with the demand for food and energy. Biosolids has a significant potential to positively contribute to meeting social and environmental ambitions.

Figure 1 – Wastewater treatment impacts on the water cycle



1: Smith, S Dr, 'Recycling biosolids to land' in The nutrient cycle: closing the loop, Green Alliance, 2007

1.2 Introduction

The term bioresources covers the solids extracted from wastewater treatment: both in untreated (sewage sludge), and after further treatment and stabilisation (biosolids). Bioresources are a valuable resource. They contain a multitude of elements and compounds, which when extracted or applied appropriately, can provide significant economic and environmental benefits.
The UK water industry bioresources operations have shifted to almost 100% biosolids recovery to agriculture[1], with a predominance of treatment via anaerobic digestion or advanced digestion over the last decade. This has evolved over multiple five-year Asset Management Periods (AMPs) and has been aided by the development of BAS. BAS has helped to drive consistency and embed best practice in biosolids management and enhance stakeholder confidence. This approach delivers environmental and economic benefits, both agriculturally in terms of boosting soil organic matter and circularity of nutrients, and economically with the benefits of reduced inorganic fertiliser purchasing and the generation of renewable energy at the anaerobic digestion facility itself.

It is uncertain, however, if the large-scale usage of this agricultural outlet for biosolids application is still considered as the best practicable environmental option for the future by all stakeholders. It is susceptible to the impact of changes in direct and adjacent regulatory frameworks and fluctuations in stakeholder confidence regarding emerging risks such as persistent organic pollutant content in biosolids. We are, in addition, witnessing a global trend moving towards bioresources recovery as part of a wider focus upon circularity, zero waste and net zero carbon strategies, with heavy reliance upon development of ongoing technology, regulatory frameworks and market development.

Following the publication by United Utilities of their thought leadership paper[2] , and the growing uncertainty in the sector regarding strategic investment for a long-term sustainable management option for bioresources in England, the English national long-term strategy for bioresources project was commissioned by Water UK.

Greater certainty regarding the long-term approach for managing bioresources is required to support the delivery of national policies, improved environmental outcomes, better planning and investment decisions for WaSCs, as well as the development of a productive bioresources market.

The objectives of the project were to:

1. Engage with key stakeholders that are involved in / or impacted by the lifecycle (or end to end) management of bioresources and obtain their input on the development of the strategy.

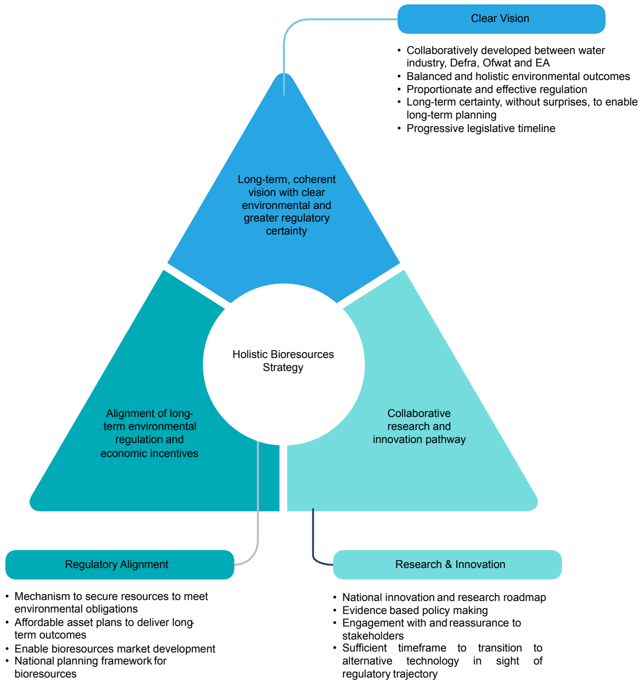
2. Undertake a literature review and wider stakeholder engagement to understand the drivers for change and opportunities that can influence bioresource management within England.

3. Consider the research / technological and regulatory needs to support a long-term strategy for bioresources including any AMP8 enhancement investment drivers and the mechanisms for their inclusion in PR24 business plans.

4. Propose a long-term (2050) strategic direction for bioresources with an appropriate route-map and timeline.

The strategy and route-map have been designed to provide WaSCs with the direction on what the future for bioresources management may look like by illustrating possible adaptive pathways. This will help inform WaSCs detailed plans that reflect their own circumstances.

Figure 2 – Proposed development of a national bioresources strategy[2]



1: ADAS & Cranfield, An assessment and evaluation of the loss of the biosolids-to-agricultural-land recycling outlet, 23 March 2022

2: United Utilities, Unlocking greater value through a national bioresource strategy, November 2021

2 Methodology

2.1 Overview of method

This section describes the overall approach for development of the strategy and the work undertaken. The project was underpinned by continuous stakeholder engagement and collaboration. The project comprised of the following four work packages as depicted in **Figure 3:**

Work Package 1 'Mobilisation and establishing approach to stakeholder engagement'. This work package finalised the procurement of the technical advisor through competitive tender (Atkins), agreement of project objectives, methodology and programme, as well as the approach to communications and engagement. This concluded with the initial stakeholder survey to gauge opinions on the current state and direction of travel for bioresources management.

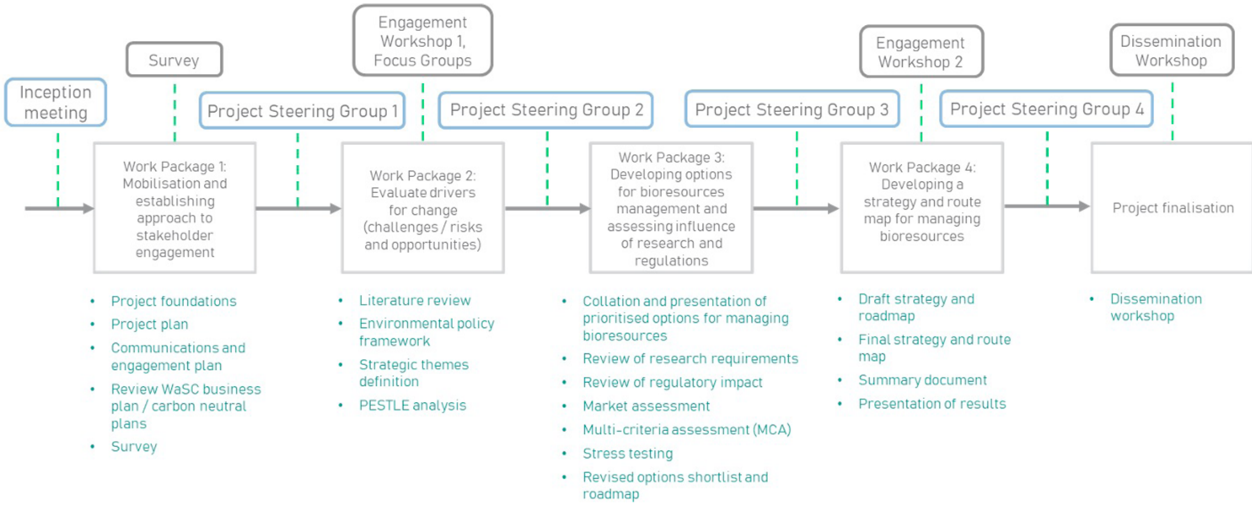
Work Package 2 'Evaluate drivers for change (challenges / risks and opportunities)', this included:

- **A Literature review** to identify and summarise the key information and findings related to bioresources management and the factors that may influence strategies now and in the future.
- **A PESTLE** analysis (Political, Economic, Social, Technological, Legal and Environmental) which was used to review the drivers for change and gain a broader understanding of the influences on the sector and stakeholders involved in sewage sludge and treated biosolids.
- **Environmental policy framework** - Key UK policy / strategy documents were identified across thematic areas where there was a possibility of enabling or challenging (either directly or indirectly) the management of bioresources.

Work Package 3 'Develop options for bioresources management and assessing influence of research and regulations', which included:

- A review of regulatory interventions with a defined timeline considering the impact the regulations could have on a forward-looking strategy. A legislative timeline was created to give an overview of potential regulatory change from 2022 to 2050, highlighting changes or decision points and programmes, incentives or funding windows.

Figure 3 – Method of approach



- A review and prioritisation of research needs for the industry. This is shown in this report within the section for WP4, as it was revised following a workshop on research needs, held with a global group of stakeholders from across the sector in January 2023.
- A strategic assessment of each of the long-list of potential bioresources strategies against the Critical Success Factors to identify the level of alignment with the desired outcomes of the project.

This enabled the long list of potential strategies to be shortlisted to a reduced number of practical candidate long-term strategies for further consideration. Of the candidate strategies which were shortlisted, these were further assessed via Multi Criteria Assessment (MCA) incorporating for example deployability, adaptability, and risk mitigation. They were then stress tested against a range of potential future scenarios to ascertain their adaptability and to produce a hierarchy of approaches against the UK policy narrative.

Work Package 4 'Developing a strategy and route-map for managing bioresources'.

There is not one single 'ideal' strategy as this is reliant on a WaSC's risk appetite, ambition, local physical, economic, social and environmental context, and individual WaSCs decision making on a preferred direction and pace of travel. For this reason, strategies were considered within an adaptive pathway route-map framework. This defines strategic / regulatory triggers for consideration against each pathway, and a timeline of enabling activities to prepare for potential adoption, for example, research needs, technology readiness, market development and regulatory framework definition. This provides flexibility to tailor a strategy to an individual WaSC's circumstances, whilst ensuring they are within the framework of the national strategy overall.

2.2 Overview of stakeholder engagement

The process has been designed to maximise engagement and collaboration. The engagement activities were undertaken with both the professional community, and those that have an understanding and interest in the management of bioresources. The main engagement activities are described below, and examples of the outputs depicted in **Figure 4**:

Governance groups

The ongoing engagement activities ensured collaborative development of a long-term strategy for bioresources. The two key independently chaired engagement groups were the technical Project Steering Group (PSG) and a Project Advisory Board (PAB).

The PSG comprised senior managers of several key UK water companies, industry experts, the English environmental and economic regulators. The PSG provided technical input and reviewed the detail of project outputs.

The PAB, independently chaired by Baroness Anne McIntosh, provided strategic, high-level input into the direction of the project. This comprised senior directors or managers with the authority to represent the water sector and environmental and economic regulators in addition to industry experts. Both groups represent a cross section of the stakeholders involved in the management of bioresources.

Online survey

An online survey was developed to understand views of different stakeholders. The survey has underpinned Work Package 2 in terms of supporting the identification of drivers for change, understanding challenges, risks and opportunities and other factors that could influence the PESTLE analysis. The online survey was also used to identify case studies of good practice.

Focus groups

Focus group sessions were held with environmental and economic regulators, water industry representatives, other parties with an interest in bioresources (such as technology providers and end-users etc.) and industry experts with the intention of diving deeper into their specific concerns, views and understanding of approaches that could be taken with respect to management of bioresources.

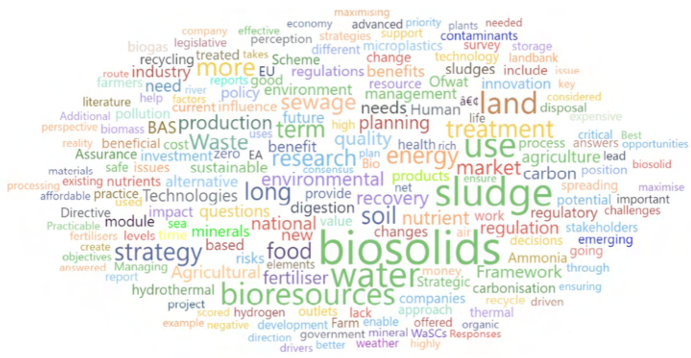
Engagement workshops

Two workshops were held, with independent facilitation, to engage with wider stakeholders to gain their views and input on specific topics of interest at various points in the project.

As part of the ongoing engagement activities the project team engaged with other stakeholders (from across the UK and globally) through additional one-to-one and group meetings, as well as engagement at conferences. Individual sessions were held with Defra and the Environment Agency (EA), the Scottish Environment Protection Agency (SEPA) and Scottish Water and NRW and Dŵr Cymru.

In-depth interviews

In-depth interviews were held with English water companies and Dŵr Cymru Welsh Water to fully understand their current bioresources strategies and to ascertain considerations for their immediate plans for AMP8 and the longer term.



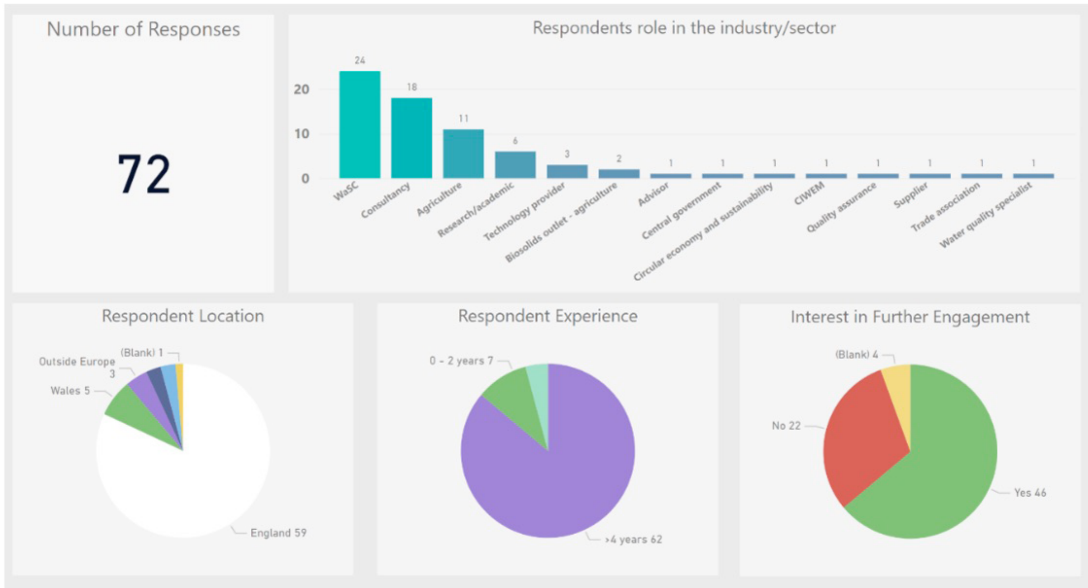


Figure 4 – A summary of the survey respondents, and key words used in their overall responses

3 Work Package 1: Mobilisation and situational awareness

3.1 Regulatory framework – change in the past five years

This section sets out the current landscape for bioresources management in England, summarising current practices, the regulatory framework governing these, and the local and global influences driving change.

The past five years have represented a period of change for regulations directly and indirectly related to bioresources management. **Figure 5** illustrates how the regulatory landscape has evolved in the last five years[1]. This has included:

- **The permitting of anaerobic digestion (AD) of sewage sludge under the Industrial Emissions Directive (IED)** – the IED came into force under Environmental Permitting Regulations in 2013 but WaSCs were formally notified that the Environment Agency was implementing this aspect of IED, and of the need to obtain Environmental Permits for the biological treatment of sewage sludge by AD, in 2019. Many WaSCs made no provision for funding in the Price Review (PR) 19 for the infrastructure changes associated with IED application to sludge treatment centres.
- **Updated EU Best Available Techniques (BAT) Reference Document (BREF) for incineration / waste treatment** – this included new / updated BAT applicable to installations since the permit was granted or last reconsidered.
- **Environment Agency's 'Biological waste treatment – appropriate measures for permitted facilities guidance'** (2022) has resulted in the need for associated investment necessary in order to ensure that BAT is implemented under IED. The guidance goes further in some instances than those requirements stipulated by EU BREF for waste treatment.
- **Introduction of the Farming Rules for Water (FRfW)** (The Reduction and Prevention of Agricultural Diffuse Pollution) – this includes nutrient management / planning which can affect biosolids spreading windows and application rates. The water industry has committed to adhering to Assured Biosolids Ltd's 'Package of Measures to Benefit the Environment'[2]
- **Environment Agency's Strategy for safe and sustainable sludge use** (2019) – the EA reviewed the current regulatory regime for sewage sludge treatment, storage and use which resulted in the recommendation to bring sewage sludge and septic tank sludge into the Environmental Permitting (England and Wales) Regulations (EPR). The Environment Agency aim to do this in 2023. With this, there is the potential for new conditions to be adhered to and tightening of limits.
- **Economic regulatory change** – the bioresources regulatory pricing landscape is evolving. Separate price controls for bioresources were introduced at PR19 to aid the development of a competitive market for bioresources and to enhance the efficiency and effectiveness of the price control (sewer and wider organic waste market).

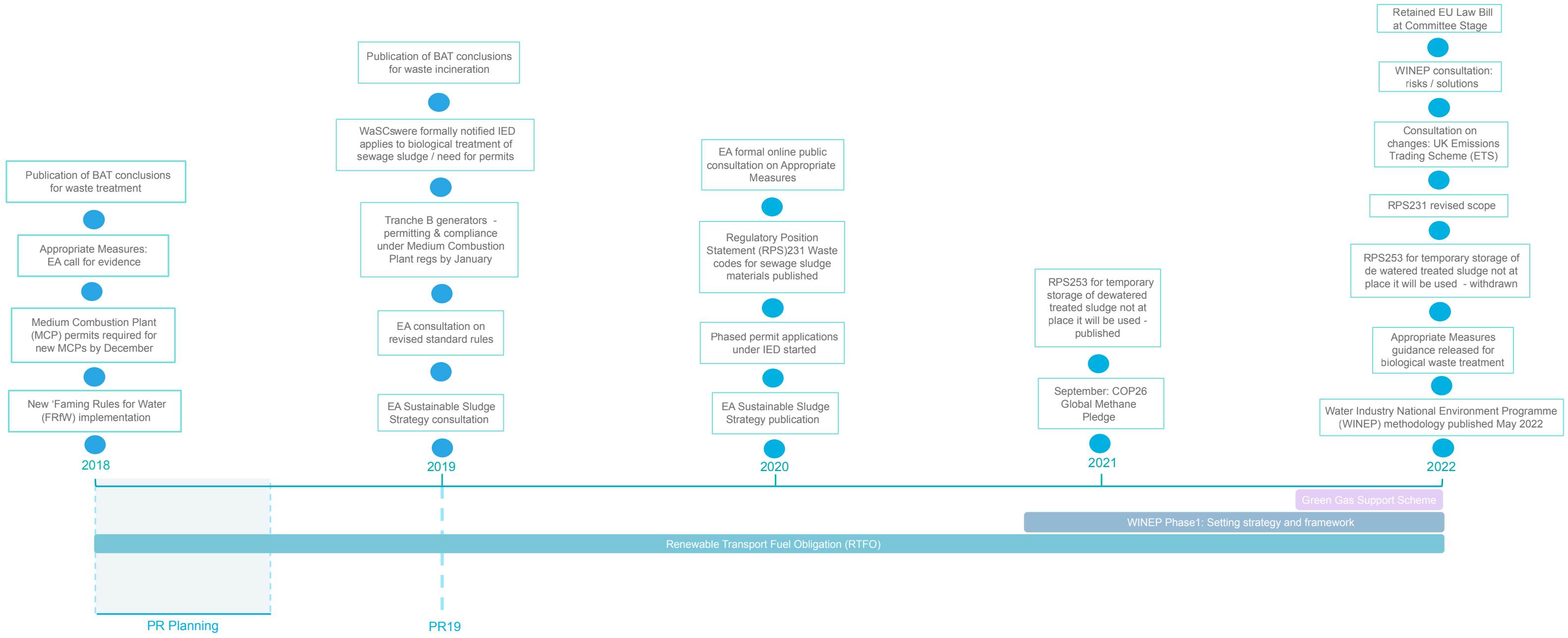


Figure 5 – Historical regulatory timeline: 2018 – 2022

1: Note this timeline is not exhaustive; it is indicative of key regulatory changes over the past AMP (five years)

2 : Farming Rules for Water and biosolids recycling to agricultural land: A package of measures to benefit the environment, Assured Biosolids Limited, 2022

3.2 English bioresources current state assessment

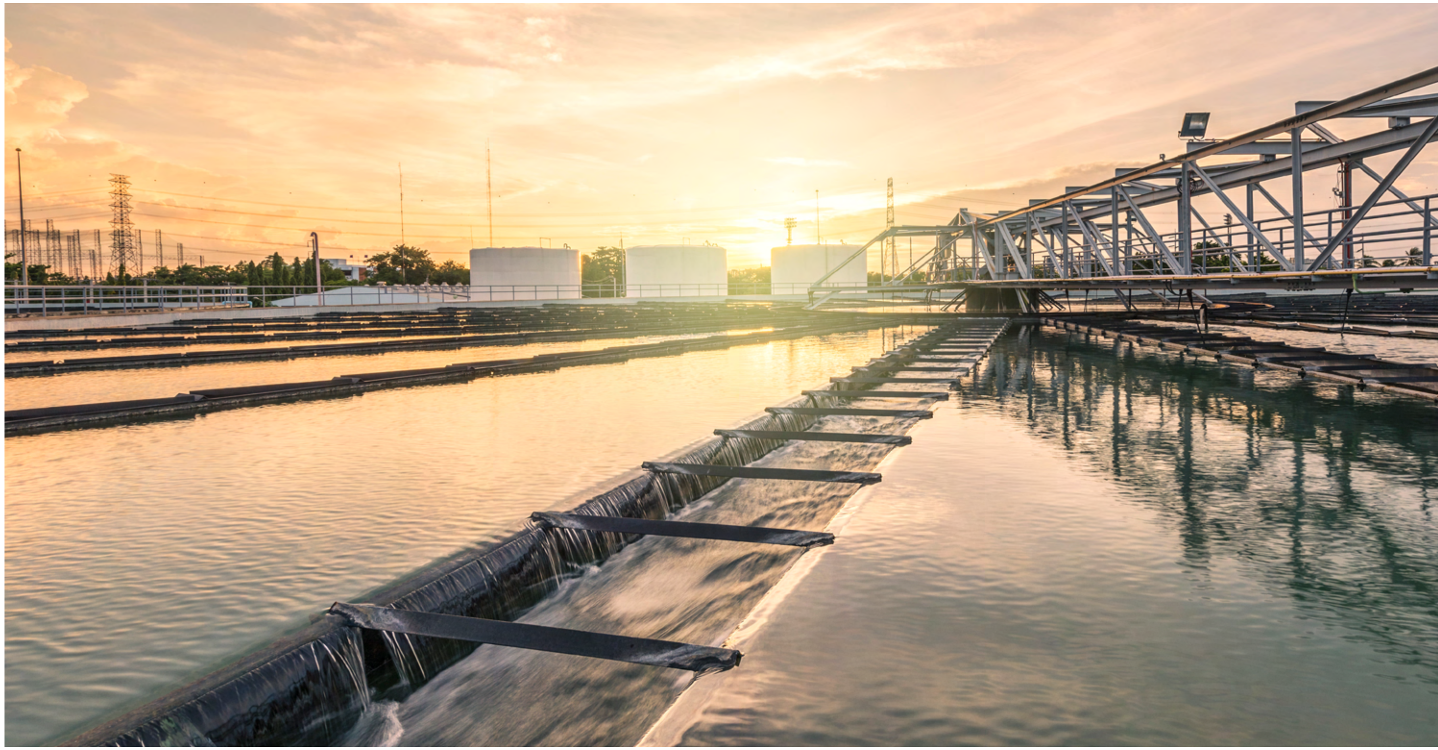
Current practices employed

Bioresources management activities fall into three main areas: resource production, recovery to agriculture / reclamation, and disposal (e.g., incineration). All of these activities are significantly influenced by the regulatory framework, markets and acceptability, of both the receiving user, (for example farmers) and general public. The English water companies and Dŵr Cymru Welsh Water were interviewed to fully understand their current bioresources operating practices and their strategies for the future, to ascertain their immediate plans for AMP8 and the longer term. The general consensus was that all companies predominately rely on agricultural recovery at this point but were aware that they need to diversify in the medium / longer term to become more resilient to changing regulations. The WaSCs predominately defined the need for short-term strategic inclusion of significant storage to mitigate immediate agricultural land challenges and a general move towards combustion (predominately defined as incineration). Several WaSCs highlighted the need to further understand alternative strategies, for example Advanced Thermal Conversion, however, this tended to be explored independently. Resource recovery was another area of divergence across WaSCs.

The current predominant bioresources operating practices in the English water sector are a mixture of advanced anaerobic digestion, or conventional anaerobic digestion and dewatering prior to land application as an enhanced or conventionally treated alternative to artificial fertiliser or soil improvers with additional focus on energy, biogas and resource recovery[1]. Recovery of biosolids to agriculture has been deemed to be a long-term strategy for the sector and is considered by the UK Government as the best practicable environmental option in most circumstances. The treatment of choice, anaerobic digestion, has benefited WaSCs from a reduction in output (digestate) due to high solids destruction requiring reduced further management and from significantly increased renewable energy generation: both from combustion of biogas on-site and/or exporting the electricity or gas into the grid.

More recently biogas has been upgraded and injected into the UK gas network as biomethane, supporting the decarbonisation of the UK energy market. This practice has increased in recent years, influenced by market prices of gas / electricity, adaptation of specifications and government driven incentives. Biomethane to grid is not, however, deployed across all WaSCs in the English water sector or entirely within each company. Resource production has predominantly focused upon energy recovery, with some nutrient recovery historically in the UK, however, greater emphasis is now being placed on the possibility of the recovery of non-energy resources from wastewater and bioresources processes. Building a long-term strategy around continuing the recovery of biosolids to agriculture in the proportions currently observed, relies heavily upon sufficient demand from the agricultural sector.

Other recovery mechanisms, for example reclamation or non-food crops (industrial), are either sporadic in nature or insufficiently scale-able to be widely deployed.



1: ADAS & Cranfield, An assessment and evaluation of the loss of the biosolids-to-agricultural-land recycling outlet, 23 March 2022

Surveys

The water industry is affected by mostly common drivers, but individual WaSCs have individual strategies and drivers which can cause divergence. For this project to better understand the views of all WaSCs and other stakeholders, an online survey was undertaken in summer 2022 to:

- Better understand the positions of key stakeholders on bioresources management.
- Understand the range of drivers for change.
- Understand the risks, challenges and opportunities for bioresources management.
- Appreciate the policy / regulatory implications for bioresources management.
- Obtain feedback on aspirations and outcomes from a bioresources strategy.

Respondents were asked to consider the influence of potential suggested challenges to the management of bioresources.

Figure 6 presents the distribution of influence for potential challenges that impact the management of biosolids. Costs to manage, demand for biosolids and the impact of contamination and diffuse pollution were considered most influential challenges. Respondents were also asked to consider the policy framework related to sewage sludge and biosolids and rate the influence of suggested future policy and legislation interventions. **Figure 6** also presents the distribution of influence for policy and legislation. When respondents were asked to provide additional comments around the drivers for change, they could be broadly summarised into three main categories:

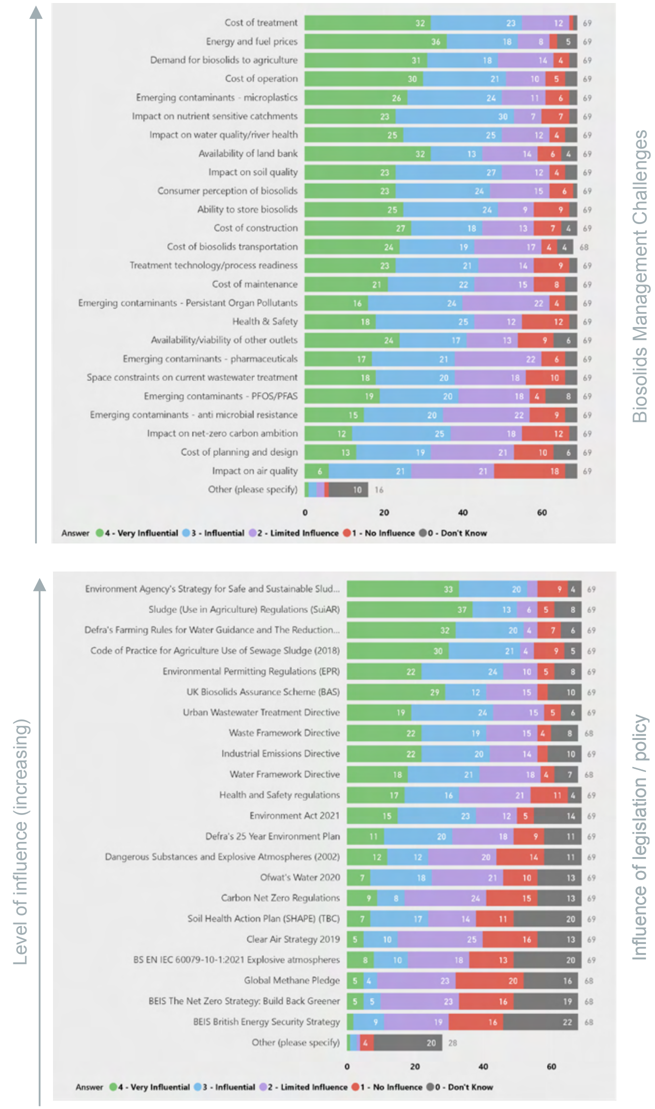
Complexity – the policy area is complex with several factors requiring consideration e.g., waste; agriculture; water; emerging contaminants / chemical; health and safety; soil; air; carbon and green investment.

Nutrient recovery – the re-use of nutrients (nitrogen and phosphate) for soil and food production is preferential to the incineration of sewage sludge whereby these could be lost or less available.

Energy – with concerns about energy security, opportunities for biogas should not be overlooked, particularly the use of biomethane, as opposed to hydrogen (which can be costly).

The survey received 72 responses, the largest number of responses were from those working in water and sewerage companies (WaSCs) (33%), followed by consultants / industry experts (25%), then those working in agriculture (15%).

Figure 6 – Distribution of influence of legislation / policy and challenges



3.3 Examples of current bioresources strategies

Bioresources strategies vary globally, as depicted in **Figure 7**, as they are influenced by a number of factors, including historic operations / practices, varying societal and cultural acceptance, operating costs, and regulatory frameworks. The majority of strategies are currently focused towards the recovery to agriculture route, recognising the inherent value of biosolids, whilst balancing availability of the outlet with disposal either through incineration or landfill.

The global bioresources strategic picture may differ significantly over the coming years as bioresources management faces similar challenges from emerging contaminants of concern. Examples of these are microplastics and persistent organic pollutants. There is also changing acceptance of using landfill for organic materials and a desire to provide resilience in less mature and / or lower soil quality regions.

There is, in addition, a significant focus being applied to understanding the opportunities available to manage bioresources in a safe and sustainable manner whilst maximising the opportunities contained within (energy, carbon and resource recovery) to aid resilience, carbon, circularity and self sufficiency drivers.

The future direction of bioresources strategies is changing across the globe and likely to be varied depending upon the existing asset-base, maturity of the sector, regional drivers, desired environmental outcomes, risk appetite, ambition, and market interest/confidence in outputs, rather than solely the environmental regulation of the agricultural outlet. The move into resource production is evident in many countries, as referenced by the annotations in **Figure 7.** The current asset-base and social, economic and environment context found in each country has a significant impact on their options and direction of travel.

For example: the Netherlands has historically pursued an incineration strategy due to the large quantities of animal manure making biosolids unable to compete for agricultural land; Germany has an existing asset-base of incinerators due to the practice of co-incineration of sludge with municipal waste. In both of these examples the starting positions are very different to the UK, meaning that although there are common drivers on emerging contaminants, the economically viable solutions implemented will differ. On the other hand in Australia, which is more aligned to the UK's bioresources strategic operations, there is a real interest in developing Advanced Thermal Conversion strategies to mitigate the impact of changes to regulation regarding persistent organic pollutants. There is an opportunity for the UK to position itself as a global leader in bioresources management by navigating these drivers successfully.

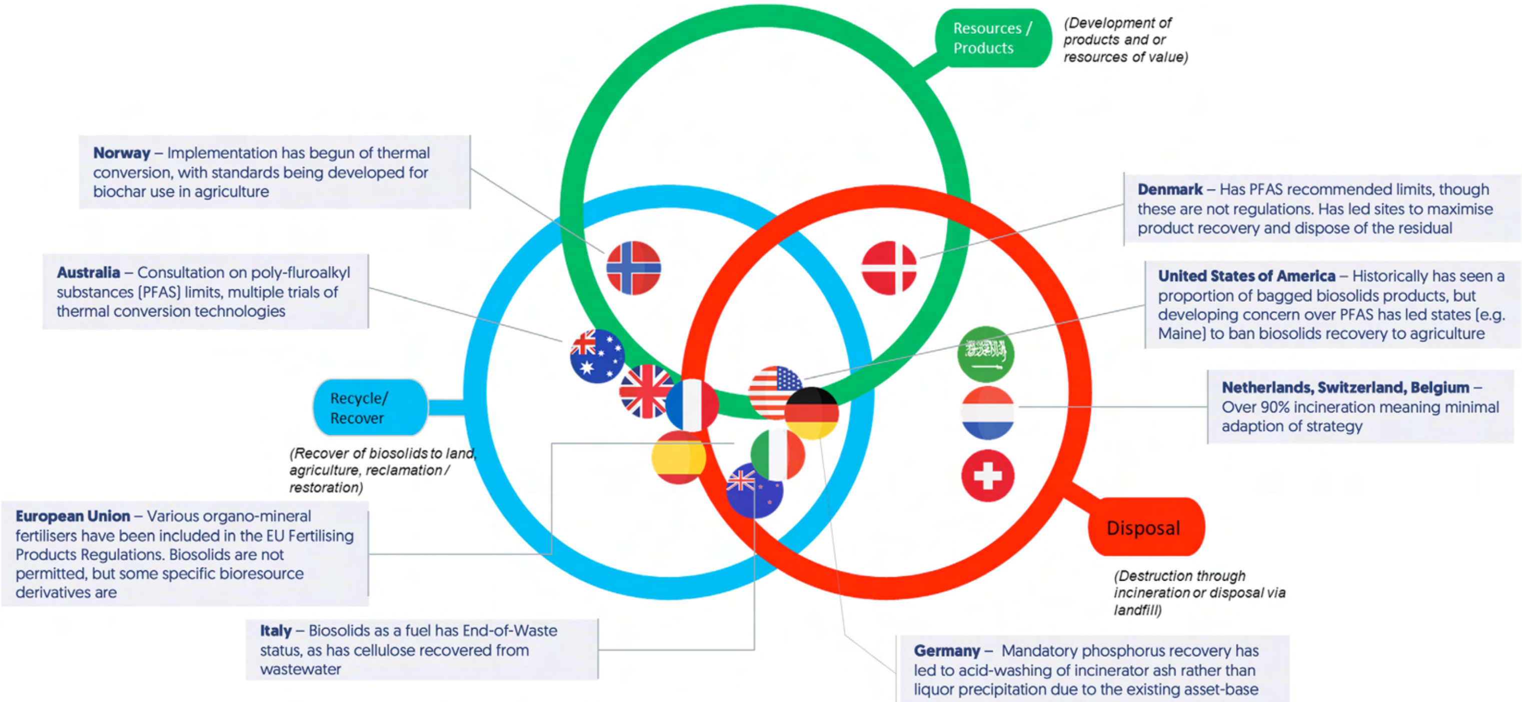
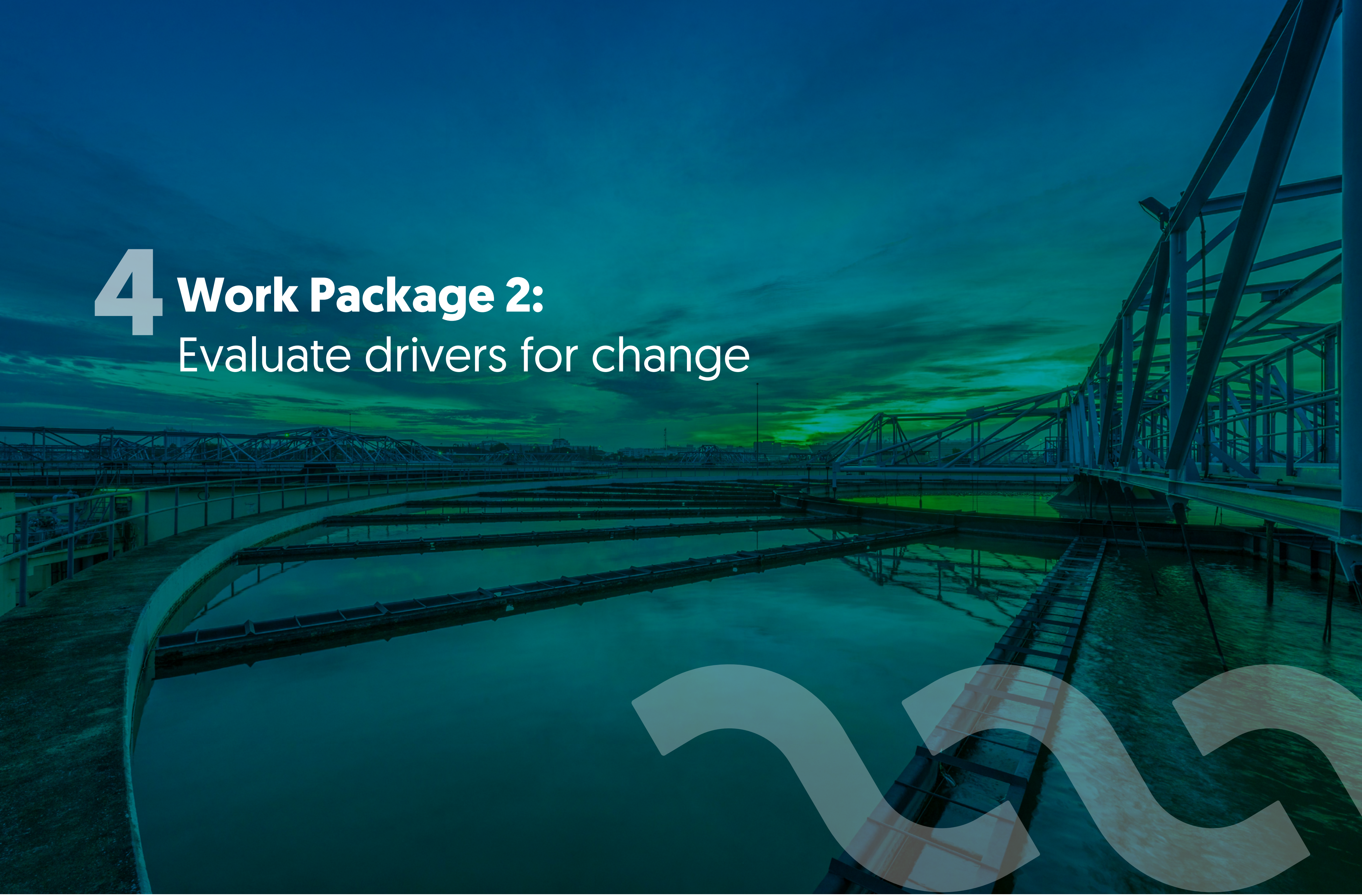


Figure 7 – Examples of global bioresources strategies – positions on the diagram mark current state

4 Work Package 2: Evaluate drivers for change



4.1 Detailed methodology – Work Package 2 and 3

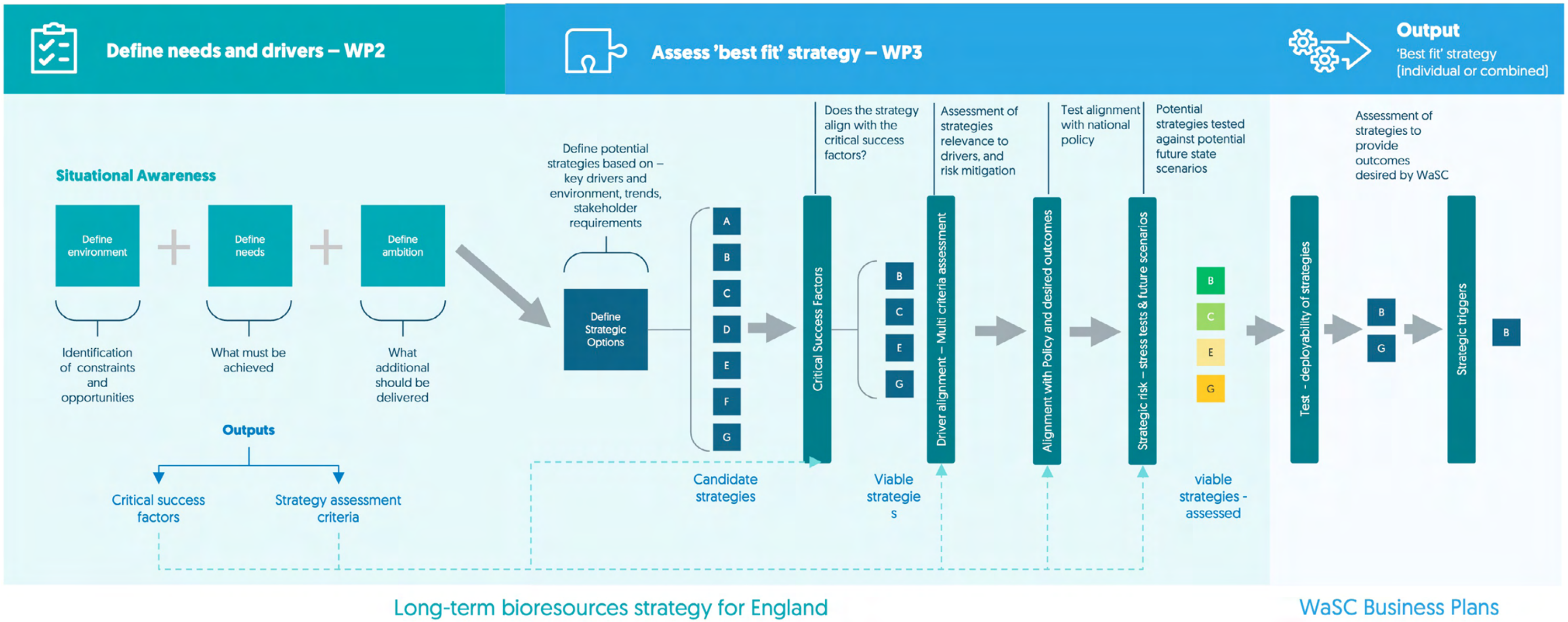
Adaptive pathways is a decision-making strategy that is made up of a sequence of decision points over time to achieve a set of pre-specified objectives under uncertain, changing conditions. This method of strategy formulation was determined to be beneficial for this project, due to the complex interactions around future regulations, markets and customer demands on WaSCs. In order to achieve this, a list of strategies needed to be formulated, refined and prioritised so that the options within the route-map are all viable for deployment. The methodology used here **(Figure 8)** produced an output that can be used to develop company specific strategies whilst also retaining a line-of-sight to an overarching national direction of travel. The determination of the strategies to include in the route-map output of this project were formulated over work packages two and three.

Work Package 2 explored and defined the needs, drivers for change, and ambition (desired outcomes). This enabled development of the Critical Success Factors (CSFs) through collaboration with the governance groups and wider stakeholders. The project also conducted a literature review, a PESTLE analysis (Political, Economic, Sociological, Technological, Legal and Environment), and assessed the environmental policy framework. These exercises allowed a full and nuanced understanding of the current position, drivers and ambitions surrounding bioresources. The methodology for the multi-criteria assessment, stress testing, policy alignment and future scenarios tests were also defined in Work Package 2.

Work Package 3 considered the 'best fit' strategies by exploring multiple strategic options and assessing each against: the CSFs (as an initial filter), multi-criteria assessment, alignment with policy and desired outcomes, stress tests (near term) and future scenario testing. This refined and prioritised the strategic options into those which were viable for inclusion in the route-map formed in Work Package 4. This is further described in **Section 5.**

This section sets out the activities undertaken in Work Package 2 and key findings. Collectively these demonstrate the national and industry specific goals, priorities, and potential risks relevant to bioresources management, which were later used to develop and refine future adaptive pathways.

Figure 8 – Methodology followed for Work Packages 2 and 3



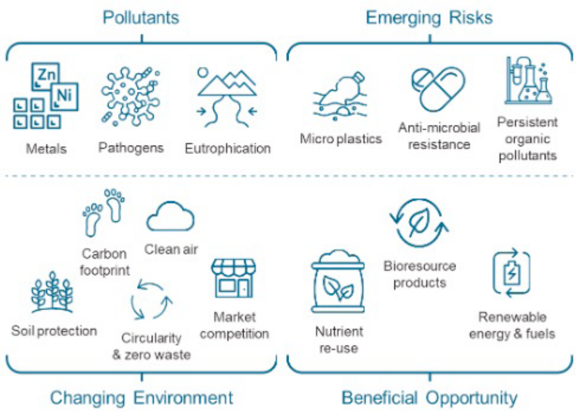
4.2 Strategic drivers linked to Critical Success Factors

Defining a long-term bioresources strategy which is least regrets, keeps pace with progressing drivers and developments, whilst balancing the need to mitigate immediate challenges, is the task being faced by the water sector globally. A shared understanding of the key drivers impacting the sector and Critical Success Factors (CSFs) that must be met was therefore crucial to developing a long-term strategy that is fit-for-purpose and delivers on the industry's collective ambitions.

Sewage sludge production continues to grow globally, whilst alongside this new developments are being made regarding its chemical composition and interactions with the wider environment. This increases the urgency for its safe and sustainable management, ensuring that any emerging risks are understood in order to continue to protect the environment.

The drivers for formulating a long-term bioresources strategy encompass both risks and opportunities. Bioresources can play a key role in climate mitigation, circularity, resilience and self sufficiency. The main issues to balance, as described in **Figure 9**, include organic and inorganic pollutants and air quality impacts. If adequately managed, the potential exists to support the delivery of national environmental outcomes including sustainable agriculture, a circular economy, net zero carbon, targets for clean energy by 2035, and affordability for customers.

Figure 9 – Outcomes to balance in delivery of a successful bioresources strategy



The drivers described play a fundamental role in the strategy development process and are incorporated within the multi-criteria assessment, medium term stress testing and future scenario testing used during the project.

In order to develop a truly collaborative strategy there was a need to collectively define the desired outcomes to be achieved from the long-term bioresources strategy, essentially a set of Critical Success Factors (CSFs) which will be used to challenge, prioritise and navigate the strategic adaptive pathways.

CSFs are defined as the high-level goals that must be met for the strategy to be deemed a success. The bioresources strategy CSFs have been defined with key stakeholders. To develop the CSFs, the following activities were undertaken:

- An online survey was circulated to stakeholders across a wide range of the community involved in, and potentially impacted by, bioresources management, and responses collated on what a successful strategy would look like.
- A focused survey was sent to PSG / PAB members around their principal objectives for a bioresources management strategy.

Common responses were grouped into six thematic areas and a headline was created for each group to summarise the overall objective. The CSFs were prioritised during the first workshop and endorsed by the governance groups. **Figure 10** shows these, and their ranked order, according to the stakeholders. These were then used in all subsequent stages of strategy formulation detailed within this document, to ensure alignment and line-of-sight.

Figure 10 – Critical Success Factors for a long-term bioresources strategy

- **CSF 1:** Ensure the safe and sustainable management of all bioresources in the context of reducing waste and the circular economy
- **CSF 2:** Protect human health and the environment, ensuring a risk based approach to bioresources outlets is employed
- **CSF 3:** Contribute positively to the Net Zero carbon ambitions of the water industry and support wider sectors
- **CSF 4:** Provide strategic investment certainty / confidence and be affordable to customers
- **CSF 5:** Protect bioresources quality
- **CSF 6:** Support UK self sufficiency

Some key factors behind the selection of these six CSFs included:

- Any strategy for bioresources must ensure that treatment and management processes are safely operated within the accordance of the regulatory standards (to minimise risk to human health and the environment).
- The wider water industry have ambitions to be operationally carbon neutral by 2030, and overall carbon neutral by 2050[1]. Bioresources offers companies the opportunity to recover renewable energy and avoid use of manufactured chemicals / products.
- The current economic climate is putting pressure on customers, meaning large-scale investment in bioresources in the short-term may not be affordable. Regrettable or abortive spend should be avoided. Having a long-term perspective and regulatory certainty would allow companies to spread investment over an extended period to mitigate this impact.
- The majority of biosolids outlets require the sewage sludge inputs to be of appropriate quality to be processed. Source control of chemicals of concern (e.g., Poly Fluorinated Alkyl Substances (PFAS)) and microplastics would lower the scale of investment required by the WaSCs to improve sewage sludge treatment. Sewage sludge quality also depends on choices made in both wastewater treatment, the management of the different sewage sludge generation stages and treatment choices, which impact the quality of the treated outputs.
- The benefits that can be extracted from bioresources such as renewable energy and nutrients can help the UK become more resilient and self sufficient through reducing the amount of imports from overseas and providing cost effective and sustainable alternatives to the industrial and agricultural sectors.

1: Water UK, Net Zero 2030 Routemap, March 2021

4.3 Environmental policy framework

UK environmental policy is reflective of the goals and strategies for national development in line with societal priorities and current challenges faced. There are opportunities for bioresources management to support and contribute towards the UK's wider ambitions, particularly concerning the protection and enhancement of the environment. In order to better understand these opportunities, as well as how current policy may support or constrain developments in the sector, an Environmental Policy Framework **(Figure 11)** was developed. This outlines the national strategies that impact bioresources management, and where and how these constrain or support the ambitions of the sector and bioresources strategy development.

The European Green Deal (EGD) sets ambitious policy objectives to enhance circularity and protect the environment. With this as a starting-point, key UK policy or strategy documents were identified across thematic areas where there was a possibility of enabling or challenging (either directly or indirectly) the management of bioresources.

Within these the project explored:

- The interactions with policies relating to environmental protection for land, air and water.
- The influence of policies related to waste, energy, carbon, agriculture/food, the natural environment and the economic regulation of the sector.
- Economic drivers and related policies that may impact regulation, markets and investment.

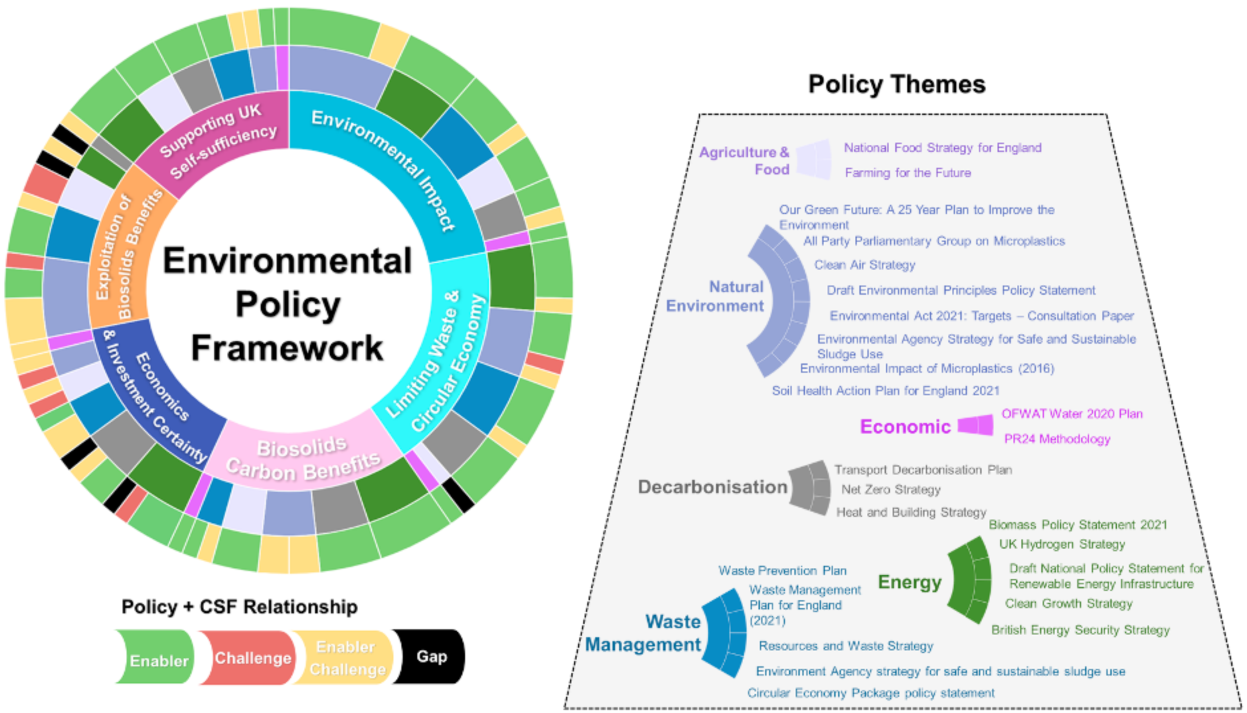
These documents were identified through:

- Atkins Subject Matter Expertise (SME) knowledge.
- Key topic search through the literature review.
- Findings from the online stakeholder surveys for this project.

The content of each document was reviewed against the CSFs and key points drawn out as they impact bioresources management. They were categorised and recorded as: 'Enablers' (in green), 'Challenges' (in red), a 'mix of enablers and challenges' (in amber) or 'Gaps' (black). This reflected whether the project team felt they enabled or promoted the CSFs, or whether they challenged or potentially hindered them, or both.

Figure 11 highlights the scope of policies and strategies and the outcomes of the assessment. Bioresources cuts across different policy areas. Whilst many strategies and policies broadly aligned with the CSFs giving bioresources an opportunity to contribute to wider UK targets, many did not include specific bioresources related targets or incentives and were more broadly directed at zero waste, or renewable energy generation for example. The areas where this was noted were classified as 'Gaps'. There is a need to clarify expectations and priorities for bioresources management in support of national strategy through policy development moving forwards.

Figure 11 – Environmental policy framework



Some of the gaps identified included:

- Policies related to agriculture and food security did not directly mention biosolids as an opportunity to offset need for raw material inputs. Organic fertilisers were referenced in one document but omitted in others.
- Whilst numerous applications for bioenergy and biofuels are referenced in relation to decarbonisation strategy, there is a lack of clear prioritisation of these to direct the efforts of the industry to achieve maximum impact.
- A number of key strategies are awaiting publication – including the Land Use Framework and the Chemicals Strategy – which may significantly impact the industry and desirability of future strategic direction(s).
- The full impact of microplastics is not yet understood, and it is therefore unclear whether it will have an impact on the self sufficiency drive. It could constrain the use of waste materials and their potential to subsidise critical inputs (e.g., fertiliser), but this is not fully addressed.

Some of the key opportunities / enablers identified a need for support and investment for innovative technologies including:

- Development of carbon capture, use and storage to drive down implementation costs.
- Development of heat networks and support for heat recycling from industrial processes.
- Support for renewable energy generation, including investment in innovative energy technologies, energy process and resource efficiency, and low carbon transport fuel development and uptake. There is a particular focus on the development of green hydrogen and the infrastructure to support this.

There was also recognition of the challenge of reducing/ removing pollutants downstream. There is increasing legislation around source control which may improve sewage sludge quality, although this will not eliminate risks.

Three key themes were drawn out that reflect high-level ambitions of the UK to consider for onward assessment of potential future pathways.

These were summarised as:

- Maximisation of resource productivity.
- Decarbonisation.
- Recovery / maintenance of healthy ecosystems.

The resulting framework from this exercise was used for the creation of the assessment methodology for selecting strategies, the regulatory assessment timeline, and the assessment and prioritisation of the strategies (these are all covered in Section 5).

4.4 PESTLE and literature analysis

PESTLE

The PESTLE framework (Political, Economic, Sociological, Technological, Legal and Environment) was used to review the drivers for change and gain a broader understanding of the factors influencing both the sector and the stakeholders involved in sewage sludge and treated biosolids management.

A workshop was used to further refine, prioritise and risk assess the PESTLE framework factors, grading the impact of risks and opportunities on the differing bioresources management strategies as shown in **Figure 13**.

The results provide an indication of the major opportunities and challenges ahead for bioresources management, as well as preferential strategic directions of travel moving forward. The factors were also ranked in terms of perceived challenges, to obtain consensus as stakeholders' views highlighted contributions and contradictions in each of the PESTLE categories.

It is clear from the PESTLE analysis that the future of bioresources management is subject to many constraints and uncertainties surrounding the regulatory framework, managing environmental and economic risks, and the perception of biosolids recovery to agriculture. Any future strategy will need to be capable of navigating this uncertain landscape and this formed a core element of strategy formulation, discussed in **Section 5**.

The top five PESTLE factor challenges identified from the workshop were:

- **Perception of using biosolids** – some see this as an opportunity to move towards a circular economy whilst others may perceive this as a risk with regards to potential for fecal contamination / low quality products creation from sewage waste. Framing of opportunities and education around the benefits of bioresources products should be considered to capitalise on opportunities.
- **Soil health** – available organic carbon and macronutrients in bioresources can contribute to soil health at lower cost, however appropriate soil health monitoring and nutrient management is required to ensure that this does not become a risk. Potentially Toxic Elements (PTEs) pose a pollution risk for bioresources application to land. Some materials (e.g., biochar) require further research to fully understand impacts on soil health.
- **Permit compliance** – Water companies are required to comply with their trading license. This imposes a duty of care on operators to treat and dispose of waste (sewage sludge) satisfactorily. Failure to comply could lead to fines and or revocation of license. Current license conditions promote market trading to allow sewage sludge and / or biosolids to be managed by other companies thereby passing on some of the costs and risks.
- **Water quality** – concerns around phosphorous / nitrogen leaching and pollution pose a risk to strategies incorporating recovery to land. National targets have been set to reduce phosphorous (P) and nitrogen (N) contribution from agriculture to the water environment.
- **Carbon** – Bioresources management can provide opportunities to accelerate decarbonisation through renewable energy generation, carbon sequestration and / or substitution of carbon intensive inputs to agriculture / industry. However, the drive towards decarbonisation also poses a risk in terms of the challenge to meet targets and maintain compliance.

Figure 13 – PESTLE analysis

PESTLE	PESTLE FACTORS	Impact on Bioresources Management
Political	Centre right – free market mechanisms	
	Centre left – prescription and regulation	
	Political Short Termism	
	Public Enquiry and Local Councils	
	Trade Unions and Industrial Action	
	Brexit	
	Devolution and Independence	
	Global Events	
Economic	Natural Gas and Fuel Prices	
	Hydrogen Economy	
	Renewable Energy	
	Fertiliser and Food Prices	
	Incentives	
	Cross Sector Collaboration	
	Decentralised Treatment	
	Further Privatisation of Bioresources Market	
	UK Economic Decline	
Social	**Perception of using biosolids**	
	Source Control	
	Perception of the Water Industry	
	Customer Values	
	Improved Public Awareness	
	Nuisance, Odour and Visual Issues	
	Transportation Movements	
Technology	Sewage Sludge Reduction	
	Sewage Sludge Increase	
	Resource Recovery	
	Cellulose Recovery	
	TRL	
	Cyber Security	
	Combability with Existing Asset Base	
	Health and Safety	
Legal	Compliance with license condition	
	Permit compliance	
	H&S Compliance	
	Competition Law	
Environment	Air Quality & Public Health	
	Soil Health	
	Water Quality	
	Carbon	
	Circular Economy	
	Climate Change	

Key	
Opportunity	Mix - opportunities & risks
Minor risk	Risk

Literature review

The literature review was aligned with the PESTLE topic areas. Focus areas were created to group key factors that may impact bioresources management and research questions were defined to direct the literature search.

The focus areas were:

- **Regulations and policy** – current and future.
- **Societal drivers** – including customer influences, perception and source control.
- **Technology** – readiness and deployability of sewage sludge treatment technologies and potential impacts from changes to wastewater treatment.
- **Resource recovery** – types of output, resource and / or product, impacts to treatment, technology readiness levels (TRL) and market interest.
- **Environment** – beneficial opportunities for bioresources and risks associated with emerging contaminants, air quality, soil health, water quality and Greenhouse Gas (GHG) emissions.
- **Economics** – value of biosolids, incentives, costs of fertilisers, energy prices, national energy make up, economic regulatory framework for bioresources.
- **Political** – macro economic events, impacts from changes to government, Brexit, independence, unions / strikes.

Literature was identified in relation to each research question, with a summary of each document and its critical findings recorded. Documents included academic papers, policy and regulatory documents, books and grey literature (i.e., literature not formally published in sources such as journals or books). In addition to available literature, direct contact with operators, industry experts and technology providers was made through Atkins global network to provide international examples of best practice or issues in other countries (e.g., the approach to organic contaminants).

Over 300 references were reviewed, including 97 journal articles / academic sources, 113 regulatory and policy documents, 63 published reports, and 85 websites. The review helped to shape the various PESTLE factors and assessment against strategic directions, understand current and potential regulations for the environmental policy framework, understand the art of the possible with regards to technological implications and ascertain future research needs.

4.5 Technologies assessment

It is important when developing any bioresources strategy to understand available and emerging technologies that may mitigate risks or maximise opportunities from bioresources management. A technology review was therefore performed to encapsulate opportunities and constraints, with a focus on the following areas of pertinence:

- **Sewage sludge treatment technologies** – these include the technologies that treat the main solids flows and can alter the ultimate biosolids product.
- **Resource recovery technologies** – these include the side stream technologies that recover resources from wastewater and / or biosolids streams.
- **Wastewater treatment technologies** – these include potential changes to wastewater treatment that may change the quality and quantity of sewage sludge produced.

Multiple technologies in all categories were identified as part of this review, and are of varying maturity and market readiness: this needs detailed investigation of the scalability, integration (compatibility) and market availability. A selection of these are listed in **Figure 14**, which is by no means an exhaustive list of the technological options available.

The biosolids treatment processes that have the greatest potential to offer solutions on emerging contaminants, such as the Advanced Thermal Conversion (ATC) and resource recovery technologies, have markedly varying operating conditions with commensurately variable outputs. The majority of ATC and / or resource recovery technologies detailed below require investment in Research and Development (R&D) before they can be considered deployable at scale as supplements or replacements for existing treatment processes.

The more mature technologies are firmly in the development phase rather than pure scientific research: these will require investigations into their scalability and compatibility with the existing assets present at English bioresources facilities. These pilot or demo facilities could also be used to understand the operating parameters, outputs, fate of carbon and contaminants within outputs. A research and development workshop, incorporating, industry experts from across the world, was held as part of this project to ascertain the prioritisation and remaining questions that require answering before some of the key technologies shown in **Figure 14** could be deemed fully deployable in a UK setting. The outcomes of this are documented in **Section 6**.

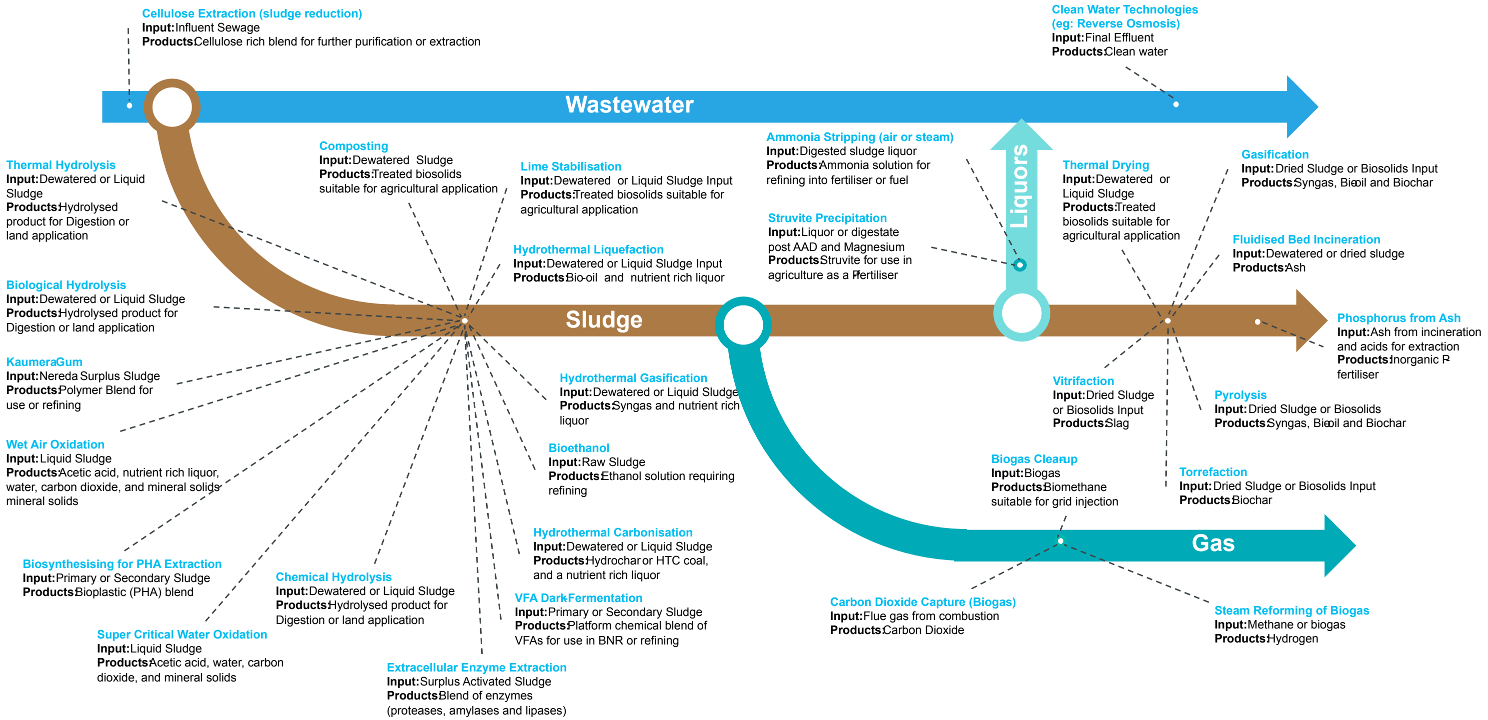


Figure 14 – Technologies assessed and their indicative position within the wastewater and bioresources treatment process

4.6 Workshops concluding Work Package 2

To conclude Work Package 2, the outputs of the literature review, PESTLE framework, environmental policy framework and technologies review, were discussed in an engagement workshop with key stakeholders. There was also a focus on the potential for bioresources management to support national priorities, and questions regarding how this could best be realised. Agriculture and Food, and Energy and Decarbonisation were areas highlighted for detailed discussion.

In strategies around **Agriculture and Food**, biosolids are often not directly considered as a renewable input to increase food security or self sufficiency. However, in literature and national strategies promotion of the use of organic fertilisers as a group to increase self sufficiency was included.

Bioenergy, including heat, green hydrogen and biofuel production, are highlighted as key elements of national strategy around **Energy and Decarbonisation**. There is significant government / private funding planned to support development in these areas, and potential to benefit from incentives.

Evidence from this Work Package suggests that there is no clear prioritisation of bioenergy options, and incentives tend to be short-term focused, making it challenging to plan long-term investments. The project sought to understand what mechanisms stakeholders felt would better support investment, and the main challenges that they experienced / foresaw.

Workshop participants suggested key enablers for these themes, and these can be broadly summarised as:

Greater engagement and promotion
Evidence and science should underpin approaches to raise awareness of risks, their mitigation and benefits for potential outlets and the general public. The industry needs to improve engagement with others on how bioresource management could contribute to achieving a more circular economy, net zero carbon and greater self sufficiency for the food and energy production sectors.

Improving collaboration
Collaboration between technology providers, WaSCs and potential end users would be beneficial in managing risks, supporting innovation and developing markets for recoverable resources. The value of collaboration between government, regulators and the industry in providing greater transparency and improving alignment on the long-term direction of travel for regulations was also highlighted.

Efficient implementation of regulation
Streamlining 'End-of-Waste' regulations to support resource recovery (i.e., nutrients, energy, other products) from biosolids would be beneficial. Greater transparency and certainty on key regulations, e.g., The Environment Agency's Strategy for Sustainable Sludge Use proposed move to using the Environmental Permitting Regulations (EPR), would improve innovation and long-term investment for the industry and related sectors. It would also be beneficial to consider interaction and harmonisation of regulations across water, land and air.

The key challenges suggested by workshop participants can be summarised as:

Future regulatory certainty
The perception of sewage sludge and biosolids as a waste can hinder resource recovery. Uncertainty around the direction of travel for the Sludge Strategy, Environmental Permitting Regulations, Farming Rules for Water and the government's approach to soil health impacted the industry's ability to innovate and effectively plan.

Managing environmental risks
The industry needs to better understand the science of materials, emerging pollutants (e.g., microplastics, anti-microbial resistance, PFAS etc.) and how they can impact soil health and water quality. Research needs to continue to demonstrate how the potential impacts can be effectively mitigated. These are issues that impact a number of industries and there may be an opportunity for cross-sector collaboration to improve understanding of and address these emerging risks.

Technology and perception of bioresources These were also commonly raised as potential challenges and enablers that need to be considered when developing the bioresources strategy.

The findings are in alignment with the rich evidence gathered through the rest of the Work Package, through engagement and research, giving a good foundation for the remainder of the project.

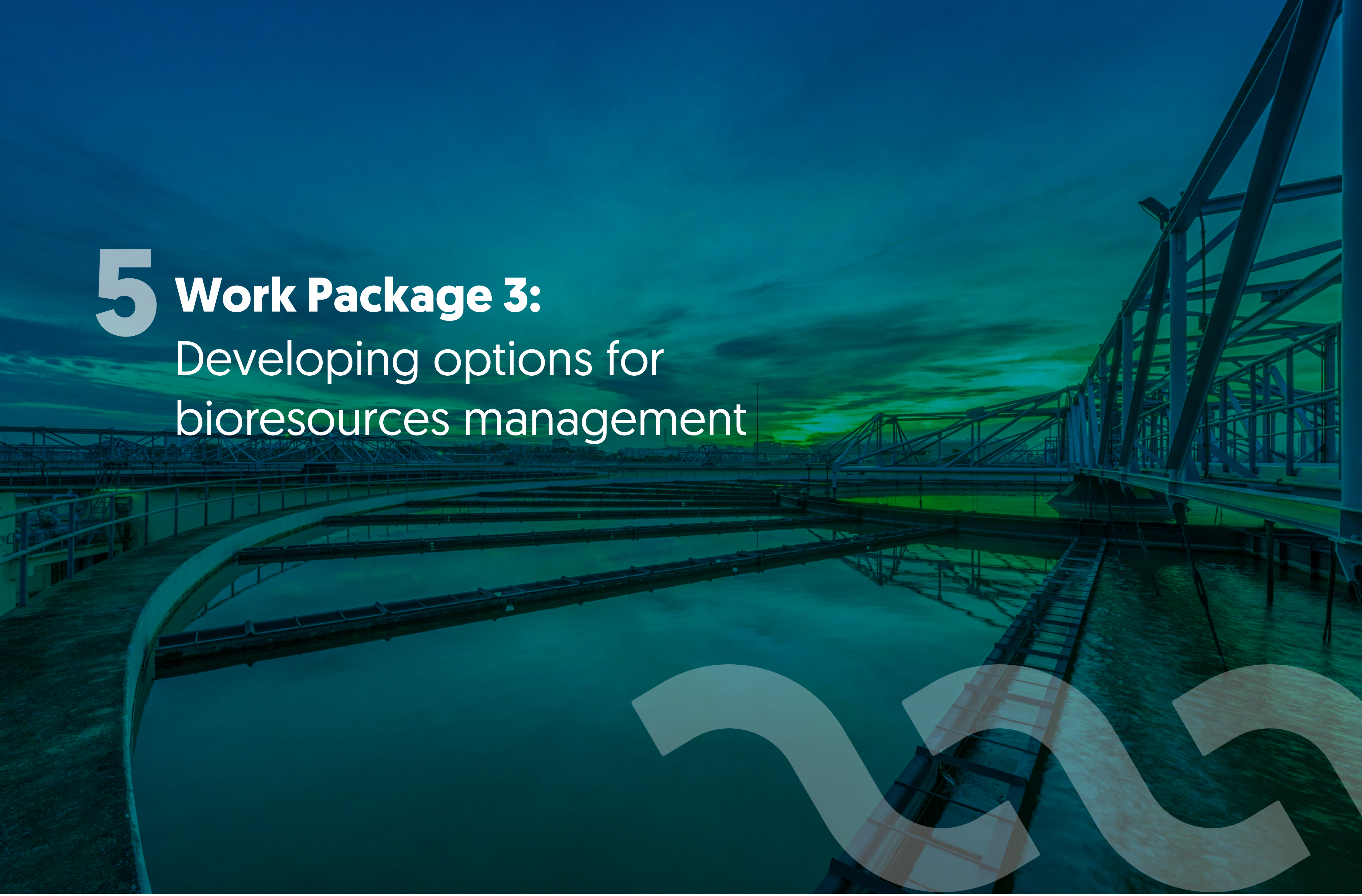
Overall, findings highlight that bioresources is a complex topic with a significant number of policy and regulatory touch points. Whilst there are numerous opportunities for the sector to support wider UK priorities and deliver benefits, as summarised in Figure 12, there is no consensus on which outputs should be prioritised. The technologies to support the achievement of these opportunities and benefits exist but require significant development to be deployable at scale. Market development for potential novel outputs associated with this is also required. Overall, there is a need for a stronger direction, which will enable the development work required to drive progress down the desired route(s).

Maximisation of Resource Productivity
- Waste hierarchy
- Circular economy
- Zero avoidable residual waste

Decarbonisation
- Operational emissions reduction
- Carbon capture, use and storage
- Bioenergy production
- Carbon footprint of infrastructure

Healthy Ecosystems
- Clean air
- Clean water
- Healthy soil
- Land use efficiency

Figure 12 – Key policy themes derived from Work Package 2



5 **Work Package 3:** Developing options for bioresources management

5.1 Alternative strategic pathways for bioresources

Work Package 3 considered the options available for bioresources management and assessed them using the methodology described in **Figure 8 (Section 4)** to refine and prioritise candidate strategies into a selected number that are viable for deployment. The strategies then formed the basis of the adaptive pathways route-map **(see Appendix A)**, the key output of this project, which can be used as a framework for English water companies to determine the 'best fit' strategic direction for their individual companies.

There are a wide range of bioresources management strategies which sit across the waste hierarchy. These can all be deployed globally to some extent, depending on the specific environment they are deployed within. This will be influenced by the market appetite for outputs, regulatory frameworks and local or regional historic trends (for example, established incineration or digestion site in the area vs need to find a new site).

The candidate strategies that were deemed as viable options to pursue for England are listed in **Figure 16**. These are listed in order of their position on the waste hierarchy. Many of these candidate strategies will produce multiple outputs as part of their treatment processes. All strategies produce a solid residual, however the nature of this varies significantly between strategies.

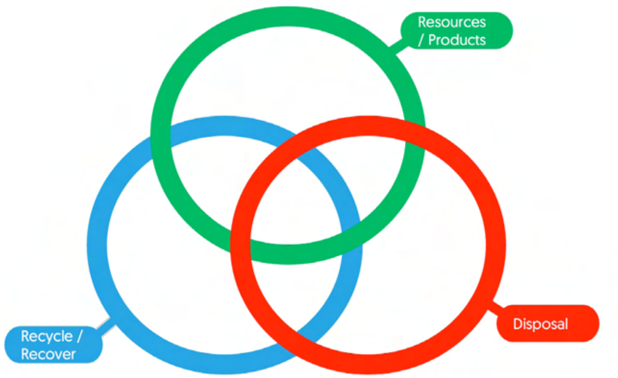


Figure 15 – The Venn diagram model used in this report to depict strategy outputs

This document uses a series of Venn type diagrams to depict the blend of outputs arising from each strategy: these are notional and based on the current knowledge of the technologies employed. The varying sizes of each circle denote their relative emphasis on biosolids disposal / recovery to land / resource production. These are depicted in **Figure 15.**

- **Biosolids reduction** – Wastewater treatment is operated to drastically reduce sewage sludge production to minimise the costs of transport, treatment and disposal.
- **Resource production** – Extraction of desirable constituents within sewage sludge and wastewater, recovering resources, and / or producing marketable products. Outputs could be nutrients (ammonia, phosphorous), valuable molecules (cellulose, acetic acid), and then residual biosolids or biochar that will require management.
- **Agriculture food** – Focus on provision of nutrients and organic matter to food-agriculture, with the main output of this strategy being treated biosolids. Biosolids would compete with inorganic fertilisers and organic manures for farmer usage and uptake.
- **Agriculture non-food** – The strategy focuses on provision of nutrients for non-food outlets (industrial crops); biosolids / digestate are the main outputs, but treated such that they are only suitable for recycling to non-food crops.
- **Restoration** – Minimum intervention for sewage sludge management. Sewage sludge or Biosolids (Conventional or enhanced treated) are managed through a land restoration / remediation
- **Thermal conversion** – Conversion using high temperatures of sewage sludge feedstocks into outputs such as chars, oils and syngas. These are then either disposed of, used for energy generation or recovered and sold as required e.g., for use in construction / wider industrial markets.
- **Industrial fuel** – Production of dried sewage sludge as an alternative sustainable fuel source for industry, e.g., biosolids pellets formed and sold as a low carbon footprint fuel. Residual Ash will need to be recovered or land-filled.
- **Incineration** – Combustion of all sewage sludge to remove any requirement for recovery to land. The resulting process output (ash) would ultimately be recovered in construction or via disposal to landfill.
- **Landfill** – The strategy focuses on minimum intervention for sewage sludge management. Sewage sludge or biosolids are managed through landfilling operation.

Figure 16 – Bioresources candidate strategies assessed

5.2 Strategic assessment – CSF filter

The first strategic assessment filter assessed each of the long list of bioresources strategies against the CSF's previously defined, to identify the level of alignment with the desired outcomes of the project. This enabled the long list of potential strategies to be shortlisted to a number of practical candidate long-term strategies for further consideration. The filter identified four strategies – incineration, thermal conversion, agriculture-food and resource production – as the key candidates for further assessment.

The restoration and non-food strategies, whilst not practical full-scale strategies, could be employed for tactical use periodically and the biosolids reduction strategy could be considered as part of an upstream optimisation of bioresources management (reducing the overall residual requiring further management via one of the candidate strategies) but this is unlikely to be a major contributor to strategy deployment over the next 20 years. These strategies were therefore excluded from further assessment.

Strategic end goals	CSF1 – safe and sustainable	CSF2 – protect the environment	CSF3 – Net zero carbon	CSF4 – investment certainty	CSF5 – bioresources quality	CSF6 – UK self sufficiency	Conclusion	Outcome
Biosolids reduction	?	?	✓	✗	✓/?	?	Unlikely to be a viable long-term strategy and will not be taken forward as a key bioresources strategy. Reduction of biosolids will inevitably become important to reduce wastewater costs, however the technologies are novel, require significant investment to be deployed in sufficient scale to impact the production of sewage sludge and will unlikely significantly reduce the overall volumes to fully mitigate the need for a bioresources strategy.	REJECT
Resource production	✓	✓	✓	?	?	✓	Increased focus on production of targeted resources and / or products in various forms will become increasingly part for any bioresources strategy. Resources required to enhance wastewater and biosolids treatment and development of resources and / or products required by the wider market will become increasingly more valuable and support the wider socio-economic drivers around a circular economy.	PROGRESS
Agriculture food	✓	✓	✓	?	?	✓	Continued focus on production of nutrients for agricultural recycling will continue to be a focus for any bioresources strategy as a cost effective solution so long as the outlet remains a socio-environmental option. Consideration to sustaining the strategic approach through adaptation of outputs to offset inorganic fertiliser utilisation (e.g. pellets, organo-mineral fertilisers) will likely be required. Understanding the impact of emerging risks and how they will be mitigated / regulated is required.	PROGRESS
Agriculture non-food	✓	✓	✓	?	?	?	Unlikely to be a viable long-term strategy and will not be taken forward as a key bioresources strategy. Production of lower quality biosolids for non-food agriculture is unlikely to be a primary strategic direction, but rather a tactical alternative outlet for biosolids as part of a combination of outlets.	REJECT
Restoration	✗	✓	✗	✗	?	✗	Not a viable long-term strategy and will not be taken forward as a key bioresources strategy. It is a tactical solution only due to costs and uncertainty over access to suitable outlets.	REJECT
Thermal conversion	✓	✓	✓	?	?	✓	Increased focus on production of energy in various forms will continue to be a focus for any bioresources strategy as a cost-effective solution. Although it is a combustion process, carbon emissions are significantly lower for ATC than incineration due to carbon sequestered in the biochar/bio-oil, which has an environmental benefit. ATC also produces more diversified outputs, opening a wider range of potential outlets. Development of ATC strategies may be viable, if supported by the appropriate understanding enhancement and clarity regarding environmental benefits / impacts of outputs and regulatory frameworks.	PROGRESS
Industrial fuels	?	?	?	?	?	✓	Not a viable long-term strategy and will not be taken forward as a key bioresources strategy. Production of an alternative low carbon fuel would be a minor contributor to the energy market. The strategy is dependent upon a single market, which may not have infrastructure suitable for deployment. Production of focused fuels could be part of a wider resource production strategy within a broader portfolio of outputs.	REJECT
Incineration	✗	?	?	✓	?	✗	Provides a guaranteed outlet although has a high carbon impact, produces a residual which requires disposal, and usually only recovers sufficient energy to offset its own requirements. Limited alignment with drivers. Incineration strategies are expensive to deploy and sustain. A significant transition to incineration across the UK may be resource and logistically constrained due to the scale of deployment required. There is merit in consideration as part of a basket of measures, particularly if considered in conjunction with mitigation measures for emissions e.g., carbon capture and storage.	PROGRESS
Landfill	✗	✗	✗	✗	✗	✗	Not a viable long-term strategy and will not be taken forward. Whilst is could be seen as tactical the costs and perception of using landfill is no longer deemed acceptable or viable. It is a 'last resort' deployment approach, suitable if no other outlets exist or sewage sludge is contaminated. It does not align with industry drivers or national environmental drivers e.g., circularity.	REJECT

Figure 17 – Strategies filtered against each of the CSFs

5.3 Bioresources regulatory assessment

To enable collaborative and adaptive planning, a review of regulations was undertaken in December 2022. The review considered the impact regulations could have on a forward-looking strategy and highlighted global practices in order to support development and prioritisation of options within the adaptive framework, by evaluating:

- What regulatory milestones (current and expected) impact on the options for bioresource management.
- Opportunities for harmonisation or improved efficiency of the regulatory frameworks.
- The timing of regulatory changes, the water industry Price Review cycle and opportunities for collaboration, such as utilising the Ofwat innovation funding mechanism.

Figure 18 provides an indication of policy (current and expected) associated with the strategies, however, is not exhaustive. A legislative timeline was created (see Figure 19) with the overall regulatory change picture from 2022 to 2050, highlighting changes or decision points and programmes, incentives or funding windows. The regulatory picture is highly dynamic at this point.

Some of these decision points are a result of regulatory milestones or a proposed change in Government strategy and some of them are being driven by targets. Also shown are the planning cycles such as the Water Industry National Environment Plan (WINEP) process stages, Periodic Review business planning including the confirmed Ofwat timetable for PR24 and the Drainage and Wastewater Management Plan (DWMP) cycles.

Clearly the impact of some of these regulatory changes has a knock-on effect on the scenarios and adaptive pathways and there is still much uncertainty, particularly further ahead in time, with a number of targets or timetables yet to be confirmed. Some key uncertainties include (but are not limited to) the following:

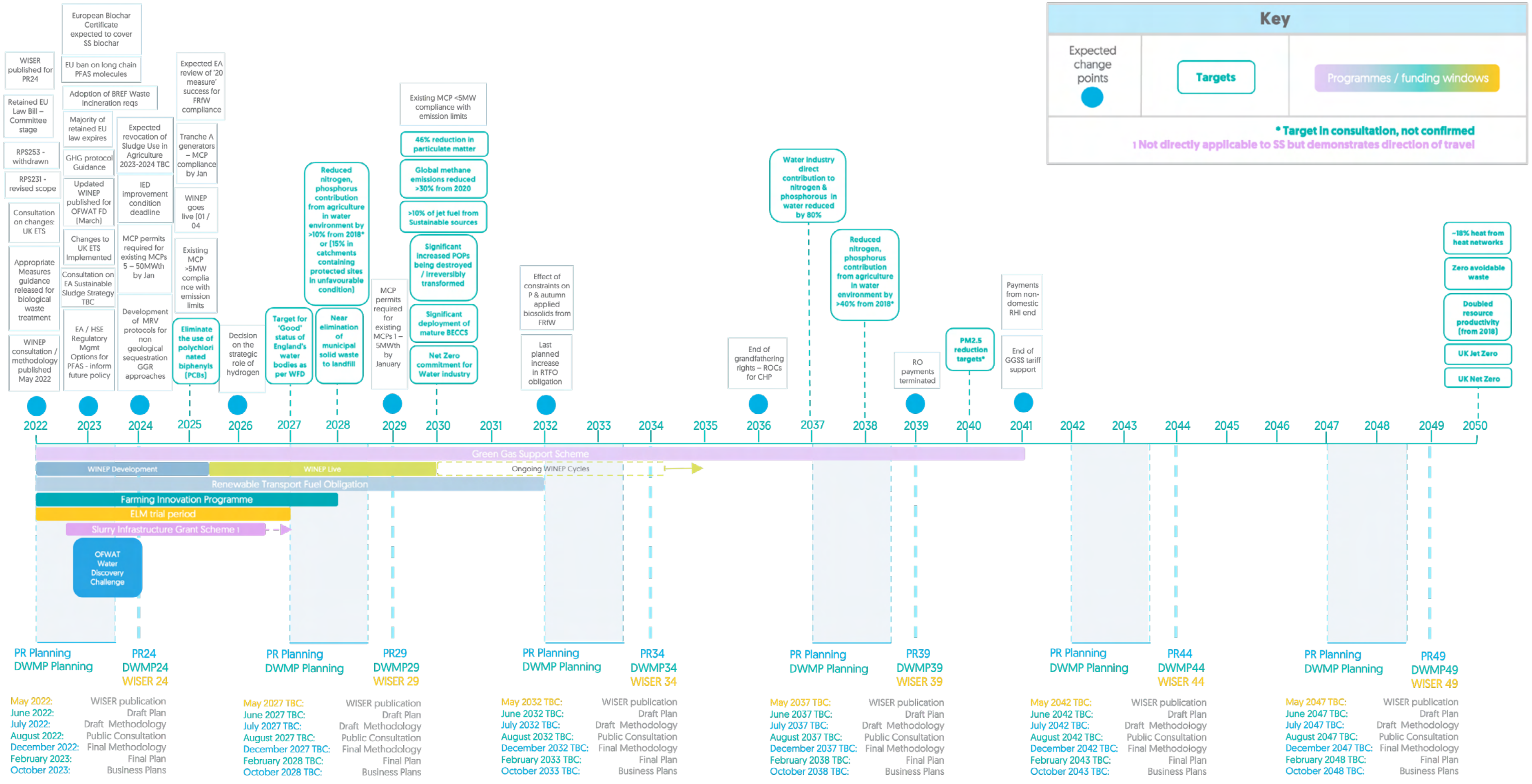
- The delayed new Chemicals Strategy and the outcome from the EA / Health & Safety Executive Regulatory Management Options Analysis (RMOA) for per- and polyfluoroalkyl substances (PFAS). The RMOA will investigate the risks posed by PFAS type chemicals and recommend the best approach to protect human health and the environment from any identified risks.

Figure 18 – Overview of legislation and relevant regulatory guidance (current and expected) as of December 2022

- Additionally, the ongoing outputs and recommendations from the Chemicals Investigation Programme in the next AMP8 may impact on the chemical standards for sewage sludge and / or biosolids and whether it remains appropriate for current uses.
- The outcome of the government's review of England's planned energy from waste (EfW) capacity, following Wales placing a moratorium on future large-scale EfW developments and further consideration of an 'incineration tax', plus Scotland's moratorium on all current and new applications for waste incineration.
- The expected National Infrastructure Assessment by National Infrastructure Commission with a possible recommendation to decommission the natural gas grid or convert to hydrogen transport by 2050.
- Definition of the government's approach to soil health in England.
- Any potential future revisions to the EU Sewage Sludge Directive, which recently underwent an EC fitness check that will inform the Commission's decision on the need to progress with an impact assessment for any proposal to revise the Directive. Changes to EU Directives and how European policy progresses over time could lead to a disparity in the UK position using the 'as adopted' regulations and there is uncertainty associated with this.

5.4 Regulatory timeline – future landscape

Each of these expected change points adds complexity and risk to the investment and the development of different strategic options:



Dates TBC:

- Chemical Strategy
- Output of government review of England's "planned" EfW capacity
- General ban of all PFAS (except for "essential uses")
- National Infrastructure Commission report (2023 tbc)
- Soil Carbon Code (SCC)
- EU Sludge Directive
- Biomass Strategy
- Land Use Framework

Figure 19 – Regulatory timeline – future landscape

Reflective of regulation (current and expected) as of December 2022, when the assessment was performed.

5.5 Strategy assessments

Two analyses were undertaken to test the reduced set of potential future strategies: a Multi-Criteria Assessment (MCA) and policy alignment analysis, which are described further below. The results of the MCA are given in **section 5.6** and of the policy alignment analysis in **section 5.7**.

Multi-criteria assessment

With input from the analyses performed in Work Packages 2 and 3, a list of criteria was defined against which to test the strategies to aid understanding of the alignment to key drivers, and to aid prioritisation within the adaptive pathways framework. The criteria are based on the industry drivers, readiness to deploy, risk and costs as highlighted by the research and engagement undertaken. A description of each criteria and their significance to strategy selection is set out below in **Figure 20.**

Adaptability
Can the strategy adapt to external changes (minor-moderate), e.g., changing regulations / market demand; how easy would it be to move into different markets / change the strategic direction

Resilience
How does the strategy respond to operational impacts or potential risk scenarios (major changes)

Deliverability
What scale of change to existing processes is required to implement this strategy and how achievable is this, how easy is it to implement the assets required in sufficient timeframe

Deployability
Are the strategies ready to deploy, for example associated technologies available at the right technology readiness level

Risk mitigation
How well does the strategy mitigate current risks faced by the industry – for example outlet certainty / management of emerging pollutants

Cost to implement
What is the level of investment required to implement the strategy

Environmental impact
What is the impact of the strategy across areas of environmental concern: air quality, water quality, soil health, GHG emissions, decarbonisation

Aligned with UK policy narrative
To what extent does the strategy support wider national policy themes – maximisation of resource productivity, decarbonisation, recovery / maintenance of healthy ecosystems

Figure 20 – Multi-criteria assessment criteria

Alignment with UK policy narrative

The 'Alignment with UK policy narrative' criteria was developed based on cross-cutting UK Policy themes outlined by the Environmental Policy Framework (maximising of resource productivity, decarbonisation and healthy ecosystems), based on the date it was undertaken (August 2022). Some of the key policies considered are defined below:

Resources and Waste Strategy – Defra, EA 2017
The strategy supports a movement towards greater resource efficiency including increasing efficiency of EfW and utilisation of resulting heat produced, increasing use of secondary resources and a general movement up the waste hierarchy. The policy is encouraging of product development / innovation to support maximisation of resource value.

Net Zero Strategy: Build Back Greener – UK Government (2021)
The policy supports circularity principles, sustainable energy generation and the maximisation of resource efficiency, and highlights specific opportunities that should be explored to support Net Zero and the reduction of wider GHG emissions. These include production of hydrogen, biogas / biomethane fuels, carbon capture, use and storage, alternative ammonia removal processes, alternative land uses to support environmental restoration.

A Green Future: Our 25 Year Plan to Improve the Environment – Defra (2018)
The policy supports maximisation of value from waste and minimisation of disposal – with a target to double resource productivity by 2050. A key tenet of the plan is to ensure that the levels of harmful chemicals entering the (air / land / water) environment are significantly reduced, which have several associated measures including identification and management of risks to water from farming land and reduction of emissions through farming activities and from combustion facilities.

Clean Air Strategy – Defra (2019)
The strategy sets out plans to reduce emissions of harmful pollutants and increase air quality with a particular focus on, fine particulate matter (PM2.5), Ammonia (NH3), Nitrogen oxides (NOx), Sulphur dioxide (SO2), Non-methane volatile organic compounds (NMVOCs). The strategy includes focused measures to decrease Ammonia emissions from digestate spreading (currently 3% UK ammonia emissions) and increase stringency of emissions limits for combustion facilities.

The Government Food Strategy – Defra (2022)
The strategy includes plans to bolster resilience of critical inputs such as carbon dioxide (CO2) and fertiliser. This will include a specific long-term plan on CO2 in 2022 and a focus on pioneering more organic-based fertilisers, to ensure continued certainty and availability for all inputs which underpin food production, which biosolids / bioresources could support. The strategy sets out changes to the ways that farming is practiced, and farmland used. Some farmland will be repurposed or adapted for environmental projects (e.g., woodland / peatland creation, carbon sequestration). The most productive areas of farmland will be retained for agricultural use with a focus on maximising efficiency and productivity.

5.6 Multi-criteria analysis

The multi-criteria assessment (MCA) was performed on the basis of the criteria outlined in **Section 5.5**, the results of which are shown in **Figure 21**. Each strategy assessed was given a red / amber / green score against each area of consideration. This was a high level assessment, with green indicating a strategy would support the driver, amber meaning it is uncertain, red meaning that the driver is unlikely to be supported. This analysis shows that the strategies most aligned with industry drivers are thermal conversion and agriculture-food, followed by resource production and finally incineration.

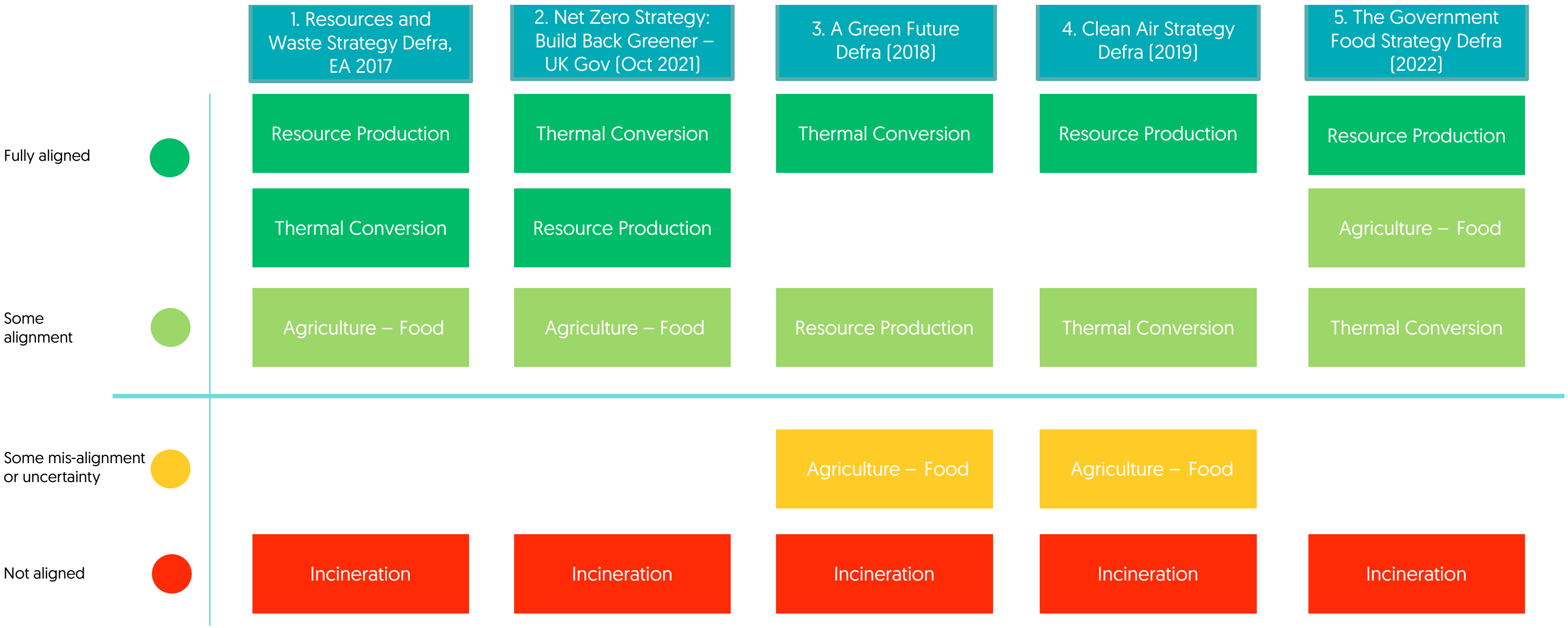
Figure 21 – Multi-criteria assessment of each strategy

	Thermal Conversion	Agriculture – Food	Resource Production	Incineration
Adaptability	Systems are / can be modular so can accommodate maintenance outage. Processes can be modified to prioritise different outputs or manage deviations in feed. Technologies used can be applicable to other pathways.	No significant change from existing asset-base, so could be modified to deploy an alternative strategy, or to sustain the route. Moving to each of the alternative candidate strategies is not constrained.	Different resources can be prioritised, though this may require changes in technology (such as extraction of organic carbon based resources upstream of incineration or thermal conversion). There are multiple market avenues available for potential outputs.	Large asset investment with minimal potential to adapt once deployed. Incineration solutions are aligned with quantity and quality of biosolids or sewage sludge feed. Deviations for example due to further upfront resource recovery will impact the solution.
Resilience	A resilient strategy, there is flexibility in terms of the outputs (biochar, bio-oil, syngas) and there are multiple outlet options available – spreading the risk across multiple outlet markets from a single technology rather than having to build distinct sites (e.g., AAD on one site, Incineration on another)	The risk to the outlet will not be mitigated, alternative products may be required to compete for greater land utilisation (reducing inorganic fertiliser use) – emerging risks not mitigated.	Low resilience to loss of outlet due to specific resource or product specification - with alignment of technology to output and market. Some resources will have internal outlets, however, where this is more controllable.	For annual maintenance shutdown requirements, contingency for sewage sludge or biosolids must be available. Incineration requires large facilities for economies of scale, the standby requirements would therefore be at a greater scale and WaSCs would likely have to share redundant capacity.
Deliverability	The system is modular, however, uncertainty in the water sector regarding utilisation remains. Technologies are available, and mature in some cases, mainly at small-scale and still require trial at full-scale in the UK. Technologies seem to be predominantly supplied by smaller organisations, therefore supply chain issues may prevail if there is a large scale shift across the sector.	This is the status quo – minimum change required. Deliverability is high. Adaptation of product deliverability, for example to a pelletised output (to minimise storage or aid development of a bespoke product to compete with inorganic fertilisers) is high as technology and application globally exists.	Likely to be limited to reductive (reduced biosolids production) resource production initially – technology and market readiness ranges significantly. Deployment at scale maybe difficult due being supplied by smaller / limited suppliers.	Significant investment in incineration across all WaSC's will lead to potential issues of supply in the market and there could be barriers in terms of achieving planning consent – reducing deliverability within a reasonable timeframe. Finding sufficient available sites to deploy may also be problematic.
Deployability	Uncertainty regarding operating models, outputs, outlets, markets and regulatory frameworks remain. Further R&D is required to enable implementation.	Numerous assets deployed enable operational flexibility, having pursued this strategy to retain the agricultural outlet, alternative products can be deployed from this starting point.	Dependent on resources recovered - markets and internal use-cases are yet to be established and the quality requirements for a range of outputs / products are not yet defined.	Technology is well-established and ready to deploy. Known to the UK sector.
Risk mitigation	Reduces risks regarding emerging pollutants and significantly reduces residual solid output – outputs can be used as fuel for the system if no other markets are available.	This is the status quo – risks around emerging pollutants / outlet certainty would not be reduced, with residual vulnerability to changes in public perception.	Likely to reduce the quantity of output, and so requirement for outlet but still some output to manage (back-end process required).	Strategy would greatly minimise risks regarding emerging pollutants and certainty of outlet.
Cost to implement at full scale	Modular in nature so lower investment potentially required than incineration.	This is the status quo – minimal change and therefore cost to implement.	Dependent on resources recovered and technologies deployed.	Large-scale investment for new facilities and higher ongoing Opex.
Environmental impact	Potential for carbon sequestration. More energy generated to displace fossil fuel requirement. Greater destruction of pollutants compared with agricultural route (treatment by AD).	Lower carbon emissions, but greater ammonia emissions. Potential for soils to benefit from valuable nutrients, but diffuse and micropollutant pollution concerns (e.g., PFAS / microplastics).	Opportunities for better environmental outcomes depending on resources recovered. Potential to displace carbon intensive raw materials and capture carbon.	Highest associated emissions and disposal requirement remain. Potential to mitigate emissions e.g., through carbon capture.
Aligned with UK policy	Aligned with decarbonisation goals - bioenergy production for hard-to-decarbonise sectors – and lower emissions compared to incineration with potential for carbon sequestration. Higher destruction of pollutants compared with agricultural route (treatment by AD) to support ecosystem health.	Lower emissions route, though less long-term carbon sequestration potential. Potential to contribute valuable nutrients to land, but issues around pollutants for ecosystem health. Minimum residual waste.	Contributes to maximisation of resource productivity. Resource recovery can support decarbonisation (e.g., through carbon capture, usage and storage). Potential issues around pollutants for ecosystem health, though dependent on applications.	Not well aligned with aims regarding decarbonisation, resource productivity or healthy ecosystems, although there may be opportunities to recover energy and mitigate emissions e.g., through heat recovery / carbon capture and storage to reduce misalignment.

5.7 Strategy alignment with UK policy

The alignment of strategies with crosscutting UK policy (themes – maximising of resource productivity, decarbonisation and healthy ecosystems) is further depicted below in **Figure 22**. The policy alignment highlighted resource production and thermal conversion as the two strategic pathways most aligned to the policy framework narrative, followed by agriculture – food which has some uncertainty regarding management of contaminants to land / water and emissions, and finally the least aligned across the entire policy framework being incineration.

Figure 22 – Strategies alignment with UK policy



5.8 Stress testing and future scenarios

Medium-term stress testing

Stress testing is an essential component of determining any corporate strategy. The stress testing process aims to illustrate whether there is inherent adaptability and resilience within each strategy, or whether there are specific risks that need to be mitigated, monitored or accounted for when a company decides upon implementation. Not all the tests below have equal probability of occurrence, and the answer to many of them will evolve and change as a result of research and development in the technologies employed, the expected outputs and markets. No one strategy passes every stress test, it is important for companies to select the pathway that they determine will result in the least regrets investment, based on their risk appetites for each element. The stress tests are focused upon the shorter timeframe for strategy implementation. The stress tests are described below in **Figure 23.**

Figure 23 – Tactical stress test assessment criteria

Air quality restrictions

The test is a measure of how each strategy would cope in the event of a further tightening of emission standards, whether those be emissions from the process itself, or from any stockpiles / storage of biosolids or other outputs.

Energy market movements

The test is a measure of the impact from energy price fluctuations in regard to the process itself or on compensation basis or reductive basis to the wider water sector if prices significantly increase or value reduces.

Carbon

The test is a measure of the impact from the carbon accounting methodology for calculating a WaSC's footprint for bioresources. It assesses the impact of it changing in a way that is adverse for each strategy as a risk, for example in price review determinations / for carbon tax accrual.

Product market movements

The test is a measure of the impact from outputs and / or end-product exposure to global markets, the desirability, demand or value of the outputs and / or products.

Landbank constriction

The test is a measure of the impact to a given strategy from further or catastrophic loss of the agricultural outlet from tightening regulatory requirements (for example the Chemicals policy), societal acceptance reduction or lack of demand from end users due to competing demand and / or general increase in competition from adjacent sectors.

Future scenarios stress testing

Future scenarios will be even more complex than we can truly plan for, but it is possible to gauge probable stresses, required transformation and pace at a high-level. Unpredicted and unplanned events such as global pandemics can dramatically and unexpectedly impact a course of action, sending it off at a tangent compared to the original destination. The impact of Covid, as an example, is a true test to resilience, speed of change and particularly financial backing. Future scenario projections made by industry bodies for different sectors were reviewed, with the applicable elements used to create the Atkins future worlds scenarios and test the responsiveness of the strategies. These are detailed in **Figure 24**. Each of these plausible scenarios face the challenges of transition with the existing asset-base and the regulatory investment cycle in which the UK water sector operates.

Legislation with conflicting aims could see the industry in conundrums and simply opting for 'the lesser of two evils' when making strategic decisions without a framework. Key examples include:

Zero sewer overflows – with more flow passing to works it also carries with it increasing grit, organic load and pollutants. An opportunity for further resource recovery will be a challenge with such a variation in flow, a greater number of detention tanks within a catchment creating older sewage leading to septicity and lower volatile solids.

Landbank availability – could drive an increase in the installation of incinerators, however, this has a negative impact on atmospheric emissions as well as carbon footprint due to the need to import natural gas when the system is not able to achieve autothermic conditions.

Figure 24 – Tactical stress test assessment criteria

Future scenario 1: Circular Economy

UK self sufficiency is achieved using Circular Economy principles. Organisations are incentivised to recover resources from wastes.

A greater shift in mindset and societal acceptance of utilisation of resources from waste to generate products, compared to mining from raw materials. Circular Economy principles are enshrined in legislation, enhancing product viability and end of waste routes. Resource recovery is embedded across the wastewater and bioresources flow sheet and source control measures have increased. Energy, resources and fertilisers are expensive and affected by supply chain delays. The UK has evolved to be self sufficient for its fertiliser and energy needs, with supply chain constraints meaning inorganic fertiliser consumption has decreased. Only by 'closing the loop' and ensuring one entity's waste is another's resource, can adaptability to this future scenario be achieved.

Future scenario 2: Enhanced Environmental Protection

This future sees a tightening of environmental standards to be met by UK water companies.

Air, water and land emissions are lowered and new parameters added, such as tighter limits on fluorine compounds. Further restrictions are applied to nutrient management in the environment and new risks have been identified in wastewater and biosolids which are of concern to health and the environment. Greater source control of contaminants and more intensive treatment within the wastewater process to achieve removal of organic pollutants and remove more phosphorous and nitrogen from discharges are implemented. Air quality and greenhouse gas emissions are carefully monitored and reported as the impact from the wider wastewater process to atmospheric pollution is understood. Thus introducing further complexity to the treatment processes deployed, impacting biosolids quality and quantities.

Future scenario 3: Climate Change

The impact of climate change is dramatic and highly disruptive to water industry practices.

Weather patterns are more dramatic, with careful water management and recycling becoming standard practice. Agriculture requires irrigation in summer and water is managed within the catchment during flood events. Greywater is the new alternative potable water for all industry. In an effort to reduce carbon footprint, the UK achieves carbon neutrality with biogenic energy increasingly desirable as a renewable base-load for the self sufficient UK energy system. The UK water sector runs zero carbon operations which includes Scope 1, 2 and 3 and direct emissions from biogenic sources. Investment is driven by carbon and natural capital accounting principles. The industry is measured by its carbon footprint and has carbon limits set for delivery of service.

Future scenario 4: Commercialisation

Bioresources management facilities are operated physically separated from the wastewater treatment works rather than just via accounting separation.

Since PR19 and the separate price control for bioresources there has been a drive to opening up the market. In this future bioresources is a fully commercial operation. No longer would WaSCs be able to partially fund this operation from customer bills and thus a fully commercial operation would need to operate purely on a gate fee approach. Sewage sludge is managed with other organics wastes to maximise the potential revenue streams, leveraging benefits from synergies in the waste streams incorporated and economies of scale for treatment and resource recovery processes. Significant focus will be placed on poor quality or contaminated sludge, as this will likely be penalised. Significant variations in asset-base are unlikely due to short term return on investment business cases driving interventions. Innovation will be driven by efficiency.

5.9 Pathway alignment with stress testing

The strategies were assessed against their ability to adapt and mitigate stresses both in the medium and longer term to provide greater investment certainty in a changing world. Strategies which are not adaptable can lead to regrettable short term solutions and abortive spend and thus form closed routes within the adaptive pathway framework. The candidate strategies' alignment with the defined medium and long term stresses are described in **Figure 25** below.

The medium-term stress tests highlighted a slight advantage to resource production, thermal conversion and agriculture – food to have the greatest potential to mitigate risk, with incineration being highlighted as having a high potential to mitigate the risk of landbank constriction. In the longer term 'future scenarios' stress test, incineration was the least adaptive in most futures. The strategies with the greatest potential to mitigate risk in the long term, aligning with future worlds, policy narrative were again thermal conversion and resource production.

Incineration

Significant process emissions from using incineration as a primary method of disposal result in high process emissions that would be a significant risk in the Air Quality Restrictions and Carbon medium-term risks, alongside also hindering adaption to the future scenarios on Enhanced Environmental Protection and Climate Change. This could be partially offset by mitigation measures however e.g., carbon capture and storage. There are also benefits to this approach in the lack of exposure to product market movements due to not relying on this outlet, alongside an uncoupling from the agricultural outlet meaning that any constrictions on land availability are no longer a significant stressor.

Thermal Conversion

The use of ATC technologies to convert sewage sludge into other products such as chars, oils and syngas means that there is a significant lowering of landbank reliance and so any issues with this outlet have reduced impact. The blend of output product types mean that there is exposure to movements in those markets. These products however are a significant driver behind the carbon sequestration benefits seen in the results of both the medium-term carbon test, and the long term alignment to the majority of future scenarios tested.

Agriculture – Food

The reliance on application of biosolids to land results in high risks for this approach around the availability of landbank and the impacts of the future scenario of enhanced environmental protection. The role that this strategy plays in the recycling of nutrients back into productive use, does, however, give it overall a slight benefit to all other stress tests used. This gives a circular economy, carbon / climate change and self sufficiency benefit by offsetting inorganic fertiliser usage, alongside lower process emissions than strategies such as incineration.

Resource Production

The reliance of resource production as a core bioresources strategy has risks in terms of the exposure to fluctuations in product markets. All markets have inherent risks to them, but the diversification of the end-products produced in this strategy would be a way of mitigating this risk, as would having multiple use-cases including internal use by a WaSC. This strategy performs well in terms of circularity, lower reliance on landbank and producing carbon positive products that can assist in mitigating climate change impacts.

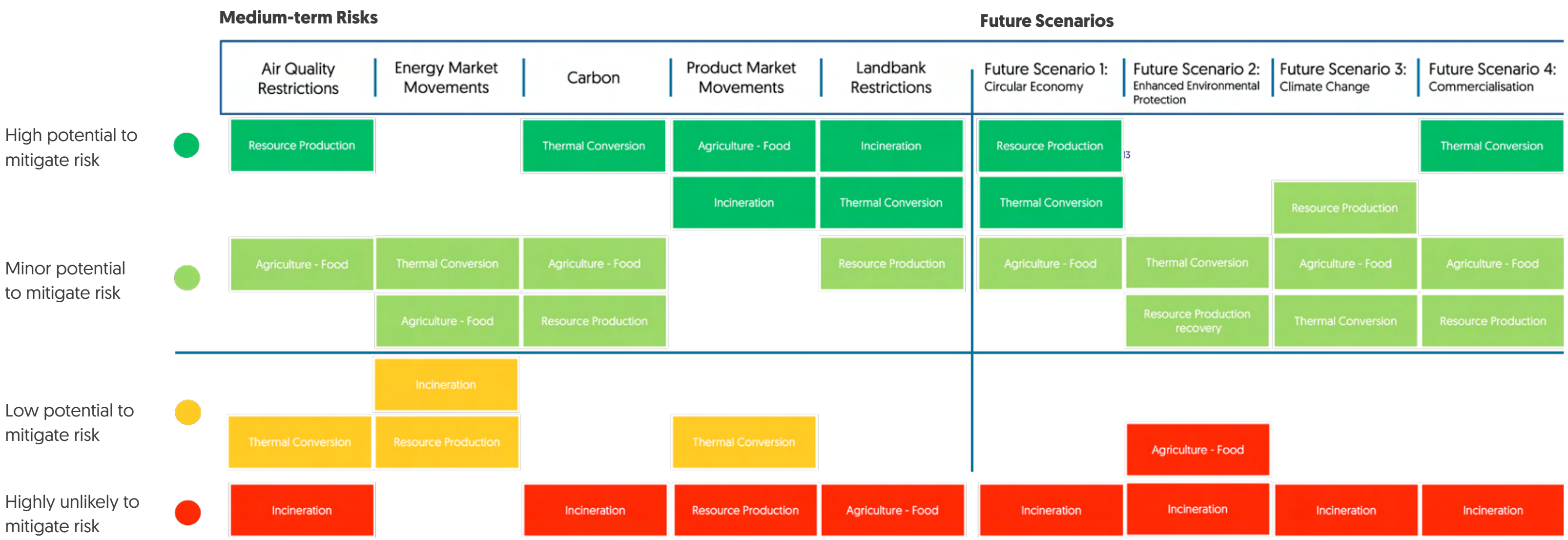


Figure 25 – Stress testing outcomes for medium and long term

5.10 Summary of Work Package 3

To summarise the results of the assessments undertaken, those candidate strategies which were best aligned to the UK policy narrative and more adaptable to potential future scenarios are as follows:

- Thermal Conversion
- Resource Production
- Agriculture – Food

The thermal conversion and resource production strategies are likely to become more viable in the shorter term once there is:

Further understanding regarding their implementation, operating models and the desired outputs.

- Greater certainty regarding their impact upon emerging risks and the fate of these in varying operating systems. For example, an increased understanding of the availability of contaminants to the environment from new outputs (e.g., hydro-char, biochar) when utilised in the agricultural sector or other outlets (e.g., construction, road surfaces etc.).
- Greater understanding regarding the fate of carbon across the processes, in the outputs and the environment.
- Increased understanding of the outlets, market demand and specification requirements for these new outputs.
- Clarity regarding the regulatory framework under which the strategies will be managed and how emerging risks will be legislated.

The recovery to agriculture – food strategy has previously been considered Best Practicable Environmental Option in most circumstances and scored in the top three across all assessments as shown in **Figure 26**. However, due to uncertainty regarding the impacts of potential policy changes on emerging contaminants, and in the nearer-term outlet availability due to nutrient management, this pathway is less aligned as we move into the future. The emissions from the land application of biosolids were the main reason the recovery to agriculture – food was not a high scoring strategy in policy alignment, and this would need assessment in detail, including mitigation measures in order to be able to score this more accurately.

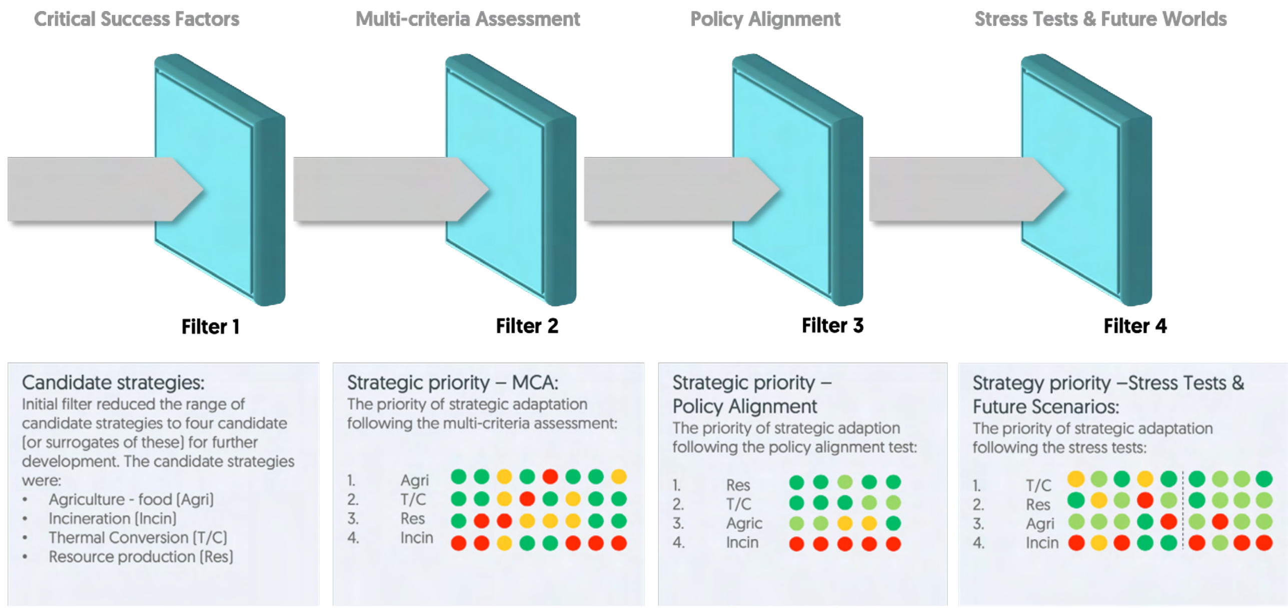


Figure 26 – Overall summary of the prioritisation assessments (based on Figures 17, 21, 22, 25)

Continuation of the agricultural strategy will require greater source control, removal of contaminants from the wastewater treatment process (to protect sewage sludge quality), limited impact on application rates from any controls applied to emerging contaminants and the potential for more bespoke products to be developed to provide a competitive alternative to inorganic fertilisers as seen elsewhere, for example in the USA.

Incineration strategies appear to provide immediate certainty of investment, as they are better known to the sector and are perceived to mitigate the current concerns regarding land deterioration and emerging risks. Incineration strategies have, however, limited alignment with UK policy and sustainability drivers. They are expensive to implement, may have greater impact on the environment than alternatives, and be extremely difficult to deploy at scale across the entirety of the UK water sector in a reasonable timeframe. In addition, uncertainty remains regarding the fate of emerging risks, for incineration strategies, such as 'forever chemicals' (e.g., PFAS).

6 Work Package 4: Adaptive pathway and route-map

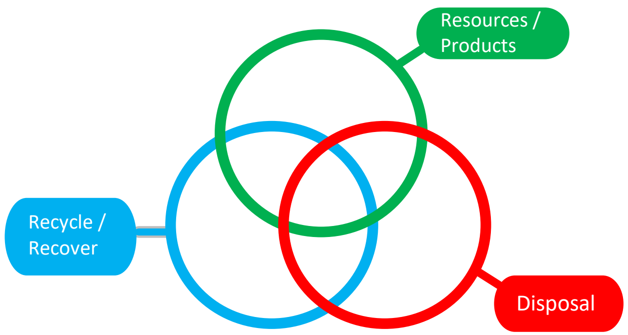
6.1 Development of the adaptive pathways framework

The four strategic pathways (incineration, thermal conversion, agriculture-food and resource production) formed the basis of the adaptive pathways depicted on the route-map and discussed in this section.

Adaptive pathways provide a sequence of decisions over time to achieve a set or pre-specified objectives under uncertain, changing conditions. The adaptive pathways used in the route-map have been developed as per the methodology in **Figure 28**. This is to highlight key decision points for WaSCs, and where these would take place within the price review mechanism.

The route-map demonstrates the complexity and diversity of options available for bioresources management, by blending the strategies detailed previously in this document. The interactions and connections between pathways are highlighted, whether from full or partial deployment to recognise the range of 'mixed strategies' available to reduce risks attributed to a single solution, output or market. The route-map uses a series of Venn diagrams to depict the blend of outputs arising from each strategy: these are routes and end-points based on the current knowledge of the technologies employed. The varying sizes of each circle denote their emphasis on biosolids disposal / recovery to land / resource production. These are depicted in **Figure 27**. The key steps on the route-map are discussed in detail in this section.

Figure 27 – The Venn diagram used in the route-map



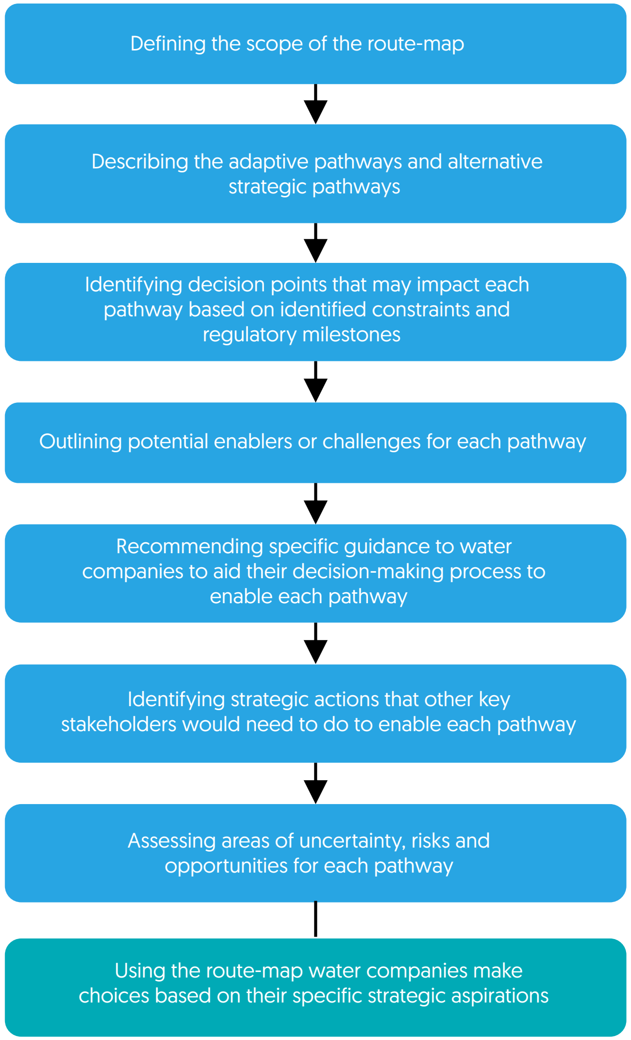
When using the route-map, WaSCs must consider their starting position, risk appetite, ambition and ability to create new sustainable and resilient markets. Each decision point on the route-map results in a change in the treatment processes employed and therefore the outputs generated. It is noteworthy to highlight that the path taken may close or reduce the potential for other paths to be enacted, for example a move towards incineration will limit the ability to enable thermal conversion and up-stream resource production.

The route-map, alongside the relevant narrative around pursuing each strategy which is provided in this section, gives insight into the key considerations in each strategic change of direction. Key policy, targets and events are defined within the route-map and aligned against each pathway. This has enabled the identification of the timescales any research and development gaps need to be closed by for a coherent decision-making timeline. In the case of all strategies, activities will be required to enhance understanding of technologies, outputs, markets and to support regulatory understanding of the end-products in question. Whilst there are regulatory frameworks available, many are not tailored to new technologies coming to the fore (e.g., advanced thermal conversion technology) and this would benefit from resolution in order to progress towards different solutions and expedite outcome benefits. This will need to be developed in parallel with the associated outlet-markets and the technologies employed.

The adaptive pathway framework is not a single bioresources strategy but an aid to be used by WaSCs in conjunction with their own strategy development mechanisms when determining when to invest, what strategic direction to take and to determine what priority is needed for resolution of the gaps in understanding to aid these decisions.

The route-map is available in full in **Appendix A**, this section of the report provides narrative and detail around the individual steps and routes that can be taken within it.

Figure 28 – Flowchart of the route-map development



6.2 Route-map decisions on incineration

Overview

Incineration becomes more attractive when combined with the uncertainty surrounding the continued recovery of biosolids to land and the potential for new contaminant limits (in addition to existing nutrient controls) which may constrain the agriculture outlet to such an extent to be unable to accommodate the entirety of UK's biosolids production, especially at certain times of the year. This pathway is very dependent on the lead-in time, planning requirements and approvals associated with deployment of such large-scale disposal installations (**Figure 29**). The Environment Act air quality targets in 2040, and potential for a moratorium on EfW development, also impact on this pathway. Residual ash would require management, current common outlets are assumed to be viable (construction or landfill).

What WaSCs need to do to enable this pathway:

- Early adoption to facilitate for planning timetable and mitigate risk in a timely manner.
- Investigate the potential to collaborate with other WaSCs / third parties on new facilities – fewer, larger incinerators might be more cost effective and deployable within a realistic timeframe.
- Discuss the potential for a National Infrastructure programme with the regulator to reduce the scale of deployment.
- Customer engagement to manage societal impacts of deployment.
- Ensure compliance with BAT / BREF updates and associated investment to meet / future proof against new air quality targets.
- Gain understanding of the fate of PFAS and other organic contaminants following incineration and a need to pursue recovery solutions where possible for the residuals (i.e., ash / air pollution control residues).
- Confirmation of sustainable and resilient outlets for the outputs produced.
- Further exploration of EfW capacity, ascertainment of gate fees, changes to permitting requirements, design changes to EfW facilities, and specifications for incoming sludge required.

Regulatory or policy implications:

- Largescale adoption of waste incineration goes against the waste hierarchy and circular economy aspirations the UK has previously championed – movement towards incineration for bioresources would require public perception management due to a potential negative response from stakeholders.
- Government to confirm their intent following their review of England's "planned" EfW capacity. Given that historically the government has focused on residual (solid) waste only, proactive engagement with the water sector on this topic is necessary.
- In relation to 'end of waste' status for recovered resources from ash, this can be procured through the definition of waste service. However, requests are site specific, and it can take up to 18 months to complete an assessment to form an opinion. Adapting this process to allow a Resource Recovery Framework or Quality Protocol (QP) for ash to be developed would aid this pathway.

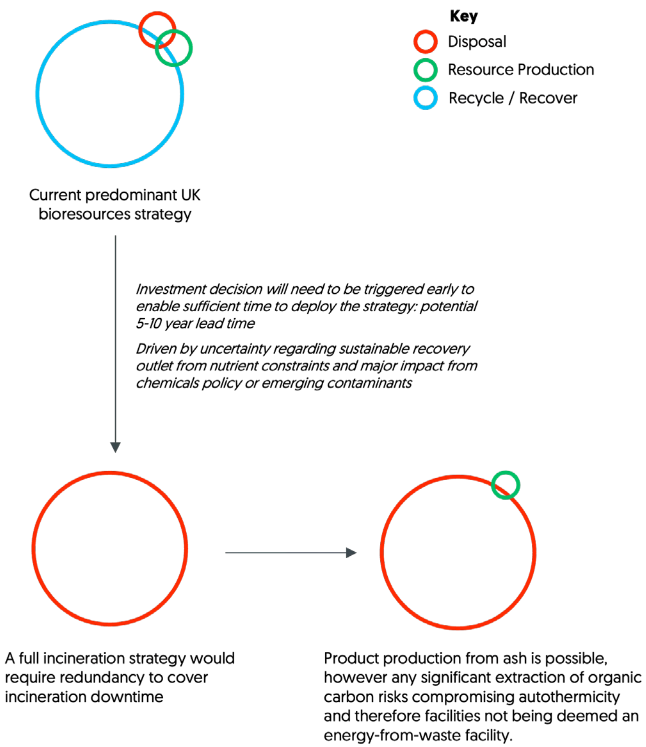
Areas of uncertainty:

- The regulatory timeline has shown that there is still much uncertainty around the approach to emerging contaminants because of the delayed new Chemicals Strategy and the Environment Agency / HSE Regulatory Management Options analysis for PFAS and the potential for investigations or limits for PFAS and other contaminants.
- Air quality Environment Act targets e.g., the 2040 annual mean concentration of fine particulate matter (PM2.5) and the outcome of the government's review of England's planned EfW capacity, following the Welsh and Scottish moratoria on any future large scale EfW developments could also impact on this pathway.
- The fate of contaminants, such as PFAS, in the flue gas and ash once incinerated requires further analysis, including the impacts of any daughter chemical species created as a result of this process.

Risks and opportunities:

- Appears to provide immediate certainty of investment, as incineration is known to the sector and are perceived to mitigate the immediate concerns regarding land deterioration and emerging risks.
- There is limited alignment with UK Policy and sustainability drivers, being lower on the waste hierarchy than other options.
- Constrained by limited existing municipal solid waste incinerators currently able to accept sewage sludge as a feedstock, so would require changes to permitting arrangements or new builds[1].

Figure 29 – Incineration decisions on the route-map



1: ADAS & Cranfield, An assessment and evaluation of the loss of the biosolids-to-agricultural-land recycling outlet, 23 March 2022

6.3 Route-map decisions on thermal conversion

Overview

The thermal conversion pathway provides a possible solution to emerging contaminants and opens more outlet options as varying technologies and operating models have the potential to produce a range of outputs. The technology is utilised within the waste sector and the number of facilities managing biosolids is growing globally, as are the number of technology providers. The technology currently lends itself to modular deployment – opening the potential for both centralised and de-centralised solutions. The pathway can also be aligned with resource production (Figure 30) as is depicted in the route-map.

What WaSCs need to do to enable this pathway:

- There is a need to understand thermal conversion outputs, operations, markets for outputs, integration within existing treatment works and the fate of contaminants within the process and outputs.
- The economic and operating models need assessment to understand the optimal use of this technology in terms of the balance between small modular units when compared to larger hub sites.

Regulatory or policy implications:

- The need for a clear picture of the priorities for energy / fuels from sewage sludge was highlighted in the first engagement workshop, which is particularly applicable to thermal conversion adoption.
- Feedback from some stakeholders indicated that there is a perceived detriment in being the first to invest in new technology as it was thought these might lead to 'lumpy investment' profiles that could skew historic investment profiles. This may act as a disincentive to more innovative technologies, and so may need addressing or revisiting.

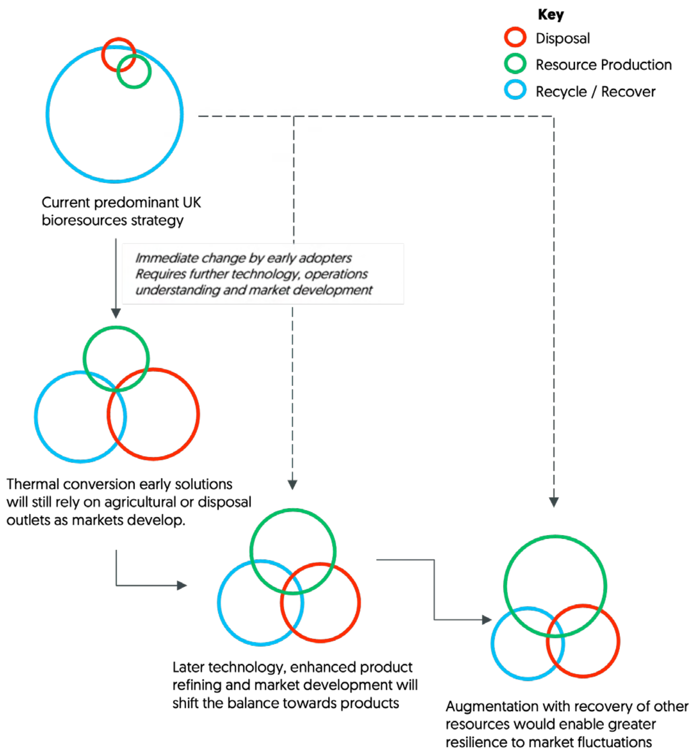
Areas of uncertainty:

- The regulatory timeline has shown that there is still much uncertainty around the approach to emerging contaminants because of the delayed new Chemicals Strategy and the Environment Agency / HSE Regulatory Management Options analysis for PFAS and the potential for investigations or limits for PFAS and other contaminants.
- Alternative biosolids products for agriculture (e.g., pellets) will not impact emerging contaminant concentrations, therefore, there is a need to understand thermal conversion routes and the fate of these contaminants.
- The use-cases of the outputs of thermal conversion are as-yet unproven in the UK, and therefore there is no established off-take route or an existing product with UK End-of-Waste accreditation.
- Other Environment Act targets such as those for air quality i.e., the 2040 annual mean concentration of fine particulate matter ($PM_{2.5}$) and the outcome of the government's review of England's planned EfW capacity, following the Welsh and Scottish moratoria on any future large-scale EfW developments could also impact on this pathway.
- There is an expectation that the National Infrastructure Assessment will be published in 2023 by the National Infrastructure Commission with a recommendation to decommission the natural gas grid or convert to hydrogen transport by 2050.

Risks and opportunities:

- This pathway has the benefit that it can be pursued in conjunction with a 'recovery (to agriculture)' or 'resource production' pathway.
- Where hydrogen production is concerned, there are concerns around the safety implications and lack of necessary infrastructure to exploit the opportunity.
- As sources of sustainable biomass become scarcer due to waste minimisation strategies, sewage sludge may become a critical source of biomethane to support 'hard-to-decarbonise' areas.

Figure 30 – Thermal conversion decisions on the route-map



6.4 Route-map decisions on recovery to agriculture – food

Overview

This pathway is currently the predominately used strategy in England and has been considered Best Practicable Environmental Option in most circumstances. The challenges facing this strategic pathway are restrictions on uptake from the agricultural outlet due to nutrient management in the near-term, and further concerns regarding upcoming policy implementation (e.g., the Chemicals Strategy and soil health). The ability to utilise this strategy in the future will depend not only upon the level of regulatory impact but also the ability to develop a product with ease of storage and greater competitive advantage to offset inorganic fertiliser use in the agricultural sector.

What WaSCs need to do to enable this pathway:

- Consider alternative outputs such as pellets and organo-mineral fertilisers to improve uptake of biosolids derived products, although this would likely not circumvent fundamental challenges around the quality of biosolids. Work closely on this through the Biosolids Assurance Scheme with the National Farmers Union, Red Tractor and other consumer groups to achieve confidence in the product, reduce societal concerns and produce bespoke products aligned to the farming sector's fertiliser needs.
- Develop further understanding (e.g., Chemicals Investigation Programme) of the fate of organic contaminants from the application of biosolids to agriculture. Understand the environmental starting-point regarding the existing impact of these contaminants on soil where no biosolids has been applied.
- Develop technology to remove contaminants of concern from the wastewater treatment process, reducing or removing them from all sewage sludge (primary and secondary) and final effluent outputs, alongside working with the Regulators regarding greater source control.

Regulatory or policy implications:

- Provide certainty regarding the likely limits attributed to emerging risks of concern.
- Champion source control for future policy and legislation to protect the value within biosolids.
- Collaborate with other regions where policy has been developed around PFAS and microplastics.

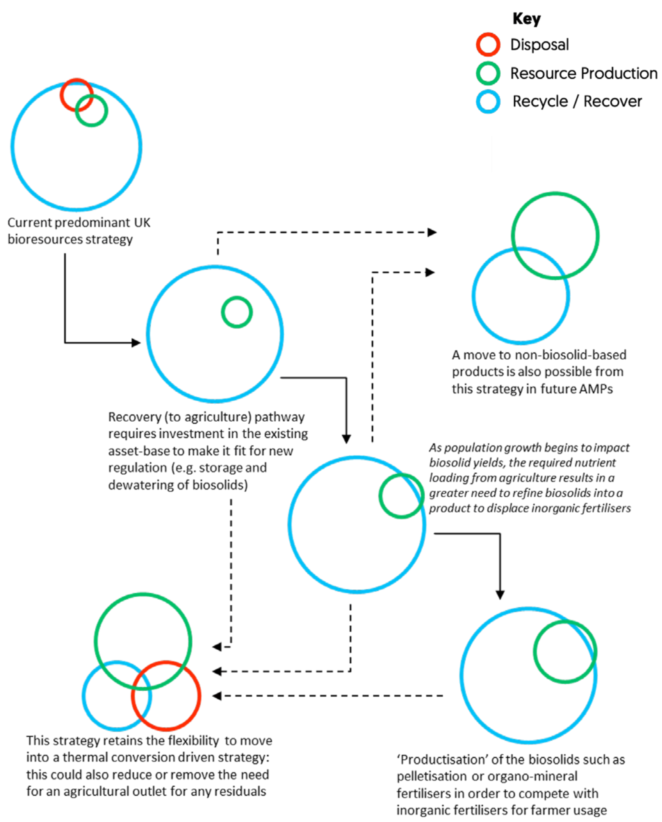
Areas of uncertainty:

- The regulatory timeline has shown that there is still much uncertainty around the approach to emerging contaminants because of the delayed new Chemicals Strategy, the House of Commons Environment, Food and Rural Affairs Committee Inquiry into soil health and the Environment Agency / HSE Regulatory Management Options analysis for PFAS and the potential for investigations or limits for PFAS and other contaminants. This clearly has the potential to impact on this pathway as the water industry remains unsighted as to the content of these.
- The Environment Agency allocation and determination time for a new standard rules permits; bespoke permits and deployments need to be borne in mind for moving from Sludge (Use in Agriculture) Regulations to Environmental Permitting Regime as this will impact operational flexibility of the current pathway.
- The 2037 Environment Act target of reduced nitrogen and phosphorous to the water environment will increase volumes of sludge and impact on land recycling, again impacting on this strategy.

Risks and opportunities:

- Further impacts from contaminants considered of concern.
- Societal acceptance of biosolids utilisation in food production.
- Support for the farming sector in reducing its carbon impact and assisting the drive towards self sufficiency and use of organic alternatives to inorganic fertiliser use.
- Future scrutiny on the ammonia emissions from organic fertiliser usage.

Figure 31 – Agriculture-food decisions on the route-map



6.5 Route-map decisions on resource production

Overview

The resource production strategic pathway can either be focused upon a reductive approach, reducing the residual biosolids requiring management, aligned with one of the other adaptive pathways or, over time, be a primary route as more resources and / or products are developed. The pathway is currently limited by technology readiness to deploy and the maturity of markets, specifications, regulations and potentially societal acceptance of outputs / products. Current technologies however mean there will remain a solid residual (biochar, ash, biosolids) that requires management.

What WaSCs need to do to enable this pathway:

- Develop understanding of the integration of technologies, their combinations and interactions as a batch of processes (compatibility between resources recovered is a key understanding requirement) and make decisions regarding which resources / products they will focus upon recovering / developing. Pooling trial data would support WaSCs in navigating the range of options available.
- Defining and developing market interest and provision of end use clarity will assist WaSC in determining whether End-of-Waste status is required.
- Working on developing a waste reuse hierarchy, for example reuse within facilities to enhance treatment, aid self sufficiency and minimise carbon impacts of the sector, aligned with resource (platform chemical production) and product development will assist in definition of the implementation of the pathway and links to other adaptive pathways.

Regulatory or policy Implications:

- Unlike other countries, there are no current direct incentives / targets or regulatory obligations for resource recovery (e.g., by making a certain percentage of recovery mandatory) from sewage sludge / sewage treatment.
- Transparency and certainty around regulation supports innovation. At this current time concerns exist around the uptake of emerging technologies where there could be permitting risks. Given the vast array of recovery technologies available (see Section 4.5), WaSCs should consider pooling trial data to support any cases to change the operational permitting approach.
- In relation to 'end of waste' status for resource production, it is recognised that there is the definition of waste service. However, the end of waste request is site specific, and this process can take up to 18 months to complete an assessment to form an opinion. Adapting this process to allow a Resource Recovery Framework or QPs to be developed would aid this pathway.
- The EA Sustainable Sludge Strategy could enable treatment of all organic material derived from sewage sludge to agriculture (e.g., biosolids, biochar) to consistent standards to support this pathway.

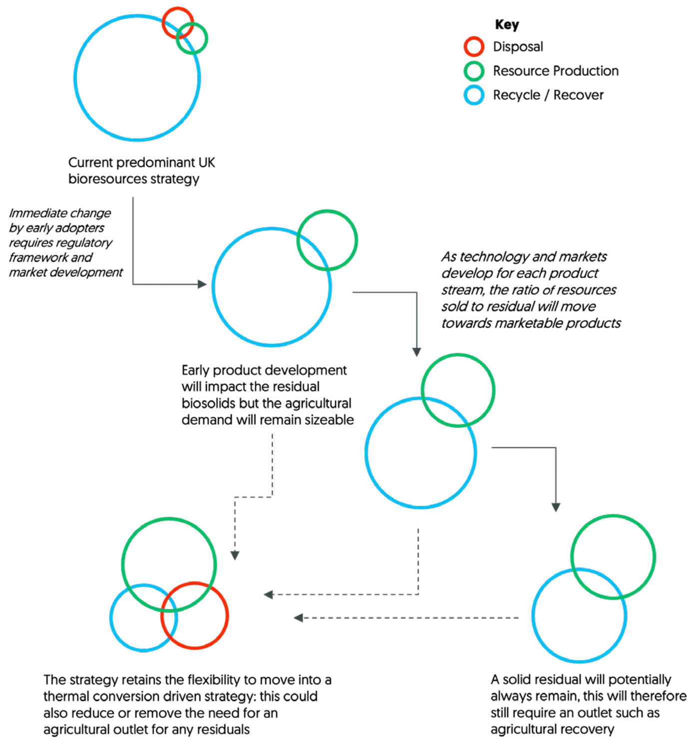
Areas of uncertainty:

- There is a regulatory framework for sewage sludge derived outputs, however, this is less developed for novel outputs and the process could be refined to enable innovation. The policy framework highlights clear opportunities for resource recovery from wastewater and biosolids to support national aims, although these are not clearly prioritised to provide direction for investment.
- Specifications and / or regulatory frameworks for resources (used internally), platform resources for development of products within industry or as products for utilisation by the market, require development.
- The combination and compatibility of technologies to deliver the ideal range of outputs.
- The fate of contaminants within potential outputs and across the process.

Risks and opportunities:

- The strategy can form part of a wider UK resource / circular economy programme to aid self sufficiency / resilience.
- Uncertainty regarding market value and societal acceptance.
- Opportunity to reduce reliance on carbon intensive and in some cases finite raw materials.

Figure 32 – Resource production decisions on the route-map



7 Conclusions and recommendations

7.1 Conclusions

The work undertaken has highlighted that there are a range of potential pathways, but not one single 'ideal' strategy. This is due to the level of uncertainty regarding the regulatory framework, (specifically regarding emerging contaminants), the need for further research and development to improve the confidence in alternative strategies and the potential lead time to deploy. However, the route-map shows the multi-faceted options available to the industry and provides flexibility to tailor to an individual WaSC's circumstances. This limits individual companies' risk by providing multiple delivery options but will require the uncertainty currently surrounding the sector to be reduced over time for informed decisions to be made. This can only be done through collaboration and open discussions between regulators, the water companies and the stakeholders in bioresources management.

The direction of travel for the sector in England is following a similar pattern to global trends. Recovery of treated biosolids to agriculture is an embedded practice and is aligned to current government policy, however there are signs that consensus is shifting towards alternative outlets due to increased restrictions being discussed or implemented on nutrient management, emerging contaminants and air quality. It is important to ensure parallel policies / strategies are aligned for the best outcome to be achieved, this is particularly relevant for the forthcoming Defra Chemicals Strategy which could mean investment decisions made in the near-term have unintended long-term consequences.

Such clarity will assist English WaSCs in developing their strategies in alignment with their wider business objectives. There are opportunities for wastewater and bioresources approaches to planning (e.g., Drainage and Wastewater Management Plans) to be better aligned: this could provide benefits for product quality as sewage sludge / liquors pass between the two operating areas. This clarity is also critical as currently Ofwat assume the investment needs for any AMP are built upon certainty at the point of Price Review submission. There currently is a perceived detriment in being the first to invest in new technology, where the driver is a change in service standard. The initial investment to deploy a new technology may make that company appear inefficient when comparing totex spend in-AMP across companies as the investment may cost more than the modelled cost, potentially leading to 'lumpy investment' profiles; over the long-term initial versions of technologies are inherently less efficient and effective than subsequent versions. The latter point can leave a company locked into a less efficient asset-base than their peers in subsequent price reviews. This may act as a disincentive to more innovative technologies, with WaSCs adopting "fast-follower" status and no "early-adopters" leading the way. However, it is appreciated that "early-adopter" could lever greater market benefit (through higher incentives or markets incomes from a less competitive market) which may offset the inefficiency of the plant.

Incineration

- Immediate investment in incineration strategies will close off other strategies or make them incrementally more expensive / difficult to justify adaptation towards due to high asset value of the installations. This would mean lost opportunities for bioresources to help England achieve policy objectives on net zero, food security, circular economy and clean air.
- If all companies adopted the same technological option at the same time due to a common driver such as the Chemicals Policy, the scale of this could create a supply chain risk.
- The lead time required to immediately deploy an incineration strategy, due to activities such as site determination, planning approvals and construction, would require significant early start investment (as part of PR24 submission). Within England it is becoming increasingly difficult to obtain permissions with timescales in excess of five years.
- Incineration could be a solution to break down emerging chemical contaminants in sewage sludge, however their fate in flue gas is not well understood, including whether the outputs are more harmful than the original compounds.
- The water industry is opposed to any option that risks increased air quality issues so the potential for these must be fully understood.
- There is the potential for misalignment between England, Wales and Scotland e.g., the moratoria on new incineration facilities in Scotland and Wales.

Thermal conversion

- Thermal conversion is being considered globally as a potential alternative strategic approach, mainly for the mitigation of emerging contaminants of concern for example PFAS and micro-plastics.
- There are a range of technologies, operating models and potential outputs which can be used. Market desire, scale of demand and the regulatory framework for potential outputs is not fully understood to make an informed decision on the implementation of thermal conversion technologies in AMP8.
- If all companies adopted the same technological option at the same time (e.g., due to landbank availability), the scale of this could create a supply chain risk for the preferred solutions due to the scale of supply organisations. There is a significant range of technologies and providers in the market, however, the lowest cost solution may become a single supplier pinch point.
- The fate of emerging contaminants and their by-products of combustion in the flue gasses of thermal conversion is not well understood.
- There is a lack of regulatory / policy structure for sewage sludge derived outputs from the thermal conversion pathway distinct from the waste regulatory structure. Other countries are already developing regulations for this purpose which has enabled innovation and diversification in their bioresources sectors.

Recovery to agriculture – food

- Recovery to agriculture proved to have the highest alignment to the CSFs and scored highly in each of the strategic assessments. Without the uncertainty relating to forthcoming policy (e.g., Defra Chemicals Policy), this strategy would have scored higher, underlining the need for improved clarity of policy direction.
- The sector moving away from recovery to agriculture could result in a lowering of UK self sufficiency as the nutrient demands of agriculture are met instead by heavier use of imported inorganic fertilisers, depending on the alternative strategy chosen.
- Continuation of the recovery to agriculture strategy will require greater source control, and removal of contaminants from the wastewater treatment process (to protect sewage sludge quality). This may also require adaptation of the end outputs (e.g., production of pellets) to minimise storage requirements and impacts to soil / air / water quality.

Resource production

- This pathway is not a 'stand-alone' option and requires co-deployment with other pathways (such as agriculture or thermal conversion) as there is always an end residual that will require management.
- The development of supportive frameworks is required to provide parity with European policy provisions. Unlike other countries, there are no direct incentives / targets or regulatory obligations in the UK for resource recovery. For example, in Europe proposals to revise the EC Urban Wastewater Treatment Directive include incentivising the reuse / recovery of water, sewage sludge and phosphorus to realise circular economy benefits.
- This strategy could cause tension due to the Ofwat market reform model separating bioresources and wastewater activities. Some of the resource recovery opportunities within the wastewater processes mean consequential downstream adverse impacts on the bioresources assets. (e.g., less sewage sludge or less calorific value), which adds greater complexity for encouraging any new market entrants.
- There is a need for policy clarification of resource reuse across facilities, and ease of applying the End-of-Waste process to enable full circularity by maximising product utilisation. Product specifics will mean that in some cases remaining under a waste status may be simpler if the market will accept this.
- There is a lack of 'pull' from the end-users for resources recovered from wastewater. It will be difficult to build this without more definition around potential regulatory requirements, and the scale and quality of the products that can be produced.

7.2 Immediate next steps

The project makes a number of recommendations for WaSCs, regulators and other stakeholders. These form a five year plan to build towards PR29 inputs, enabling all regulators and companies to be aligned and informed in order to operate within the environment and economic planning frameworks. These are depicted in **Figure 33**: all of the items are required urgently in AMP7 as part of this preparation for PR29 but follow a logical order.

This project has marked a significant milestone for bioresources in England, whereby all regulators, stakeholders and the water companies have come together and collaborated on finding solutions to their short and long-term needs. This should be capitalised upon with the formation of a **National Bioresources Strategy Steering Group** including all these parties. This group would be the ongoing owners of ensuring this culture of communication and collaboration is maintained, and the next steps itemised in this report are delivered. The establishment of this programme of work, and the resources to deliver it would be this group's immediate priority. This group would consider how further engagement or public consultation could be undertaken to support the development of the strategy.

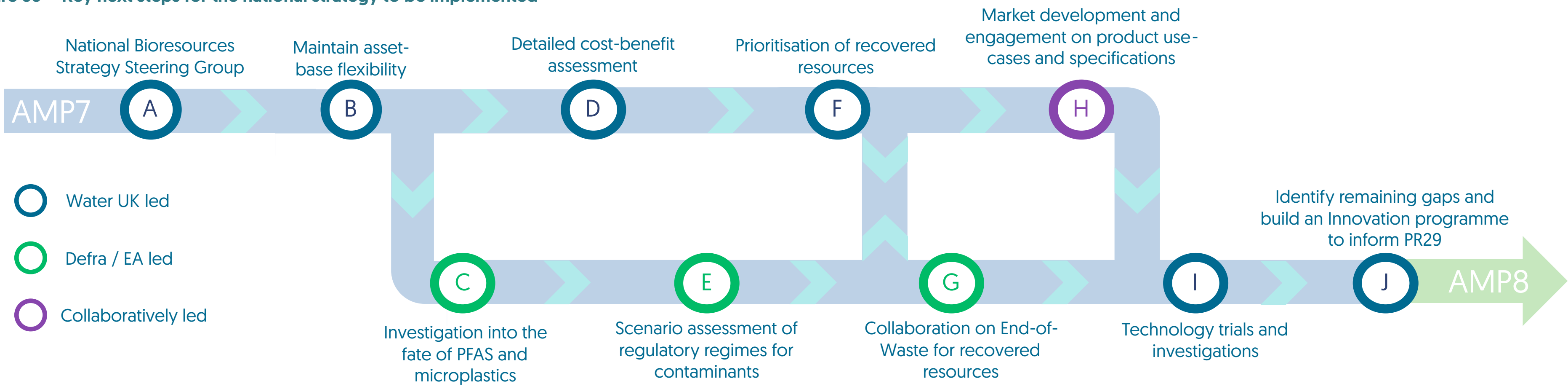
In the immediate term, the uncertainties around technological readiness and contaminant fates mean that England should look to **maintain asset-base flexibility** through the next price review cycle (PR24). The bioresources asset-base in England has evolved to be configured to maximise recovery to agriculture, which gives England enviable flexibility to move into any of the alternative strategies identified in this document. Capital commitments by the water industry in AMP8 (2025 – 2030) should focus on low-regrets investments that are common across strategies, deferring high-capital solutions (e.g., incineration) until there is more definition on the technologies available, and the optimal response to contaminants (e.g., PFAS, microplastics).

To reduce this uncertainty, **investigations into the fate of PFAS and microplastics** across the end-to-end bioresources system are required to identify the scale of the problem (e.g. the Chemicals Investigations Programme). This will require a full research programme to look at not only the technologies currently employed, but also any others used in other countries. This must be impartial and technology / product agnostic, rather than relying on technology providers themselves. There also needs to be **a scenario assessment of regulatory regimes for contaminants**, benchmarking against those employed in other countries in order to better understand the best approach for England.

Undertaking a **detailed cost-benefit assessment** of each strategy, alongside the water industry coming together with regulators, policy makers and stakeholders to agree a **prioritisation of recovered resources** are key steps. This will give both definition for water companies and new market entrants to build their own investment cases, alongside a clear direction for travel for England as a whole.

There is a need for a wider communication of the circular economy benefits from using recovered resources. This is common across all strategies and entails the sustainability and desirability of bioresources-derived products to be publicised and championed. This can be accelerated by **collaboration on End-of-Waste for recovered resources** so that companies can undertake the process together where this aligns with national policy goals (e.g., previous work on biomethane injection to the grid). The market development and engagement on product use-cases and specifications is important in justifying the usability of any such applications, alongside technology trials and investigations to prove that these are deliverable and practicable. The national bioresources strategy steering group owning these activities would then be best placed to consolidate this information, **identify any remaining gaps and build an innovation programme to inform PR29**.

Figure 33 – Key next steps for the national strategy to be implemented



7.3 Additional research and development needs

Alongside the completion of the next steps in **Section 7.2,** there will be uncertainties to be resolved that could significantly impact the sector and each of the strategies. The research needs identified in this section are a way of answering these uncertainties. This section should be reviewed, amended and updated by the National Bioresources Strategy Steering Group once it is formed. This group can profile the scale of research to be completed and the sequencing required to inform PR29 in-line with the next steps in **Figure 33**.

In order to collate this list and prioritise the key needs for the industry, a workshop on the future research and development needs of the sector was held in January 2023. The priority research questions coming out of the session were:

- How do we create a clear, unified framework for measuring environmental impact / benefit for new pathways, considering elements including Greenhouse Gas (GHG emissions) measurement and carbon accounting (including sequestration) for the industry?
- Could applying biosolids to land in a different form (such as activated sludge only, dried granules or pellets) mitigate against environmental risks (air quality, water quality, emerging contaminants)?
- How can we create a resource recovery framework for all materials recovered from a sewage sources, prioritise resources for England and lobby for incentives?

The general consensus from the workshop sessions was an emphasis on collaboration and organisations working together to resolve issues blocking progress. Building upon this, ideas put forward in the session were used as the basis for the initiatives identified in **Figure 34**.

There are multiple unanswered questions around the environmental impact of each of the technologies and outputs produced by the treatment technologies that would be used to implement the strategies that this report has identified as viable. Each has a very different profile of environmental impact on water, air and soil quality. These need a holistic assessment in order to quantify the balance of these and therefore enable a prioritisation.

The economic factors involved for each strategy are subject to different risks and opportunities. The key risk is that any novel technology or immature market exposure is likely to be seen as a risk for companies. The balance of financial drivers and market development is key for these technologies that produce resources to be viable options that benefit the wider environment and get England closer to a circular economy. Any research completed should look to give insight into consumer attitudes and preferences, alongside aiding the development of markets for bioresources-derived products in order to 'dial up the pull' from the market.

The regulatory framework governing any emerging technology and their outputs is often not as defined as for mature technology / outputs. England is not the first country to adopt technology such as thermal conversion or resource recovery, therefore there are multiple examples in other countries to be examined and critically assessed in order to make the right decision for England's unique drivers and direction of travel.

For many thermal conversion and resource recovery solutions, the technological readiness and proven ability to integrate into an English WwTW is not at a level where they are proven at scale and in the English operating environment. A collaborative approach is required where multiple technologies are trialled, with data shared. The range of options is sizeable, and therefore does not lend itself to companies pursuing this in isolation.

Figure 34 – Research needs identified and prioritised based on impacts on movements between strategies. These are annotated with the next-step they align to in Figure 33 using brackets

Thermal conversion

- Investigate the technological readiness and future potential of non-biochar forming ATC technologies.
- Research the different technical solutions for hydrogen production (methane cracking, syngas cleanup etc.) in preparation for the UK Govt. decision on the roles of methane vs hydrogen.
- Study to determine the regulatory framework of recovery of biochar in the agricultural market and other markets, and comparison with other countries to determine the best direction of travel for the UK.

Resource production

- Quantify the financial benefits of resource extraction followed by internal WaSC usage (e.g., Volatile Fatty Acid input to Biological Nutrient Removal, ammonia for energy production, hydrogen upgrading).
- Quantify the environmental benefits of product or resource generation from bioresources, with a particular focus on benefits of offsetting less-sustainable products.
- Focus groups and engagement with the wider public on the perception of sewage-derived resources, and how best to market and position these products.

Recovery to agriculture – food

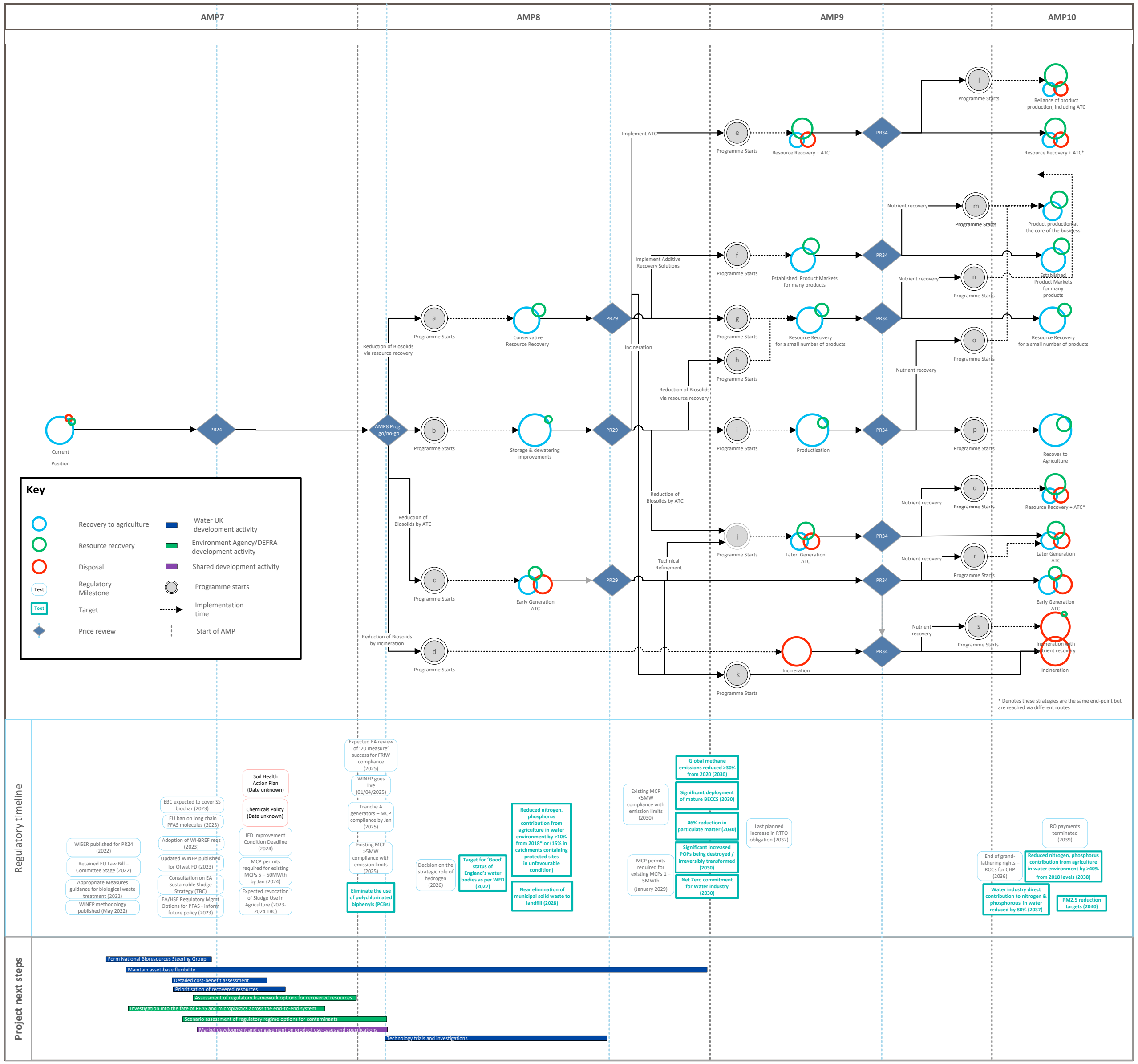
- Investigate and quantify the overall environmental and human health impact of emerging contaminants and pollutants from applying biosolids to agricultural land.

All strategies

- Assess the impact of concentrating heavy metals in the resulting ash or char produced by Incineration and thermal conversion, and the impact of this on outlet recovery options.
- Investigate how we move beyond government incentives and lower the market barriers to enable production based on cost-benefit to the producer (e.g., the move from wind power over the last decade).
- Quantify the GHG and air pollutants emissions associated with different strategies and product outputs. Stress testing scenarios with uncertainties for future carbon and GHG accounting rules.
- Review of bioresources and other organic waste regulations to get greater alignment and co-treatment potential, particularly for thermal treatment.

Appendices

Appendix A: Route map for the future



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Lucinda Gilfoyle	Water UK
Jo Harrison	United Utilities
Baroness Anne McIntosh (Chair)	Independent Chair
Diane Mitchell	National Farmers Union
David Tompkins	Aqua Enviro (now WSP) and representing Chartered Institute of Waste (CIWM)
Eugenia Vela	Ofwat
Helen Wakeham	Environment Agency
Alex Whitmarsh	Ofwat

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