SLUDGE MANAGEMENT: A RESEARCH STRATEGY TOWARDS INNOVATIVE AND SUSTAINABLE PRACTICES AND TECHNOLOGIES

F. Gouws, J.E. Burgess, C. Ramcharan-Kotze, S. Woolley

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Sludge Management:

A Research Strategy Towards Innovative and Sustainable Practices and Technologies

Report
to the Water Research Commission

by

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This is the final report of WRC project no. C2022/2023-01191.

This report forms part of a set of two reports. The other report is *Sludge Management: Understanding the current trends and advances in municipal sludge technology and innovative options related to sludge management* (WRC report no. 3178/1/24).

EXECUTIVE SUMMARY

BACKGROUND

The continuous advancement of sludge treatment processes is critical to municipal wastewater treatment operations and the healthy development of the sewage treatment industry. The last 30 years have shown a global diversification of sludge management, processing, and treatment technologies. Even though the three main treated sludge disposal routes are still dominant (i.e., land application, landfill, and stockpiling), new approaches are emerging that cover using sludge for recovering resources (hydrogen, biochar, nutrients) and energy.

The overarching aim of the project is to analyse the latest trends and advances in municipal wastewater sludge management research, development, and innovation. The associated research report (Gouws et al., 2024) covers shifts in technology, practice aligned to the climate agenda and related legislation, sludges as a resource, breakthrough innovations, and management processes. This report provides a high-level strategic pathway for research investment in wastewater sludge treatment.

RESEARCH STRATEGY HIGHLIGHTS

Based on the priority areas and challenges identified in the associated research report, a high-level research strategy was developed, encompassing short-, medium- and long-term key priority areas, spanning periods of two, five and ten years, respectively. The strategic outline is visually depicted below in Figure 1. The strategy was developed as a challenge statement for each priority area, with proposed research designs and methodologies outlined and success criteria and outputs recommended to guide the planning and implementation of sludge management and related research and innovation activities in the sector.

The strategic priority areas were developed and aligned in a nested structure, with shorter term priorities supporting the achievement of longer-term targets, as depicted. For instance, the development of regulatory frameworks for emerging sludge management technologies will expand market opportunities and guide skills development programmes in the longer term, which in turn will support the continued development of sound governance practices within the industry and build resilience to adapt to the evolving needs of the sector in coming years.

CONCLUDING REMARKS

This study has sought to understand current trends and recent advances in sludge management practices and technologies in the context of South African water treatment infrastructure. The research identified several key priority areas and laid out recent developments and progress towards more sustainable sludge management in the long term. In addition, the study also identified gaps in the research that require further attention, for which this high-level research strategy was developed.

However, it is worth emphasising that research and innovation in sludge management approaches and technologies is an active field of development and many of the challenges faced have solutions readily available. However, these are not easy to adopt due to institutional and regulatory barriers.

The strategy lays out a roadmap for future research in the field of sludge management. Yet, the findings from the research have elucidated the reality that more research will not move the needle substantially if technical solutions are not supported by application and scaling on the ground. An enabling regulatory and procurement environment is needed, and development of business models essential to ensure that the deployment deficit is addressed. This is important for further investment into the future of the water and wastewater sectors.

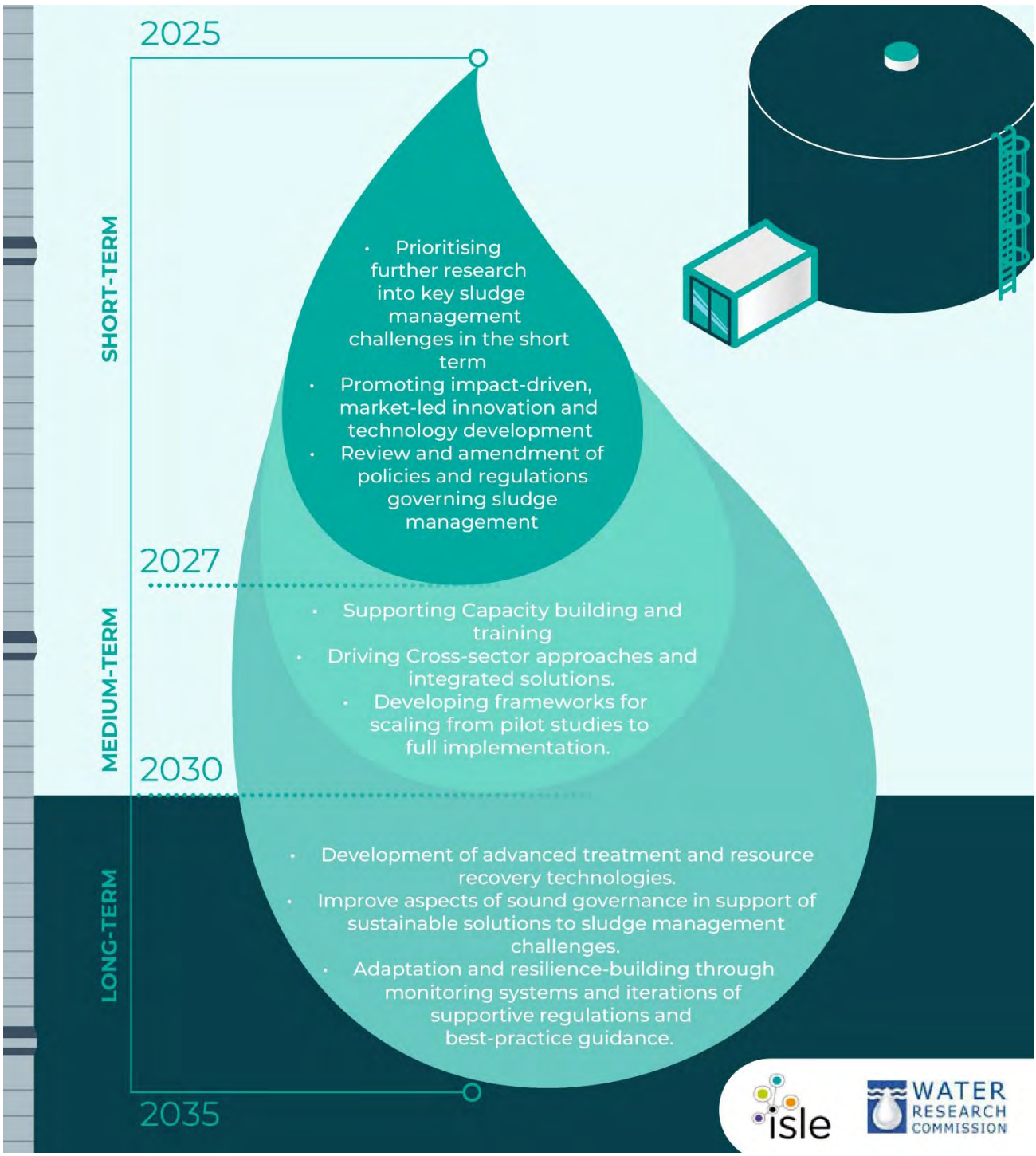

Figure 1. Strategy developed for targeted Research Funding towards Sludge Management Innovation

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Dr Linda Godfrey	Council for Scientific and Industrial Research

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ACRONYMS & ABBREVIATIONS

AD	Anaerobic Digestion
CEC	Contaminants of Emerging Concern
DEFF	Department of Environment, Forestry and Fisheries
DSI	Department of Science and Innovation
DWS	Department of Water and Sanitation
EDCs	Endocrine disrupting Compounds
FS	Faecal Sludge
FSM	Faecal Sludge Management
GHG	Greenhouse Gas
MFMA	Municipal Finance Management Act
NSIP	National Sanitation Implementation Plan
PFAS	Per- and polyfluoroalkyl substances
PFMA	Public Finance Management Act
PPCP	Plastic Particles, Pharmaceuticals and Personal Care Products
R&D	Research and Development
SASTEP	South African Sanitation Technology Enterprise Programme
SDGs	Sustainable Development Goals
SMME	Small, Micro and Medium Enterprises
WRC	Water Research Commission
WSA	Water Services Authority
WWTP	Wastewater Treatment Plant

GLOSSARY

Anaerobic Digestion. A biological process that breaks down organic matter in the absence of oxygen, often used to treat sewage sludge and other organic waste and produce biogas and digestate that can be reused or recycled back to environment.

Biogas. A renewable gas typically containing up to 60% of methane and is produced during the decomposition of organic matter, often in anaerobic digestion; can be used as energy source or be flared.

Black Soldier Fly Larvae. *Hermetia illucens.* Insect larvae used in waste management to convert organic waste into protein-rich biomass.

Climate Agenda. Policy related to climate change mitigation.

Co-Digestion. The process of combining different organic materials for anaerobic digestion to enhance biogas production. See also Anaerobic Digestion.

Decentralisation. The distribution of activities, organisations, or authority (of e.g., wastewater treatment and sanitation services) from one main group or body to several smaller, localised bodies.

Endocrine disrupting compounds. Compounds, usually organic molecules, which are known to exert an effect on the endocrine / hormonal systems of humans and animals.

Faecal Sludge. A mixture of human excreta, both solid and liquid, and water, often found in onsite/non-sewered sanitation systems.

Gasification. A process that converts organic materials into synthesis gas through high-temperature heating without combustion.

GHG Emissions. Greenhouse gas emissions including CO_2, CH_4, N_2O and industrial gases, which contribute to global warming and climate change.

Green Economy. An economy that aims to reduce environmental impact and promote sustainability.

Hydrodynamic Cavitation. The formation and collapse of vapour-filled cavities in a fluid under low pressure.

Just Transition. A socio-economic concept that aims to ensure a fair and equitable transition to a green economy.

Microplastics. Plastic particles smaller than 5 mm in diameter.

Municipal Waste. Solid and liquid waste generated in urban areas, typically consisting of household waste.

Non-Sewered Sanitation. Sanitation systems that do not rely on traditional combined sewer infrastructure.

Peri-Urban Area. The transitional zone between urban and rural areas.

PFAS. Per- and polyfluoroalkyl group of substances that are chemically stable and do not break down in the environment and bioaccumulate in living organisms. The impact of PFAS bioaccumulation on human and animal health is still poorly understood.

Pyrolysis. Thermal cracking of organic in the absence of oxygen at highly elevated temperatures; an endothermic reaction that converts organic materials into biochar, bio-oil, and gases.

Resource Recovery. The process of extracting valuable materials or energy from waste.

Rural Area. A sparsely populated region outside of towns and cities typically dominated by agriculture.

Sludge. A thick, semi-solid mixture of water and solid waste materials, often produced during wastewater treatment.

Sludge Dewatering. The process of removing water from sludge to reduce its volume.

Sludge Minimisation. Practices aimed at reducing the mass and volume of sludge produced during wastewater treatment.

Urban Area. A region characterised by high population density and extensive infrastructure.

Ventilated Improved Pit. A type of improved sanitation facility with a vertical vent pipe.

Waste Management. The collection, transportation, processing, disposal, and re-use/recycling of waste materials.

Wastewater Treatment. The process of removing contaminants from wastewater to make it safe for discharge or reuse.

CHAPTER 1: BACKGROUND

1.1 INTRODUCTION

The continuous advancement of sludge treatment processes is critical to municipal wastewater treatment operations and the healthy development of the sewage treatment industry. A global diversification of sludge management, processing, and treatment technologies has taken place over the past 30 years. Even though the three main treated sludge disposal routes are still dominant (i.e., land application, landfill, and stockpiling), new approaches are emerging that cover using sludge for recovering resources (hydrogen, biochar, nutrients).

With water and wastewater assets that will generate sludges for many years to come, there is a need to assess issues and trends around volume/pathogen reduction for cost and carbon footprint minimisation and maximise energy and resource recovery to fit into the wider water sector circular economy, resilience, and decarbonisation agenda. Additionally, increasing scrutiny on the sludge content and its role within the wider environment is putting more pressure on options related to the land recycling route. The further diversification of the sludge management strategy in terms of recycling/reuse and thermal treatment options will enable utilities to reduce risk should sludge use as a fertiliser on land be eliminated.

The overarching aim of the project was to analyse the latest trends and advancements in municipal wastewater sludge management research, development, and innovation. From the research conducted, this high-level strategic pathway for research investment in wastewater sludge treatment was developed.

1.2 PROJECT AIMS

The aims of the project were:

1. To review the literature of the latest trends in wastewater sludge management, research, development, and innovation.
2. To identify key issues, strategic trends, and priorities.
3. To develop a high-level research strategy responding to short, medium, and long-term issues identified.

1.3 SCOPE AND LIMITATIONS

This report encompasses the Research Strategy developed based on the findings of the associated research report.

CHAPTER 2: RESEARCH STRATEGY

2.1 INTRODUCTION

Sludge management forms a major component in the treatment of wastewater, sewage and industrial waste. If not managed properly, waste sludge has the potential to cause major environmental and public health challenges, from pollution of clean water sources to exposure to pathogens and hazardous material and beyond. In addition, the economic cost of poor sludge management exceeds that of effective treatment and disposal in the long term, primarily due to the aforementioned ecological and public health damage that poorly managed sludge causes.

It is therefore crucial to consider current and future barriers to effective sludge management. With sludge volumes set to increase as the population and industrial output grows, traditional sludge management practices like landfilling have become unfeasible, while other methods of sludge disposal, such as land application, have come under increased scrutiny in recent years, as the same environmental and human health considerations are focussed on the practice. These challenges require new and innovative approaches to address.

Indeed, sludge management practices in South Africa are undergoing significant changes as part of the water sector's drive to innovate and develop more sustainable solutions to challenges facing the sector today. In particular, the sector is moving away from considering sludge as a waste product and towards a more circular and sustainable approach by generating value from waste (DSI, 2022). This is also reflected in the recently released National Faecal Sludge Management Strategy by the Department of Water and Sanitation (DWS). The strategy emphasises the shift in focus as a key pillar in faecal sludge management, which is represented in the Circular Economy Diagram on the cover page, and supported throughout the strategy (DWS, 2023). These policy shifts, and others, such as the impending ban of organic waste disposal to landfill in the Western Cape, are a signal to the sector and to innovators to redouble their efforts in closing the Circular Economy loop. Even though the stricter Western Cape policy position could be extrapolated to the rest of South Africa, the national policy position has already encouraged the diversion of waste away from landfill as far as feasible, since the publication of the National Waste Management Strategy of 2020 (DEFF, 2020).

The trends and focus areas on sludge management were outlined in the associated research report (Gouws et al., 2024), which broadly grouped the reviewed research into six focus areas. These areas focus on the volume of sludge produced and how this can be reduced, the quality of produced sludge and how this can be improved for use or disposal, the management of faecal sludge in the context of South African sanitation, beneficiation of sludge and trends in innovation of both technologies and approaches to addressing sludge management within the current context.

The output targets of the reviewed research are broad, with considerations for greenhouse gas emissions reductions, economic sustainability and suitability for different markets, cost reduction and energy efficiency being apparent, while varying contracting models are also being tested to determine which models work best in different markets and scenarios. Digitisation and optimisation of processes, as is the case across industries currently, is being driven by a need for cost reduction and efficiency gains, while pressure to decarbonise and establish circular economies is driving innovation.

However, innovations and developments of sustainable approaches have presented several challenges and opportunities for future research, while other challenges are yet to be addressed thoroughly. These research gaps in sludge management were identified in previous chapters of this report. With an eye on the future of sludge management practices, it is critical to allocate resources for research and development to target the most pressing issues first, while planning for future innovation and development needs as well. In addition, South Africa's particular range of challenges would benefit from the deployment of both simple and advanced

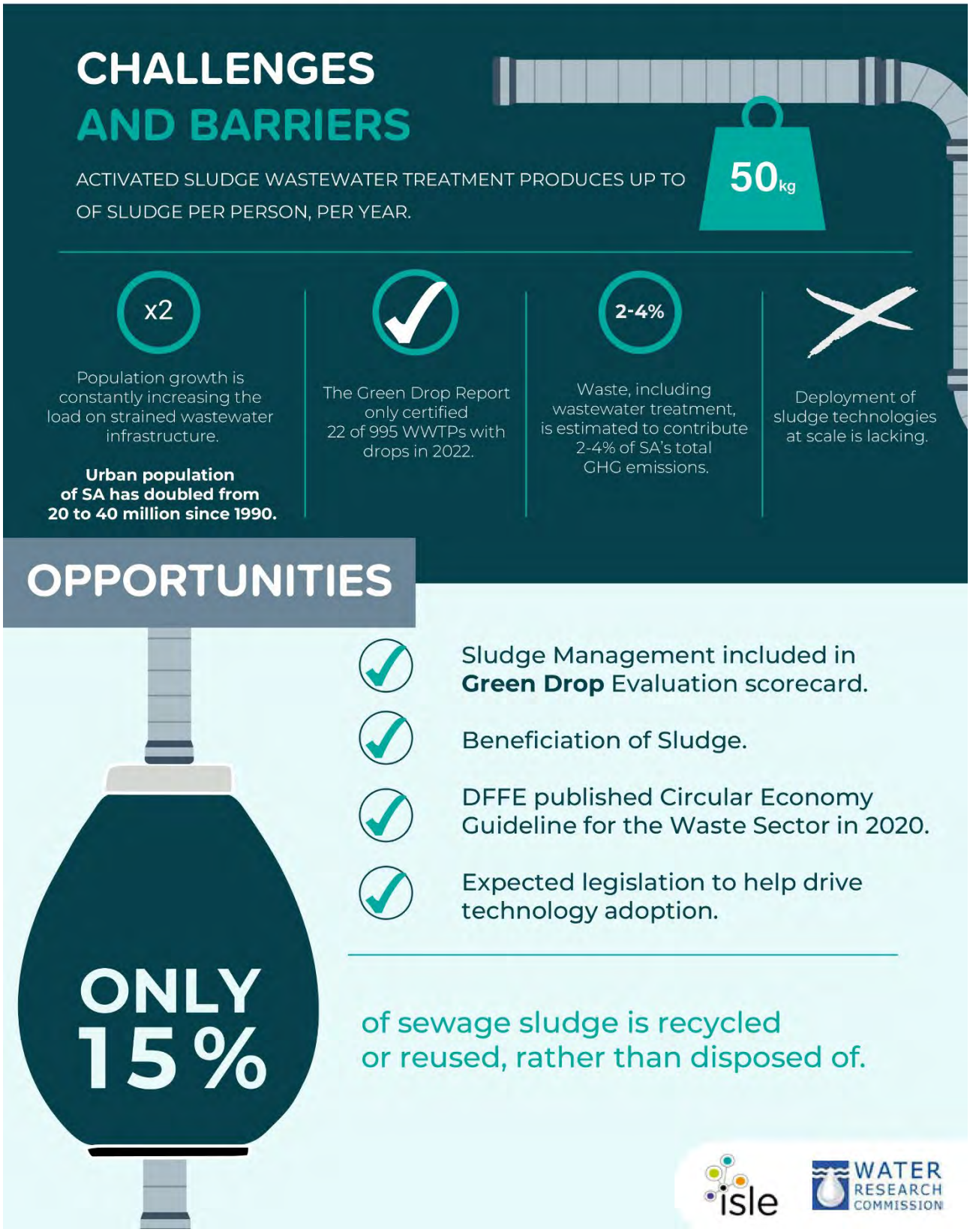
solutions. Some challenges may benefit from basic technologies, and allow for rapid and localised manufacturing, while others may demand more advanced systems to thoroughly address the challenge.

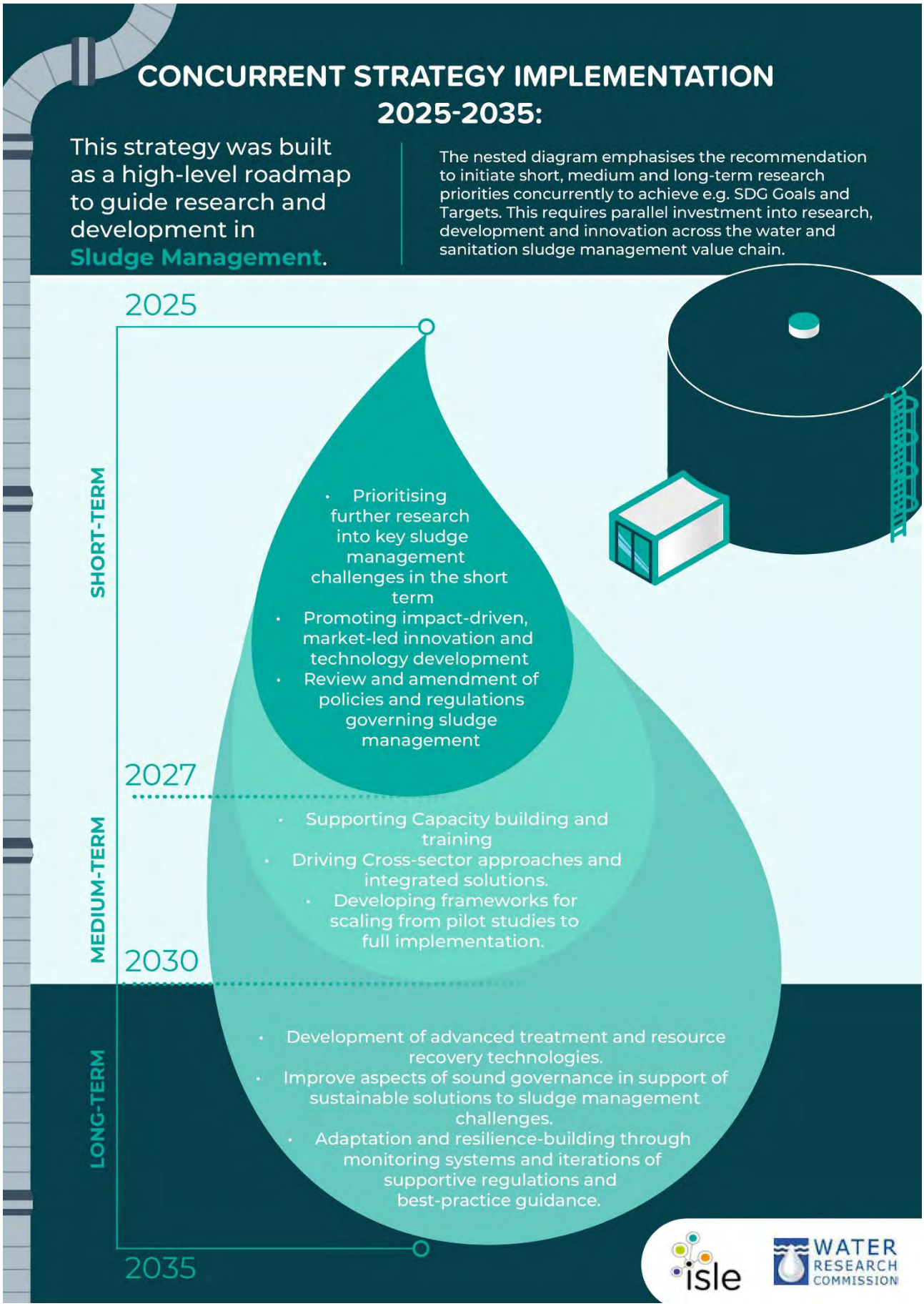
This chapter aims to package many of these challenges into a strategic framework to inform investment in research and innovation into sludge management practices, policies and technologies that will sustain this strive towards more sustainable sludge management in the coming years.

This strategy will encompass three priority areas each for the short, medium, and long term (i.e. the next two, five and ten years, respectively). The priority areas are structured with a chronological flow in mind, where progress in short term issues support and feed into the longer-term priorities (Figure 2).

It is worth noting that not all challenges require further research to address due to a variety of reasons. Some do not pose new questions for research to answer, since knowledge has been generated and solutions developed. The solutions are simply not implemented at scale at the time of publishing. Some of these challenges therefore do not fall within the scope of the research strategy since they have progressed beyond the mandate of the WRC and the research community. These will be summarised to indicate proposed future work to be undertaken but are not addressed in this strategy.

STRATEGIC ROADMAP - TRANSITIONING TO SUSTAINABLE SLUDGE MANAGEMENT




CONCURRENT STRATEGY IMPLEMENTATION 2025-2035:
This strategy was built as a high-level roadmap to guide research and development in Sludge Management.
The nested diagram emphasises the recommendation to initiate short, medium and long-term research priorities concurrently to achieve e.g. SDG Goals and Targets. This requires parallel investment into research, development and innovation across the water and sanitation sludge management value chain.
2025
SHORT-TERM
Prioritising further research into key sludge management challenges in the short term
Promoting impact-driven, market-led innovation and technology development
Review and amendment of policies and regulations governing sludge management
2027
MEDIUM-TERM
Supporting Capacity building and training
Driving Cross-sector approaches and integrated solutions.
Developing frameworks for scaling from pilot studies to full implementation.
2030
LONG-TERM
Development of advanced treatment and resource recovery technologies.
Improve aspects of sound governance in support of sustainable solutions to sludge management challenges.
Adaptation and resilience-building through monitoring systems and iterations of supportive regulations and best-practice guidance.
2035
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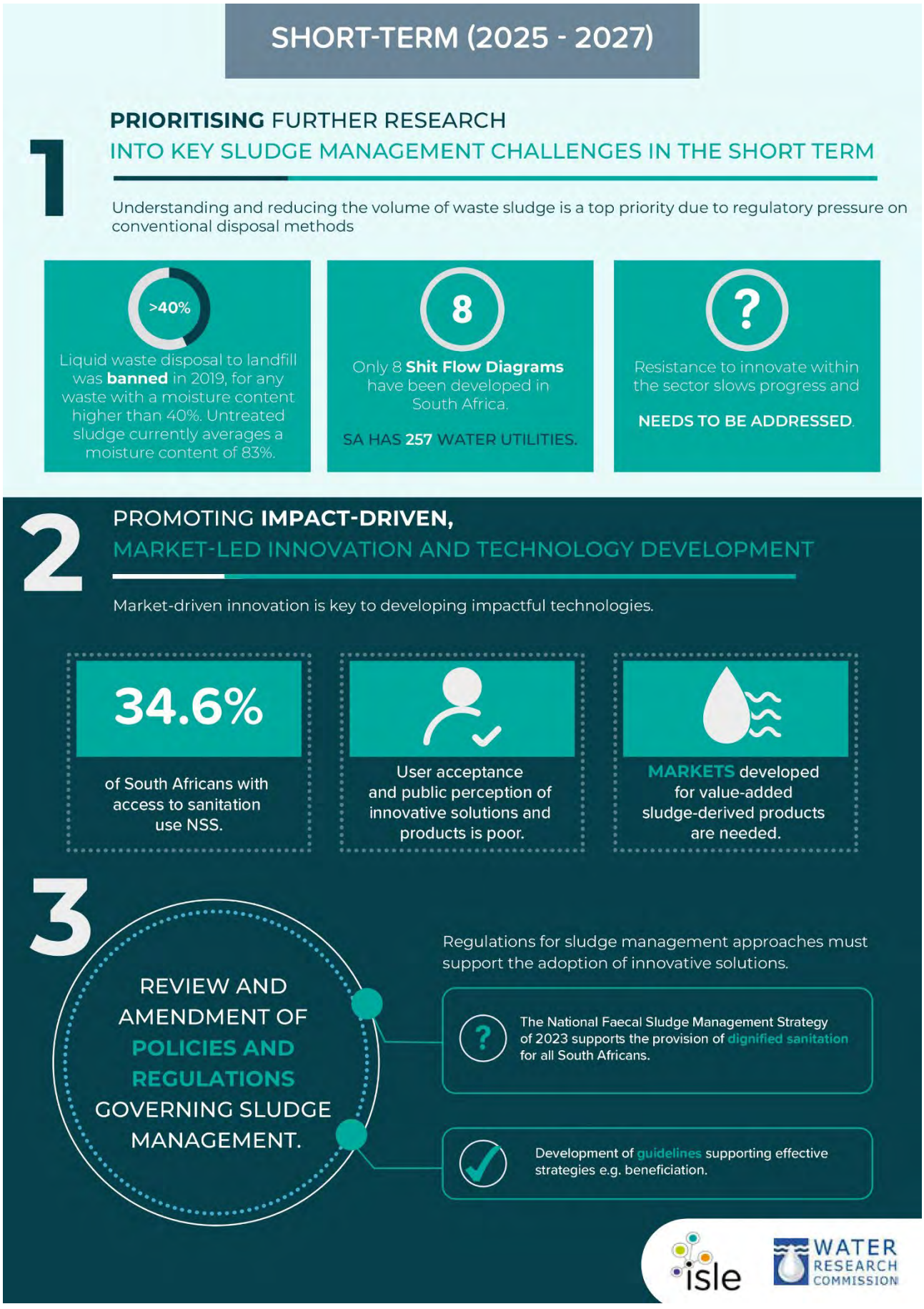
SHORT-TERM (2025 - 2027)
1
PRIORITISING FURTHER RESEARCH
INTO KEY SLUDGE MANAGEMENT CHALLENGES IN THE SHORT TERM
Understanding and reducing the volume of waste sludge is a top priority due to regulatory pressure on conventional disposal methods
>40%
Liquid waste disposal to landfill was banned in 2019, for any waste with a moisture content higher than 40%. Untreated sludge currently averages a moisture content of 83%.
8
Only 8 Shit Flow Diagrams have been developed in South Africa.
SA HAS 257 WATER UTILITIES.
?
Resistance to innovate within the sector slows progress and
NEEDS TO BE ADDRESSED.
2
PROMOTING IMPACT-DRIVEN,
MARKET-LED INNOVATION AND TECHNOLOGY DEVELOPMENT
Market-driven innovation is key to developing impactful technologies.
34.6%
of South Africans with access to sanitation use NSS.
User acceptance and public perception of innovative solutions and products is poor.
MARKETS developed for value-added sludge-derived products are needed.
3
REVIEW AND AMENDMENT OF POLICIES AND REGULATIONS GOVERNING SLUDGE MANAGEMENT.
Regulations for sludge management approaches must support the adoption of innovative solutions.
The National Faecal Sludge Management Strategy of 2023 supports the provision of dignified sanitation for all South Africans.
Development of guidelines supporting effective strategies e.g. beneficiation.
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MEDIUM-TERM (2025 - 2029)

1 SUPPORTING CAPACITY BUILDING AND **TRAINING**:

The sector grapples with skills shortages, which will only become worse if training does not keep apace with the adoption of novel technologies.

1 IN 3

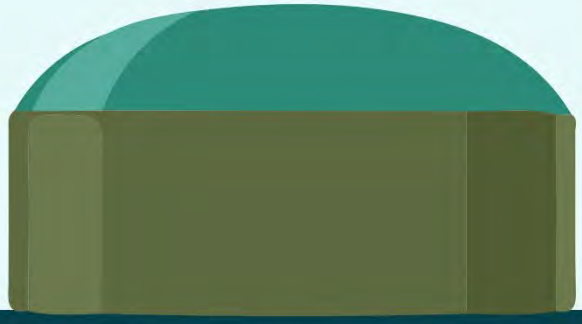
Water Services Authorities are considered dysfunctional, mainly due to a lack of capacity and expertise.

Both EWSETA and LGSETA provide training programmes.

WISA is implementing a professionalisation strategy for process controllers.

2 DRIVING CROSS-SECTOR APPROACHES AND **INTEGRATED** SOLUTIONS

Integration of waste management across sectors has emerged as a productive alternative to siloed waste management.



The Bioeconomy Strategy promotes the integration of waste management practices and the green economy.

WWTPs are embracing transitions to **WRRFs**.

Integrated wastewater and solid waste management have been conceptualised and studied.

3 DEVELOPING FRAMEWORKS FOR **SCALING** FROM PILOT STUDIES TO FULL IMPLEMENTATION

Planning and structuring of **scaled implementation** projects is required to actualise the benefits of developed technologies.

Case studies on developed and piloted technologies.

Feasibility studies for scaled implementation of innovative solutions are lacking.

Deployment strategies for innovative dewatering, AD pre-treatment and NSS solutions need to be developed.

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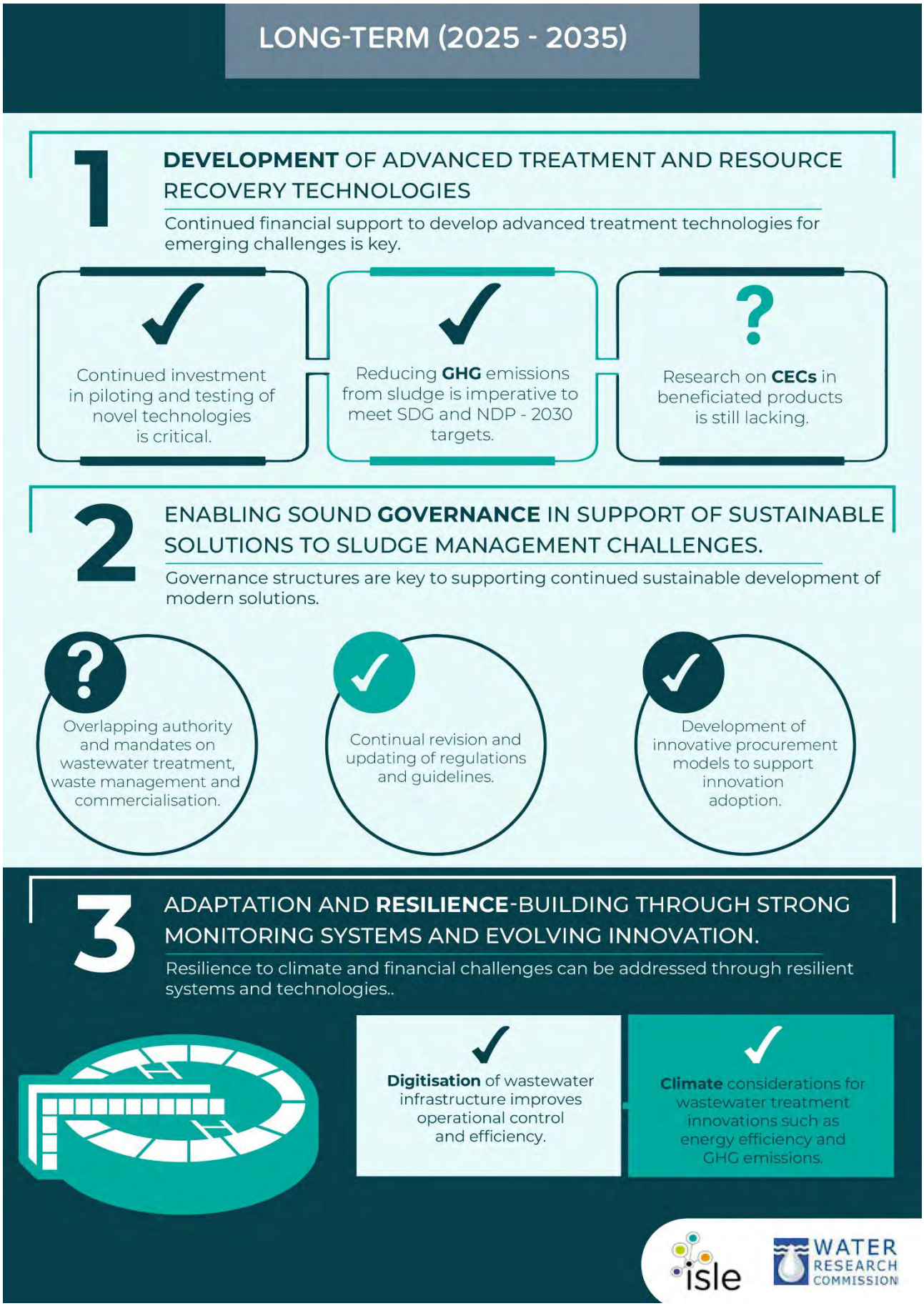


Figure 2. Infographic summary of the research strategy on sludge management innovation.

2.2 SHORT-TERM PRIORITIES (2025-2028)

The short-term priorities in the strategy aim to address the most pressing research gaps that can be addressed rapidly, with the intention of generating outputs that will dictate the more detailed approaches of the medium- and long-term priorities, while also paving the way for impact-driven innovation and adoption of sustainable solutions. The three priority areas are listed in Figure 3 on the left.

Figure 3. Short-Term Priorities of the Sludge Management Research Strategy.

2.2.1 Prioritisation of Key Sludge Management Challenges in the Short Term

2.2.1.1 Challenge Statement

The revival of the Green Drop Report by the DWS in 2021 has provided critically important information on the state of wastewater treatment systems in South Africa, including sludge management practices. In addition, the report has reported on the trends emanating from the sector in the recent past regarding sludge management practices. However, guidance on the prioritisation of sludge management is still lacking.

The most pressing challenge facing sludge management now is that of volume. The proposed ban of the sludge-to-landfill disposal route with policy and regulations supporting the phased banning of sludge landfilling in the coming years is already in place. This is exerting pressure on treatment facilities, who are resorting to stockpiling sludge on site. This requires a lot of space, generates Greenhouse Gases (GHG) emissions, contaminates water sources and is not a sustainable solution to addressing waste sludge in the long-term. Interim alternative strategies to address stockpiling are sorely needed in the short-term, while more sustainable solutions mature over the medium to long-term.

From a utility / water service authority perspective, the development of Sanitation Flow Diagrams (SFDs) are valuable tools for infrastructure planning and maintenance scheduling. However, the widespread development and use of this valuable tool is yet to be realised across South Africa, and in peri-urban and rural areas.

The water sector is a notoriously slow adopter of innovation and highly resistant to the change brought about by innovation. Wastewater treatment operators are concerned with implementing untested and unfamiliar processes when existing systems are not functional. This is a major barrier to adoption or even testing of novel treatment technologies. This extends beyond sludge management to the entire wastewater treatment sector.

2.2.1.2 Research Design

Understanding the challenges and benefits of different research methodologies, sludge management design, and the market-readiness of each solution can empower stakeholders to make informed decisions on which solutions best suit their use cases. This can be supported by developing side-by-side comparisons for specific handling, treatment, and beneficiation technologies, with prioritisation of technology readiness and market readiness.

To address the issue of sludge stockpiling, a side-by-side comparison of viable market-ready alternatives to sludge stockpiling, such as sludge volume reduction or beneficiation routes should be evaluated. In addition, the financial and regulatory pre-feasibility and feasibility of considered solutions require in-depth investigation, while the GHG emissions of stockpiling should be investigated further to strengthen the case for transitioning away from stockpiling. The timelines for transitioning from landfilling to stockpiling, to eventual alternatives is also required to plan for transitions and associated costs around such transitions.

Development of SFDs must be prioritised in the short term to support more informed decision making and planning for infrastructure development, deployment of novel solutions and capacity provision in wastewater treatment, as well as to support the development of emerging non-sewered sanitation technologies and value chains.

Understanding the reluctance of the sector to innovate and adopt novel approaches requires further investigation. Such research will enable researchers and technology developers to target the reluctance of the industry by addressing and allaying the concerns of their potential end-users. Additionally, a pivot within the sector to become more accepting of innovation is required to support the sector's Just Transition, which may be catalysed through research on the sector's reservations towards innovation.

2.2.1.3 Methodology

The prioritisation of sludge management techniques and technologies must be understood from the basis of thorough case studies, pre-feasibility and feasibility assessments that consider aspects of financial, technical, socio-economic, regulatory, and environmental suitability.

Environmental studies on sludge stockpiling practices, considering GHG emissions are required. Surveying landfill and stockpiling capacities for individual utilities and municipalities will empower these entities to develop strategies for transitioning away from landfilling and stockpiling of sludge, while providing market insights into the volumes of sludge available for beneficiation.

The methodology for SFD development was standardised by the Sustainable Sanitation Alliance (SuSanA) network on their digital SFD generation tool. Data on different sources of sludge collected from public records such as census data, Green Drop reports and surveys is gathered and fed into a digital tool to generate the SFD graphic and accompanying report. The challenge with generating SFDs is ensuring the accuracy and completeness of the datasets used to generate the graphics and reports.

To understand the reluctance of the sector to adopt innovation, participate in surveys and workshop/forums hosted to gather information, will support research into sectoral limitations and concerns. Further research designs should go beyond systemic reviews and desktop studies. Market readiness studies for specific technologies will also support and encourage the adoption of suitable innovations. Pilot studies have the power to tangibly highlight the regulatory and compliance barriers facing utilities.

2.2.1.4 Success Criteria

- Identification of market and utility relevant and financially viable alternatives to sludge stockpiling, with recommendations for suitability to guide decision making.
- Literature and market opportunity assessments on regional and national sludge stockpiling practices, with subsequent development of user/utility driven best practices for sludge management.
- Research published on GHG emissions of sludge stockpiling, building on the Green Drop audits and recommendations for aligned responses.
- SFDs have been developed for all municipalities, water service providers, and water service authorities in South Africa to support more efficient sludge management in future.

- Well-developed understanding of industry aversion to innovation adoption and strategies to address reluctance to adopt.

2.2.2 Technology, Innovation and Markets

Technology development and innovation is of paramount importance to solving the current challenges faced by the water sector pertaining to sludge management. New solutions and improvements to existing methodologies are required to address current challenges. A trend of sludge beneficiation becoming commonplace in sludge management strategies globally is evident and attests to the circular economy aspirations of the sector. However, the market for value-added products is still developing. Solutions that address the concerns of the market (most notably the public) require considerations in terms of health and environmental safety implications for sludge reuse and beneficiation.

2.2.2.1 Challenge Statement

One aspect that the analysis did not consider in-depth is the market or end-user component of sustainable innovation adoption. Understanding the barriers to adoption for non-sewered sanitation systems, sludge-derived products, and similar sludge management innovations with revenue potential in South Africa is an active field of investigation. Understanding the socio-economic challenges and public concerns within targeted communities and markets will guide further development of sludge technologies that acceptable and effective. This will also support the business case for waste valorisation and sanitation-as-a-service to attract funding and build a sustainable sludge-based market.

Based on the recently published National Faecal Sludge Management Strategy (DWS, 2023), the following challenges were identified, in conjunction with the findings of the literature study. Firstly, there is a lot of room for development and innovation in the non-sewered sanitation (NSS) field, with current solutions addressing some, but not all challenges associated with providing sanitation to communities with infrastructure challenges. One major challenge faced by NSS technologies and Faecal Sludge Management (FSM) more broadly is user acceptance and social licensing to operate, caused by a lack of paying customers to develop viable markets for sludge products, and poor investment in beneficiation approaches in the wastewater sector. International standards such as ISO 24521, 30500 and 31800 have been developed to provide guidance on tailoring solutions that address some of these challenges, yet effective and accepted deployment is still lacking. Understanding the challenges related to this lack of compliance should be explored. In addition, sustainability aspects regarding business development and job creation may enhance the success of NSS technologies in future.

2.2.2.2 Research Design

Although an active field of investigation, further research is required to understand the willingness of markets to purchase sludge-derived products and adopt NSS approaches to faecal sludge. Such engagements will serve to inform technology developers as to how their solutions can be improved and what challenges still require addressing, while involving the community in solution-driven projects that benefit them, engaging communities on the benefits of and processes involved in deployed solutions and ensuring the security and sustainability of the solution. This is particularly important in informal communities where communal solutions are the most viable approach. In addition, considerations for commercialisation, new service lines and small, micro and medium enterprises (SMME) development opportunities related to revenue generation, will be valuable to understand in terms of the sustainability of different sludge technologies and sludge-derived products, with an emphasis on local economic development.

Non-sewered sanitation and other technologies in the FSM value chain, as well as monitoring technologies, must enjoy continued support for further development and innovation. Development aimed at gender inclusive sanitation systems have been a priority for some time, and deserves continued attention, especially regarding safety considerations, enhancing the work done by the WRC's South African Sanitation Technology Enterprise Programme (SASTEP) (https://sastep.org.za/). Developing sustainable business models for NSS implementation should also be explored and potential opportunities for local economic development and job creation in the NSS sector must be prioritised to drive the shift in policy and regulation

2.2.2.3 Methodology

Research approaches include techno-economic assessments and business case development for emerging technologies and sludge derived products, for example investigating faecal sludge sanitation-as-a-service models, as well as market maturity assessments for such sludge-derived products and technologies.

Business case and financial viability assessments through financial modelling and feasibility studies will support the investigation of the sustainability of NSS solutions to address FSM challenges. Additionally, further development of emerging technologies, as well as design innovations in front-end systems guided by end-user input are needed to produce dignified and sustainable sanitation solutions and FSM value chains.

Developing markets for alternative use and beneficiation of sludge through the promotion of and support for resource recovery and the shift in focus towards how wastewater is considered socially will enable the adoption of and growth of markets for beneficiated sludge products.

2.2.2.4 Success Criteria

- Case studies / business cases and financial models for different sludge beneficiation and treatment technologies developed. Market maturity assessments completed for emerging technologies.
- Business models and feasibility studies on available FSM and NSS technologies. Further development of emerging technologies into viable alternatives to Ventilated Improved Pit latrines. Development and deployment of end user-oriented sanitation solutions.

2.2.3 Regulatory Framework

2.2.3.1 Challenge Statement

When considering sludge beneficiation, such as resource recovery, the regulatory landscape is difficult to navigate for service providers and public sector entities alike. Government also provides minimal incentives to support innovation in sludge management from the private sector, and regulations regarding the handling of sludge limit innovation. Minimal incentivisation and high investment requirements are two major barriers to adoption of sludge management technologies. For instance, regulations and government support for the adoption of anaerobic digestion (AD) sludge-to-energy schemes are lacking. Other examples of lacking regulations include protein and fertiliser production via Black Soldier Fly Larvae farming.

The recently released National FSM Strategy also paves the way for the implementation of decentralised or on-site sanitation systems. The FSM strategy requires the development of regulatory guidelines to support the sustainable deployment of such technologies. Other recent research (unpublished at time of writing, but shared in a stakeholder workshop) revealed that the sludge management guidelines and national legislation are misaligned, leading to water services authorities essentially breaking the law when adhering to the guidelines set forth by sector experts.

2.2.3.2 Research Design

Understanding the regulatory and legal framework through which resource recovery and sludge beneficiation should navigate will be beneficial to the adoption of beneficiation technologies.

Research regarding incentivisation of innovation and innovation adoption in sludge management is also required. The development of guidelines for the implementation of novel circular economy strategies, with accompanying incentives, will catalyse its adoption.

Although substantial research has been done on these topics, regulatory guidelines for emerging technologies, for example Black Soldier Fly cultivation and AD sludge-to-energy deployment, and associated production processes are lacking. For instance, as discussed by Grewan and Trois (IEA Bioenergy, 2023), South Africa does not have a specific Waste-to-Energy management framework to support the implementation of sludge-to-energy infrastructure and technologies from a national level. The development of such regulations and guidelines will support and guide the adoption of such innovations and is a key focus area from a governance perspective.

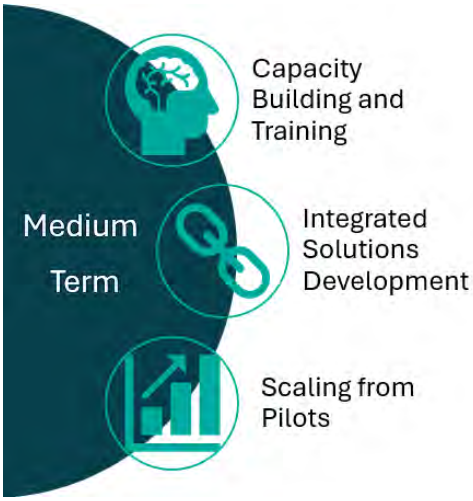
2.2.3.3 Methodology

The development of regulations and guidelines for emerging technologies and topics through focussed literary reviews (where lacking) and consultative workshops, especially with technology developers and utilities present, will provide a strong regulatory foundation for the deployment of emerging technologies. Such regulations will enable the development of high-level innovation adoption strategies that consider the requirements of legislation, notably the Public- and Municipal Finance Management Acts (PFMA and MFMA, respectively) among others, while also allowing for enabling supply chain management policies (Paladh et al., 2024).

2.2.3.4 Success Criteria

- Guidelines developed to support the adoption of sludge beneficiation from a regulatory perspective.
- Recommendations for potential incentives and market stimuli to facilitate the development, adoption, and implementation of circular economy solutions for sludge management.
- Guidelines developed for the sustainable deployment and uptake of novel technologies.

2.3 MEDIUM-TERM PRIORITIES (2025-2030)



Whilst the short-term priorities are aimed at rapid progress and alignment with current international best practice, the medium-term priorities are aimed at tackling more systemic challenges faced by modern sludge management strategies. Development of programmes and practices that will support the sustainable deployment of solutions and technologies, as well as opening up market opportunities for fiscal sustainability are the focus over the medium-term, with the priority areas summarised in Figure 4. It is important to emphasise at this point that medium- and long-term priority areas are not of a lower priority than the short-term priority areas, but rather require longer timelines to address effectively.

Figure 4. Medium-Term Priorities of the Sludge Management Research Strategy.

2.3.1 Capacity Building and Training

2.3.1.1 Challenge Statement

The wastewater treatment sector is plagued by capability and capacity challenges, most notably in technical competence to skilfully operate AD systems. Specific technical skills shortages beyond AD are also not clearly identified.

The capacity and competence of WWTP staff to maintain and operate novel sludge management approaches is crucial for the successful implementation of such solutions. Digitisation and smart technologies are poorly understood, due to the relative novelty of digitised and AI-based solutions and technologies.

2.3.1.2 Research Design

Understanding the root causes of capability and capacity challenges at WWTPs for sludge management must be investigated. It is especially crucial to determine whether insufficient training and development opportunities are available to staff (which this study did not investigate) or whether other barriers to entry for training programmes (such as training budgets, for example) are limiting the pool of available skills in the sector. Additionally, understanding the specific skills requirements in different regions and across disciplines within sludge management and wastewater treatment will enable the development of targeted training and recruiting programmes.

Research and development of specialised training programmes is needed to capacitate new and existing staff in the sector on operating advanced technologies, for example biogas production, energy generation and sludge-derived production approaches. Investigations and partnerships with higher education institutions as well as technology developers to present training to staff is a priority. Developing training programmes to build the capabilities of current staff to adapt to modern and more advanced technologies will secure employment for experienced operators and industry professionals and prevent skills shortages in future. It can also add to sector scarce and critical skills designations managed by the Energy and Water Sector Education Authorities (EWSETA) and the Local Government Sector Education and Training Authority (LGSETA).

2.3.1.3 Methodology

Survey-based research and interviewing relevant stakeholders at utilities and in the wider sector must be conducted to understand the causes of skills shortages and capacity development challenges within the sector, building on previous studies done. A technology-oriented focus will be beneficial to ensure targeted and focussed capacity-building programmes.

Development of course materials and training programmes, such as those presented by WISA, and especially focussed on cutting edge technologies will provide a platform for continued skills transfer, exposure and development. Investigations into the financial and technical feasibility of mentorship programmes, where experienced senior operators guide and mentor employed youths within the sector, as part of succession planning, and skills transfer programmes within utilities is recommended.

2.3.1.4 Success Criteria

- Reports documenting the challenges faced by WWTPs regarding capacity and capability shortages in the sector.
- Feasibility studies conducted for mentorship programmes that enable skills transfer to young professionals and operators and how such programmes can be funded sustainably.
- Support for training providers and SETAs, such as WISA, EWSETA, LGSETA and others, by developing a platform for continued skills development to progress innovative sludge management.

2.3.2 Cross-sector approaches and integrated solutions

2.3.2.1 Challenge Statement

Co-digestion and combined valorisation of sludge and solid organic wastes have been investigated from a technical perspective and compared to conventional sludge digestion, but little information is available on the financial and economic implications and the supply-chain requirements to enable integrated waste management systems at scale in a South African context. Additionally, it was discussed among stakeholders in a Sludge Management workshop, hosted in August 2024, that a lack of integrated planning and strategic management of solid waste, including sludge, has led to the stockpiling challenges that were previously mentioned.

A major barrier to the valorisation of sludge to manufacture products is a lack of established markets for such products in the country. Some products, such as fertiliser are highly regulated, making production from sludge challenging and costly, which impacts the sustainability of such a product, considering that current technologies are not cost-competitive with chemical fertiliser production. In addition, public perception regarding sludge-derived products is poor, as an extension of poor confidence in public sector utilities to provide basic services such as water, sanitation and energy efficiently, let alone monitor and/or efficiently manufacture safe products using hazardous wastes as feedstock.

2.3.2.2 Research Design

The commercial and financial feasibility of integrated waste management value chains in South Africa should be explored. Market readiness assessments and supply chain barriers, as well as institutional and regulatory hurdles require further exploration to understand the opportunities and challenges in product and energy generation from wastes. Several projects have been initiated and completed in the space of waste-to-energy and waste-to-product in South Africa and abroad (Gouws et al., 2024). These case studies can serve as

starting points for deeper investigation into integrated waste management strategies and systems in South Africa.

Research on and engagement with government departments, industry, and investment partnerships to identify markets for sludge beneficiation products, as per the NFSM Strategy's focus area on unlocking private sector opportunities. For instance, partnerships with the Department of Agriculture on agricultural use and fertiliser production, as well as Department of Trade, Industry and Competition and the Industrial Development Corporation along with private industry can develop scaling opportunities to generate products from sludge. Additionally, the work done in engaging Department of Basic Education can be enhanced by developing better business cases to support the implementation of decentralised technologies in rural schools. Strategic and policy development to support such cross-sectoral initiatives will support and drive the adoption of integrated waste and sludge management systems.

2.3.2.3 Methodology

Pre-feasibility and feasibility assessments from a network and supply chain perspective, as well as the financial feasibility of integrated waste management systems are recommended. Investigations aimed at understanding the challenges and requirements associated with waste co-digestion and other integrated waste management systems warrant attention across the research and development (R&D) pipeline.

Nexus and trade-off research projects will add value to knowledge generation efforts whereby cross-sectoral regulatory, mandate and policy implications will be surfaced. Market readiness studies for waste management integration and combined treatment systems must be researched. Furthermore, innovation and development of integrated waste management technologies has seen little attention outside of co-digestion and should be prioritised.

2.3.2.4 Success Criteria

- Feasibility studies of emerging integrated waste management systems are applied.
- Research outputs regarding aspects of the integrated waste management nexus, such as market readiness, technical developments and climate impacts.

2.3.3 Pilot Scale to Implementation

2.3.3.1 Challenge Statement

Anaerobic digestion has been identified globally as having major potential for sludge beneficiation, due to the wide range of potential products, such as biogas and production feedstocks, which can be produced from sludge. However, AD faces several challenges in the South African context. Firstly, waste sludge bioavailability and biodegradability are typically low. Several methodologies for addressing this challenge have been discussed in the research (Gouws et al., 2024), but many of these technologies are still untested in large-scale settings due to the limited understanding of the financial implications of operating the technologies at scale.

In addition, the by-products of the AD process also require further consideration, since not all products from the AD process are necessarily valuable outright and may require further post-treatment to produce fully circular treatment trains. Considerations for energy demands in the context of the current energy crisis should be considered prior to deployment as well.

The National FSM Strategy prioritises the rapid deployment of NSS solutions to peri-urban and rural communities, in support of the government mandate to provide dignified sanitation to all South Africans.

However, challenges related to the deployment of NSS solutions with efficient FS handling and treatment capabilities still exist. However, the availability of suitable solutions is not one of these challenges. Understanding how to deploy such technologies efficiently and sustainably is critical.

Sludge dewatering and drying is a major expense in wastewater treatment trains, with a need for commercial implementation of cheaper and more advanced sludge drying and dewatering technologies to both reduce sludge volumes and improve sludge quality for beneficial use.

More broadly, challenges in implementation of technologies are far-ranging, many already discussed under the short-term priorities of this strategy, and a need for a focussed drive to enable adoption and implementation of available solutions is critical.

2.3.3.2 Research Design

More thorough understanding of the feasibilities of different AD and related pre- and post-treatment technologies must be developed. Understanding operational and financial models related to scaled adoption of AD waste valorisation systems will enable the sustainable implementation of such systems. Such models should also consider the energy intensive nature of AD in the context of the current energy crisis. Considerations regarding the adoption of modern bioreactor treatment systems and the quality of sludge such systems produce should also be investigated for AD potential.

Research into understanding the barriers to adoption for NSS technologies and the development of viable business and operational models to support the sustainable adoption of NSS solutions, especially in indigent communities is key. Sustainable operational and business models that are community-focussed and provide low-skilled employment opportunities while simultaneously addressing the FS challenges in these communities is essential.

Continued development and cost-optimisation of sludge drying and dewatering technologies, as well as alternative sludge volume reduction methodologies require further optimisation to improve the cost-efficiency of sludge management overall. A two-pronged approach to both sludge volume reduction and operational cost (such as energy use) reduction will support future sustainable sludge management practices.

2.3.3.3 Methodology

Pre-feasibility and feasibility assessments of AD pretreatment technologies to improve sludge biodegradability, as well as post-treatment technologies to treat poor quality supernatant are recommended. For example, technologies such as hydrodynamic cavitation and ultrasonication technologies, as well as combination pretreatment systems, gasification, and pyrolysis, among others, show promise. Investigating methodologies that improve the biodegradability of waste sludge is suggested.

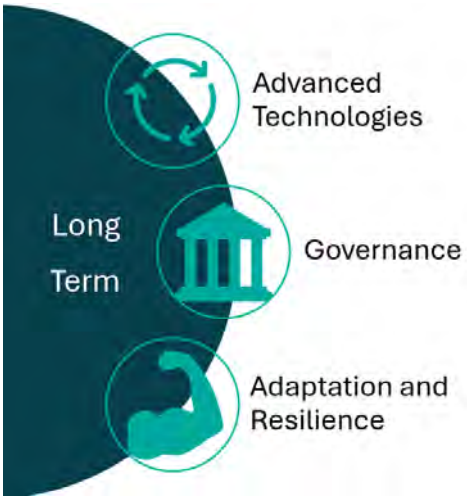
It is suggested that community-based research and citizen-science approaches to the deployment and sustainable management of NSS technologies and other FSM approaches are tested and implemented. Inclusive and collaborative development, testing and deployment of sanitation solutions where the communities benefitting from the solution are heard and their needs considered will support sustainable and impactful implementation of NSS solutions.

Modern sludge minimisation technologies should be tested at scale to determine operational feasibility and cost competitiveness, while informing further development of future sludge drying and dewatering approaches.

2.3.3.4 Success Criteria

- Case studies published on pretreatment and optimisation of AD technologies in the South African context. For example, literature published and/or patents filed for novel techniques or technologies to improve the biodegradability of waste sludge prior to AD will support future beneficiation efforts.
- Citizen-science initiatives launched, and in-community trials developed to empower communities to take ownership of NSS solutions in their communities.
- Operational models and cost-feasibility assessments developed from pilot studies on sludge minimisation technologies. This may include operational scale sludge quality to inform decision-making on downstream valorisation potential.

2.4 LONG-TERM PRIORITIES (2025-2035)



The long-term priorities are aimed at building resilience in the research and innovation pipeline, by investing in advanced treatment and resource recovery technologies, addressing governance challenges related to sludge management and water treatment, and adaptation to changing regulatory and practical challenges, while implementation of monitoring strategies builds on the guidance of established best-practice regulations. These priorities are depicted in Figure 5 on the left.

Figure 5. Long-Term Priorities of the Sludge Management Research Strategy.

2.4.1 Advanced Treatment and Resource Recovery

2.4.1.1 Challenge Statement

Contaminants of Emerging Concern (CECs) such as plastic particles, pharmaceuticals and personal care products (PPCPs), e are a primary focus area in water and wastewater quality. Many of the health concerns in water extend towards beneficiation of sludge, especially when considering sludge-to-product applications. In the case of sludge-to-energy, factors such as air pollution potential and climate impacts are of concern as well.

Existing wastewater treatment systems have high carbon footprints and exert major pressure on South Africa's ability to fully decarbonise our society. Climate change impacts in the wastewater sector are well-documented and a shift towards more climate-suitable solutions is being prioritised. However, this shift requires the development and adoption of more climate-suitable solutions.

The water sector is undergoing a major shift towards digital automation and smart technologies. South Africa has the capacity and capabilities to contribute to this emerging market. With the cost of wastewater treatment increasing over time, and legislation imposing climate and environmental tariffs and penalties on utilities and waste generators, cost and process efficiencies become more and more imperative for the sustainability of wastewater treatment and by extension, sludge management as well. The recently completed Digital Utility Maturity Assessment revealed that major challenges are present in South African bulk water suppliers, which present an opportunity for market expansion (Southgate et al., 2024).

2.4.1.2 Research Design

Investigations concerning the life cycle of CECs present in sludge and how these compounds impact the utility of sludge in various reuse and beneficiation strategies are recommended. Also recommended are investigations into the safety of sludge-derived products to ensure sustainable sludge beneficiation and market development.

Continued support for innovation in climate-conscious solutions is suggested to support the sector's climate goals and contributions to the broader Just Transition framework. Research and innovation, including innovation adoption, are key to sustain South Africa's current climate response efforts.

Research and development of digital and smart technologies such as AI and artificial neural networks integrations in wastewater treatment and sludge valorisation systems will open new opportunities for economic growth and employment in wastewater-related treatment systems, while reducing costs, supporting infrastructure and process management, and improving efficiency of existing and new infrastructure systems.

2.4.1.3 Methodology

Investigate the activity and effect of CECs present in sludge-derived products on environmental and human health through toxicological testing. For example, what happens to different CECs during fertiliser production? What are the environmental and human health risks associated with CECs present in sludge-derived products such as fertiliser, construction materials, etc.?

Pilot studies and pre-commercial proof-of-concept installations of novel technologies, including advanced treatment and climate conscious solutions, are to be supported to maintain a healthy RD&I pipeline of novel solutions that address current and future challenges in sludge management as the field expands, needs change and capabilities improve.

Pilot testing and continued development of digital technologies, both hardware and software, are recommended priorities. Digitisation strategies should be developed for common technologies in sludge management, for example AD and sludge minimisation approaches. It is also recommended that sludge quantity estimation systems are developed, potentially based on Smart metering technologies, that support sustainability and operational continuity for beneficiation partners and installation.

2.4.1.4 Success Criteria

- Literature and knowledge produced on the toxicological activity of various CECs present in sludge-derived products, such as briquettes, construction materials, soil enhancers and fertilisers. Technologies developed to remove or mitigate any potential negative effects of CECs from sludge for use in sludge beneficiation.
- Trialling and successful co-development of novel sludge management technologies that address the needs of the future and improve on the methods of the present.
- Development, testing and deployment of digital and AI-based technologies that improve the efficiency and optimisation of existing systems and address the operational and financial challenges currently facing the sludge management space.

2.4.2 Governance

2.4.2.1 Challenge Statement

Overlapping authority on water treatment, pollution, waste management and resource recovery complicates the adoption of technologies, since multiple government departments and entities must designate resource recovery and sludge-based technologies, parts and components manufacturing. The overlap in authority also delays adoption due to bureaucratic barriers.

Different procurement models each have their own challenges, such as the high transaction costs associated with Build-Operate-Transfer models and corruption vulnerability of Public-Private Partnerships.

Regulations are limited by the available body of knowledge at the time of development. Although regulations and policies are a critical element of South Africa's public services infrastructure, including sludge management, regulations can become outdated if not reviewed and evaluated against modern research findings and international best practices. Such initiatives are already underway, for instance with the updating of the WRC's National Surveys (Natsurv) on the water use of specific industries.

A recent study by the WRC, Bosch Capital and Isle Utilities South Africa (Paladh et al., 2024) surfaced several behavioural factors due to a lack of knowledge of the procurement framework and the perceived effort that is required to navigate through the procurement processes within utilities as being major barriers to innovation uptake. A lack of coordination between water practitioners and Supply Change Management (SCM) practitioners within utilities, coupled with poor and/or lack of internal Innovation Policies could exacerbate the challenges linked to procurement and adoption of innovative sludge management technologies and solutions. Opportunities to address these issues include designing procurement strategies for different clusters of emerging innovations and the development of a roadmap for improving the maturity of innovation systems within the South African context.

2.4.2.2 Research Design

Understanding and clearly defining the division of authority regarding water treatment and resource recovery will simplify government's role in transitioning to a circular economy through waste valorisation.

Better interpretation of the PFMA and MFMA, innovation and procurement policies and models for technology adoption by the public sector may allow for more rapid implementation of solutions at scale. Procurement challenges should be research to understand what aspects of the current procurement landscape are hampering the implementation of innovative solutions.

Continuous research and reviewing of sludge management policies and regulations are recommended to ensure alignment with current best practices and cutting-edge research. Regular and continuous updating and strengthening of policies and procedures are suggested for good governance in the long term.

2.4.2.3 Methodology

Methodologies previously employed focused on scientific development. Consideration should be given to the complex governance structures of the water, sanitation, and waste sectors in supporting tiered approaches and qualitative studies that help surface inherent and perceived barriers created by Governance and Policy for the deployment of new sludge management techniques.

Current studies skim the surface of policy and regulation, and do not fully engage policy makers and regulators in making the case for progressive governance that enables South Africa to make progress against SDG targets. Studies undertaken with support from the Panel on Climate Change (PCC) in South Africa have shown significant impact on SAs Gross Domestic Product (GDP) if the global decarbonisation pathway is ignored. More in-depth analyses are therefore recommended.

2.4.2.4 Success Criteria

- Development of policy-impacting research regarding the governance structures associated with wastewater management and circular economy industries.
- Adapted or novel contracting models for procurement that support rapid adoption and deployment of sludge management technologies. More in-depth understanding of the challenges and opportunities for procurement and beneficiation within the current regulatory framework.
- Policy recommendations and updated regulations produced on a continuous basis.

2.4.3 Adaptation to Evolving Needs and Challenges

2.4.3.1 Challenge Statement

As was previously mentioned, the level of digitisation in wastewater treatment systems and their associated sludge management systems is lacking in South Africa. Although the industry has seen a surge in the development of smart and digital technologies, especially in bulk water infrastructure, very few of these technologies are focussed on monitoring and digitisation of sludge handling and disposal systems.

Climate change impacts on wastewater treatment and conventional sludge management systems have been an active area of investigation. An understanding of emissions and the high energy use of sludge management and treatment systems is of concern and requires redress.

2.4.3.2 Research Design

Research and development of digitised systems for monitoring and control of existing and novel sludge management approaches will improve cost-efficiency and performance, while allowing operators finer control of systems.

Further development of climate-smart technologies for sludge management is recommended, to address the current carbon emissions and high energy use involved in sludge management systems. Development and deployment of solutions should keep pace with current and future climate research.

2.4.3.3 Methodology

Investment and incentives to develop digital monitoring instruments for sludge-specific quality parameters and sludge treatment systems are recommended. Implementation strategies and regulatory support for digitised and monitored sludge management systems are suggested.

Development of more energy efficient or carbon neutral alternative technologies and methods to retroactively improve climate impacts of existing wastewater and sludge treatment infrastructure are recommended as priorities. The climate element is also to be evaluated in innovations that do not necessarily take the approach of a climate conscious solution, while incentivising innovation to consider climate responsibility in their design and development.

2.4.3.4 Success Criteria

- Innovations and testing of digitisation strategies and technologies for sludge monitoring, handling, and treatment systems.
- Development of energy efficient and climate smart technologies to handle, monitor and treat sludge in more environmentally sustainable ways.

2.5 CONCLUSION

This report has laid out the needs for research moving forward regarding sludge management, with an emphasis on challenges faced in the South African context with applicability in other Low- and Middle-Income Countries (LMICs). However, it is worth pointing out that a lot of research and development has been done in the space of repurposing sludge as a resource, rather than disposing of it as a waste. It is worth emphasising that implementation are the primary areas that require attention. Research and innovation are progressing well, but demonstration and adoption of innovation is lagging, with the implementation of novel strategies to translate research into impact requiring more attention if South Africa is to address the financial, environmental and social challenges associated with sludge management.

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APPENDIX

LIST OF ALL RELEVANT STAKEHOLDERS

Stakeholder Group	Stakeholder name
Organisations	GreenCape
	Association for Water and Rural Development (AWARD)
	Faecal Sludge Field Laboratory
	United States Agency for International Development (USAID)
	International Federation of Red Cross and Red Crescent Societies
	South African Local Government Association (SALGA)
	Water Research Commission (WRC)
	Department of Water and Sanitation (DWS)
	Department of Environmental Affairs (DEA)
	Department of Science and Innovation (DSI)
	Department of Higher Education and Training (DHET)
Research Institutions	Eawag – Sandec
	Bremen Overseas Research and Development Association (BORDA)
	AdMaS (Advanced Materials, Structures and Technologies), part of the Faculty of Civil Engineering at Brno University of Technology
	Regional Centre for Energy and Environmental Sustainability at University of Energy and Natural Resources Sunyani Ghana
	Council for Scientific and Industrial Research (CSIR)
	WASH R&D Centre at University of KwaZulu-Natal
	CSIR-National Institute for Interdisciplinary Science and Technology
	Fraunhofer IGB
Universities	Vaal University of Technology
	University of KwaZulu Natal
	State University of the Northern Rio de Janeiro
	Stellenbosch University
	College of Natural Resources and Environment
	Department of Civil Engineering & Architecture, University of Pavia
	Pohang University of Science and Technology
	University of Energy and Natural Resources Sunyani Ghana
	Faculty of Chemistry, Gdańsk University of Technology, Poland
	School of Environment and Natural Resources, Doon University, India
	Kluyver Laboratory for Biotechnology, Delft University of Technology

Funding bodies	Gates Foundation
	Humanitarian Innovation Fund
	Swedish Red Cross
	Swiss Agency for Development and Cooperation
Other	Agriman Pty Ltd
	SMART Plant Innovation Action
	Sanitation and Water for All
	AfricaSan from African Ministers' Council on Water (AMCOW)
	Department of Sanitation and Health, ONEA, Bobo-Dioulasso, Burkina Faso
	eThekwini Municipality in Durban
	Department of Water and Sanitation, RSA
	USAID Resilient Waters
	Polokwane Local Municipality
	Africa Biogas Partnership Programme (ABPP)

SLUDGE MANAGEMENT: A RESEARCH STRATEGY TOWARDS INNOVATIVE AND SUSTAINABLE PRACTICES AND TECHNOLOGIES

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