Market Analysis to Determine the Extent and Potential of Water-to-Energy Market in South Africa (Waste and Small/Micro Hydro)

Report to the

WATER RESEARCH COMMISSION

by

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EXECUTIVE SUMMARY

BACKGROUND

The concept of water and waste to energy has been around for decades. When considering that wastewater is a carrier of over 50% of waste resources that is either lost or unrecovered materials, energy or water. However, despite global reports estimating that the waste to energy market value was US$28.4 billion in 2017 and would increase to US$42.7 billion by 2025, there has been limited implementation in South Africa despite projects being identified as technically and financially viable.

RATIONALE

There is significant potential to generate energy from water and wastewater sources and references within the global market suggest that these projects can be successfully executed at scale. These opportunities can create significant benefit to the South African economy in that:

- These opportunities could contribute to the eradication of the electricity backlog in South Africa.
- This could lead to a reduction of operational expenditure (Opex) in the municipal sector thereby allowing for the redirection of funds towards other local government priorities.
- A greater focus on extracting value from sludge could increase the operational performance of wastewater treatment works (WWTW).

However, despite these obvious benefits, there has been limited implementation of water to energy solutions despite viable opportunities being identified.

AIMS AND OBJECTIVES

The study was positioned to undertake a market analysis of various water to energy applications in South Africa and understand the market size and the challenges within this market. The overarching objective was to develop a strategy that would attract investment in water to energy projects and unlock the potential within this area of the water value chain. The recommendations from the study include a roadmap that will catalyse investment for these projects and enable their successful implementation.

STRUCTURE OF THE REPORT

The report has been structured to provide the key findings from the research, with the underlying data and analysis being included in the analysis. The description of each chapter within the report is presented in the table below.

Table 1: Structure of the report

Chapter	Comment
Chapter 1: Introduction and objectives	Provides the background to the study and study objectives. This section also includes the organisations that participated in the study.
Chapter 2: The energy market in South Africa	Focusses on the consumers of energy in South Africa and the link to the water sector.
Chapter 3: The potential for water to energy markets	Considers what water to energy projects that could be implemented.
Chapter 4: Structuring a bankable project	Outlines the key requirements for a bankable water to energy project.
Chapter 5: Opportunities map and recommendations	Highlights the opportunities in the water to energy sector and outlines key steps to unlock the opportunity.

KEY FINDINGS

The study explored the relationship within the different market segments in both the water market as a source of renewable energy and the energy market as a consumer of this energy. This yielded the market segments in the table below.

Table 2: Market segments

Market segment	Comment
Industry and Mining	Industry generates the highest demand for energy in South Africa at 52%. Industry and Mining are also amongst the highest water users in the country with the highest industrial water use is located within the Vaal catchment.
Agriculture	Irrigation uses the highest proportion of water in South Africa and also consumes 6% of the energy within the country. This represents a potential market segment that has a relatively high-water consumption profile across all catchments in the country, that has the potential for mini and small hydropower schemes.
Domestic	The residential market in South Africa accounts for 8% of energy but 15.7% of water being consumed by water supply services. This is seen to be for the provision of domestic water and sanitation services.
Municipalities	Municipalities are seen to have a key role to play in the provision of water services, as well as, the provision of electricity to their customers.
Water Boards	Rand Water is listed as one of the 29 highest energy users in South Africa and the utility is also the largest Water Board in the country. It is possible that given the scale of operations, all Water Boards may be well placed to benefit from Water to Energy interventions.

There is a strong correlation between water and energy consumers. This thus links the energy source (water and wastewater) to the consumer of the energy. The table above also highlights that municipalities have an important role to play in both the provision of water and electricity services. Water Boards also have a relatively high energy consumption and an important role in the provision of bulk water supply.

Potential water to energy projects

The impact of implementing WTE projects in South Africa is massive as potentially 206 MW of electrical capacity could be added to the electrical grid with an annual revenue generation potential of just over R2 billion. The impact of these projects are provided in the table below.

The annual revenue generation was based on a tariff of R1.40 kWh and household consumption was assumed to be 20 kWh per day.

Table 3: Established technology and source

Application	Generation Capacity (MWh/annum)	MW	Equivalent no. of HH	Annual Revenue (ZAR)
Anaerobic Digestion at WWTW	190 232	27	26 421	266 325 024
Refurbishment/upgrading of existing plants in ownership of municipalities or DWA (Hydropower)	70 000	10	9 722	98 000 000
Hydropower sets to existing (new) dam	500 000	71	69 444	700 000 000
Inter-basin Water Transfer Schemes (Hydropower)	300 000	43	41 667	420 000 000
Municipal/Water Utility Distribution systems (Hydropower)	375 000	54	52 083	525 000 000
"Greenfield" Hydropower sites	5 000	0.71	694	7 000 000
		206	**200 032**	**2 016 325 024**

Hydropower and anaerobic digestion in rural areas that could benefit either rural communities or agricultural consumers were considered. This has potential, but from a water to energy perspective, anaerobic digestion in rural areas would require the introduction of a supplementary feedstock as sewerage at a micro scale would not generate enough biogas. Importantly, the physical location at which the electricity is generated and could be used is a critical consideration in rural applications. Project costs increase significantly if the electricity generated is required to be transported over long transmission lines for consumption. The development costs associated with the smaller installations are also seen to be prohibitive.

Emerging water to energy innovations that have potential in the future but would need further development being considered for large scale investment are:

- Wave to Energy;
- Microbial Fuel Cell;
- Generating biofuel from wastewater sludge; and
- Thermal treatment of sludge.

The combustion of wastewater sludge is an internationally mature technology, however, the study confirmed that this technology had limited application in the South African water sector at this stage.

The big question – Are these projects bankable?

Projects need to be deemed bankable if they are to attract investment from funders. This includes the development of the strategic, financial, commercial and management case for each project. The diagram below indicates the key risks that would need to be overcome during each phase of the project for the successful implementation of water to energy projects.

<table>
<tr><th>Risk</th><th>Conception</th><th>Design</th><th>Build</th><th>Operate & Maintain</th></tr>
<tr><td>Political</td><td colspan="4">Political support
Regulatory environment that supports the implementation of WTE projects</td></tr>
<tr><td rowspan="2">Financial</td><td>Ensure projects are financially viable</td><td>Cashflow to fund project development</td><td colspan="2">Necessary agreements to execute projects</td></tr>
<tr><td>Usually funded by the Developer</td><td colspan="2">Certainity that the costs are accurate</td><td>Sufficient cashflow can be collected and used to service debt</td></tr>
<tr><td>Operational</td><td colspan="4">Necessary skills to execute each phase</td></tr>
</table>

Figure 1: Bankability requirements/risk potential for water to energy projects

The diagram above also highlights the need for a 'Developer' or Project Sponsor to move a project from Concept towards Implementation and Operations and Maintenance. The Developer should be able to provide comfort to the Investor that the project can be successfully implemented and the ability to attract the right partners at each stage of the project development process.

CONCLUSIONS

The diagram below provides an indication of the potential water to energy opportunities that funders may have an interest in.

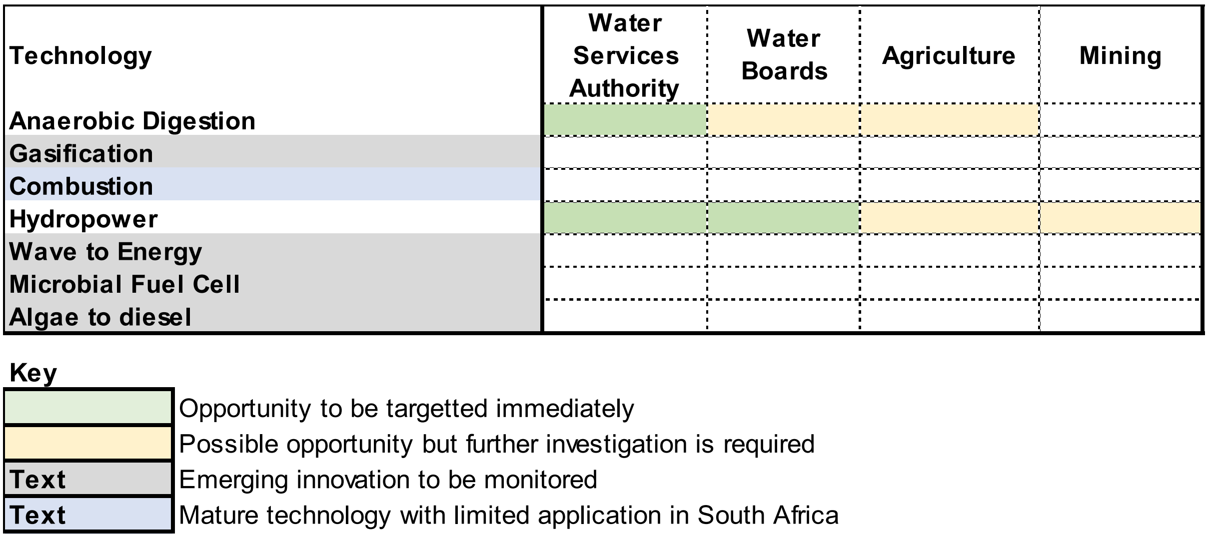

Figure 2: Opportunities map

Anaerobic digestion and hydropower provide clear opportunities for water to energy projects. These projects have been evaluated by Water Boards and Metropolitan Municipalities and are seen to be viable in particular areas within their jurisdiction. Feasibility studies were previously completed but these need to be updated to reflect the current capital costs and tariffs. These studies must move beyond a technical assessment and address the key bankability requirements that have been identified. This includes how the water to energy sites are going to be operated. Operations could be done internally within the organisation or by a private party through the Public Private Partnership model.

It is expected that most of the electricity generated by the projects would be for on-site use or supply into the municipal grid. This reduces the risk of non-payment for the electricity generated from the sites. This also reduces the requirements to engage with additional parties for off-take agreements and/or the use of transmission infrastructure.

The mining sector could also contribute a potential 1 200 MW in Gauteng from mining applications. However, there is a need to confirm the practical application of hydropower solutions or energy recovery in mining applications. This is an opportunity that will need to be explored further.

It is noted that Water Boards and Municipalities have been investigating the potential for hydropower applications and anaerobic digestion at various sites. These projects are seen be at concept stage and need to be further developed. It is therefore proposed that:

- Funding from DFIs is allocated towards the development of feasibility studies for the sites that have been identified, as these may be outdated and would need to reflect current capital, operating and revenue;
- Project Preparation Funding should also be allocated to sites in the metropolitan municipalities and Water Boards to assist with the design components associated with Water to Energy projects;
- Consider the development of an office similar to the Independent Power Producer Office at the DBSA to assist municipalities with the implementation of water to energy projects;
- Political support and alignment will be required from all key stakeholders. This will have to be driven from Central Government by ensuring appropriate legislation, incentives and adequate funding for operations and maintenance are in place. Incentives will need to be aligned by the different institutions and staff that are involved in the projects; and
- Explore the potential to establish specialised units within institutions that can manage the operational and maintenance risks associated with water to energy projects.

The potential impact of implementing the water to energy opportunities that have been identified are significant in that:

- It contributes to enhancing South Africa's electricity supply;
- It could assist municipalities in obtaining electricity at a lower price than that provided by Eskom;
- Job creation benefits through each phase of project implementation;
- Economic and environmental benefits through investment in renewable energy and reduction on the reliance of coal; and
- It stimulates innovation and the implementation of circular economy principles.

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• Katrina Zlobich	Grundfos
• Jones Mnisi	Joburg Water
• Nicole Algio	REEEP
• Noluthando Msibi	SANEDI
• Bo Barta	Small Hydropower Association
• Gaylor Montmasson-Clair	TIPS
• Kevin Meier	Umgeni Water

Other stakeholders that were engaged during the course of the study included:

• Ms Dolly Mafa	City of Tshwane Metropolitan Municipality
• Dr Karen Sturridge	SANEDI
• Mr Marco van Dijk	University of Pretoria
• Dr Marlene van der Merwe Botha	Water Group Holdings (Pty) Ltd

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AD:	Anaerobic Digestion
DCF:	Discounted Cash Flow
DFI:	Development Finance Institutions
DTI:	Department of Trade and Industry
DWS:	Department of Water and Sanitation
EIA:	Environmental Impact Assessment
EIUG:	Energy Intensive Users Group
HTC:	Hydrothermal Carbonisation
IPAP:	Industrial Policy Action Plan
IPP:	Independent Power Producer
IRP2019:	Integrated Resources Plan 2019
ISWA:	Independent Solid Waste Association
MCDA:	Multi Criteria Decision Analysis
MFC:	Microbial Fuel Cell
Ml/d:	Megalitre per day
MRL:	Market Readiness Level
MSW:	Municipal Solid Waste
MTPPP:	Medium Term Power Purchase Programme
MW:	Megawatt
NDP2030:	National Development Plan 2030
NEMA:	National Environmental Management Act
NERSA:	National Energy Regulator of South Africa
NWA:	National Water Act
PFMA:	Public Finance Management Act
RDF:	Refuse Derived Fuel
REIPP:	Renewable Energy Independent Power Procurement Programme
SMMEs:	Small, Medium and Micro Enterprises
STI:	Science, Technology and Innovation
TH:	Thermal Hydrolysis
TRL:	Technology Readiness Levels
WRC:	Water Research Commission
WSA:	Water Services Act
WTE:	Water to Energy
WtE	Waste to Energy
WWTW:	Wastewater Treatment Works
4IR:	Fourth Industrial Revolution

LIST OF DEFINITIONS

Clustering:	Grouping of technologies based on similar characteristics.
Commercialisation:	The process of introducing a new product, service or process into the market with the purpose of generating revenue. The launch of a new product is the final stage of product development, where funds are spent primarily on, sales promotion and other marketing efforts. (Department of Trade and Industry, 2016)
Innovations:	Technologies, process and social interventions that could generate energy from water sources.
Investment:	Funding that is required to be provided for the implementation of a water to energy intervention that generates a return to the funder.
Market value:	The quantum of revenue that can be generated from the sale of energy during a specified period of time from a particular technology.
PESTEL:	Political, Economic, Social, Technology, Environment, Legal

1. INTRODUCTION AND OBJECTIVES

This study explored the extent and potential of the water to energy market in South Africa[1]. This was based on a market segmentation analysis of potential energy consumers in South Africa and compared to potential sources of energy within the water value chain. The study also included a review of technologies and process that are available to extract energy inherent in the water sources. The objective of the study is to attract interest from potential investors to the water to energy market. It is expected that this will lead to the development of sustainable water to energy solutions.

1.1 Background

Global reports approximate the waste to energy market value at US$ 28.4 billion in 2017 and is expected to increase to US$ 42.7 billion by 2025. Previous studies have also shown that the organic matter in wastewater contains sufficient energy required for the treatment of the water, as well as supply to other consumers. It has also been estimated that the hydropower potential was estimated to be 12 160 MW.

There has been interest shown in water to energy projects in South Africa, but the implementation has been limited despite certain projects being identified as technically and financially viable. Therefore, there is a need to determine the potential market for water to energy projects and determine the blockages and structural issues within the market that limit the implementation of these projects.

The potential impact of water to energy projects are seen to be significant in a South African context as 16% of the population do not have access to electricity. Institutional challenges within the electricity supply has led to intermittent supply of electricity (load shedding), as well as above inflationary increases in the tariff.

Water to energy projects are seen to have significant development impact. This could be in the form of jobs created during project development and implementation, as well as, contributing to enhancing the security of energy supplied and moving towards a more sustainable energy mix.

There is significant benefit to implementing water to energy projects in South Africa. However, despite this benefit and interest, implementation has been a challenge. There is a need to understand the challenges and develop a strategy that can unlock the water to energy market in South Africa.

[1] Any reference to water-to-energy includes both water and wastewater within the context of this report.

1.2 Project Objective

The project aimed to undertake a market analysis of various water to energy sources for South Africa. This included reflecting and unpacking areas of opportunity within the public water sector, domestic and commercial activities. The specific objectives included:

- A detailed market analysis of current and future trends, forecasts, growth drivers, constraints and risks;
- A market segmentation analysis in relation to geography, technology and emerging innovations;
- Outline the key requirements to improve the market structure; and
- Recommendations for industrial development, strategies to be pursued, future research, policy and practice.

The overarching objective of the study was to develop a strategy that would attract investors to fund water to energy projects and unlock the inherent potential within the water to energy market.

The project was completed in a phased manner in order to achieve the project objectives. The methodology utilised to achieve the objectives is presented in Appendix A: Methodology.

1.3 Structure of the report

This report has been structured so as to present the key findings of the study with the underlying data been presented in the Appendices. Chapter 2 of the report focusses on the energy sector in South Africa. This includes a review of energy sources, institutional and regulatory framework. The consumers are segmented by type and volumes of energy consumed, with additional information on the challenges being faced in the sector being noted. This chapter also notes the link between water sources to energy consumers.

Chapter 3 of the report focusses on the potential for water to energy projects in South Africa. This chapter also included a financial viability assessment and details the areas in which it must be noted that this section was underpinned by a process to identify mature technologies that would be applicable in a South Africa context. Emerging innovations have potential but would not be able to attract significant investment for wide scale implementation.

Chapter 4 of the report focusses on bankability segments the key risks inherent in implementing a water to energy projects and outlines the manner in which these risks can be mitigated. Chapter 4 also outlines the project development cycle and the requirements for each phase of a project.

Chapter 5 of the report focusses on the opportunities in the water to energy market and outlines the next steps to be completed in order to unlock investment for water to energy projects.

1.4 Participating organisations

The study was led by Bosch Capital and supported by Bosch Projects as the engineering lead. Bosch Capital and Bosch Projects are subsidiaries of Bosch Holdings ("Bosch"), the multidisciplinary consulting engineering group based in Durban, South Africa. Bosch was established in 1961 and has operating entities in South Africa, Brazil, Kenya and the United Kingdom.

1.4.1 Bosch Capital

Bosch Capital provides integrated project finance advisory, capital raising and investment facilitation services for private and public sector clients in multiple industries/sectors. Bosch Capital was established in 2014 and is built on over 60 years' experience across the Bosch Holdings group of companies. At Bosch Capital, we combine financial and engineering expertise to facilitate the financing and development of projects to drive economic growth and development in Africa.

The Bosch Capital team comprises seasoned professionals with extensive experience in performing financial feasibility studies, fund raising and investment facilitation on capital projects up to financial close and the subsequent disbursement of funds.

1.4.2 Bosch Projects

Bosch Projects is also a proud member of the Bosch Holdings group with a focus on innovative consulting engineering solutions and project management in both the broader industrial and infrastructure sectors. With our focus on projects in the commercial, industrial, building developments, sugar, energy including renewable energy, and agricultural sectors, Bosch Projects also provides appropriate infrastructure engineering solutions for Africa's built environment including roads, human settlements, water and wastewater.

Bosch Projects was the first entity established by the group in Durban, South Africa in 1961. Bosch Projects is fully committed to BBBEE development. The company employs professionals based in offices in Durban, Johannesburg, Pretoria, East London, Port Elizabeth and Cape Town from which we render services for both local and international projects.

2. THE ENERGY MARKET IN SOUTH AFRICA

The energy market are the various customers that consume energy in the country from the various sources source of energy. Energy can be provided in the form of electricity or through other fuel sources such as, liquid fuels and gas.

2.1 The South African Energy context

The NDP2030 envisages that by 2030, South Africa will have an energy sector that: (Department of Energy, 2019).

- Provides a reliable and efficient energy service at competitive rates,
- Is socially equitable through expanded access to energy at affordable tariffs and,
- Is environmentally sustainable through reduced pollution.

2.1.1 A summary of the legal and policy framework

The South African regulatory, policy and planning framework not only governs but promotes the use of water to energy technologies. The salient items from key national legislation and policy documents are highlighted below with further detail being provided in Appendix B: The National Legislative, Planning and Policy Framework.

<u>Legislation</u>

All prospective water to energy projects need to ensure compliance with National regulation. This may necessitate the need for additional studies, permissions, authorisations and licenses. The cost of completing the studies and obtaining approvals should be included in the project costs and could increase the time required to complete the project.

The current legislative process may be considered onerous, and work is underway to establish processes that could promote the uptake of water to energy projects. This includes increasing the size of projects that would require a generation license and allowing municipalities to procure electricity from Independent Power Producers,

<u>Sustainability</u>

The regulatory framework promotes the sustainable and beneficial use of water in the public interest. Water and Environmental regulation places and emphasis on the re-us, recovery and recycling of waste before disposal. The Guidelines for the Utilisation and Disposal of sludges and residues further emphasis the need for sustainable disposal interventions.

This focus on sustainability is further highlighted in the promotion of renewable energy sources in the NDP2030 and IRP2019. IRP2019 envisages that hydropower, pumped storage and biogas are expected to feature as part of the proposed energy mix by 2030.

Increased access to energy

NDP2030 also promotes increasing access to energy to all South Africans by 2030 given that at least 3 million households currently do not have access to grid-based electricity. This is expected to be a combination of grid and non-grid supply solutions. IRP2019 encourages municipalities to diversify their energy supply mix as biomass, biogas and biomass are seen to hold great potential to improving municipal revenue. DTI (2017) further highlights the opportunities in small-scale waste to energy projects. It is also noted that mechanisms will be established to ensure municipalities, in good financial standing, procure their own power from independent power producers.

Increased technology development

NDP2030 promotes the development of new and innovative technologies and services, as this is seen as a mechanism to promote economic growth and enhance the competitiveness of the national economy. This is supported in IPAP2018. The development of the hydrogen economy and the Hydrogen Initiative is seen to be an area that holds great potential in this area.

Financing mechanisms

The 2020 National Budget highlights that funding towards national water, sanitation and energy interventions has been allocated. It has also been noted that the mandates of DFIs will be expanded to scale up the quantum of funding available for industrial innovation activities, as well as the establishment of a Sovereign Innovation Fund to address funding for commercialisation activities.

A further R100 billion has been committed to the Infrastructure Fund that is located within DBSA. These interventions highlight the availability of funding for suitably prepared projects. Funding will also be made available for project preparation and packaging.

2.1.2 Institutional Framework

The electricity sector in South Africa is dominated by the national utility Eskom, which is responsible for the generation of approximately 90% of the electricity in South Africa. The remainder is generated by municipalities, redistributors and private generators. An overview of the institutional framework of the electricity sector is provided in the diagram below.

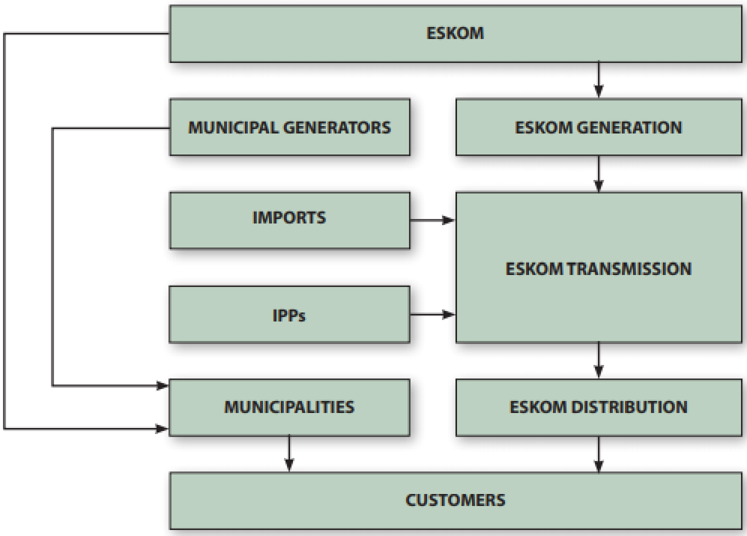

Figure 23: Institutional Framework – Electricity

Source: Department of Energy (2019)

The diagram above highlights the important role that municipalities have in the generation and distribution of electricity. They are able to generate their own electricity to supply to customers, as well as provide electricity generated by Eskom through to customers. An overview of the roles of the institutions involved in the energy sector in South Africa are presented in the table below.

Table 37: Role players in the energy sector

Name	Type of entity	Primary mandate or function
National Assembly Portfolio Committee on Energy (PCE)	Parliamentary committee	Make laws, review draft policies, exercise oversight of DoE operations and budgets and energy-related SOEs [6].
Department of Energy	National government	Optimise use of national resources related to energy supply [21].
Minister of Energy	Cabinet	Political head of the DoE, exercise oversight of energy regulators and energy-related SOEs, make energy policy and procurement determinations.
Eskom	SOE	Generation, transmission and distribution of electricity.
Central Energy Fund (CEF)	SOE	Contribute to the security of energy supply through commercial operations and developmental investments [22].
NERSA	Regulatory authority	Regulate the electricity, piped-gas and petroleum pipelines industries of SA [23], including tariff determination.
National Nuclear Regulator (NNR)	Regulatory authority	Protection of people, property and the environment against nuclear damage though safety and regulatory practices [24].
Nuclear Energy Corporation of SA (NECSA)	SOE	Research into nuclear energy, processing of source materials, operates Vaalputs low- and medium-level waste disposal facility [25].
SA National Energy Development Institute	SOE	Applied energy activities that promote the uptake of clean energy and energy efficiency in SA [26].
Sasol	Private international corporation	Produce synthetic liquid fuels from coal [27].
Transnet Pipelines	SOE	Provide liquid fuel and gas pipeline infrastructure [28].
Municipalities	Local government	Buy, sell and distribute electricity, manage cross-subsidies from national government at local level.
IPPs	Private sector	Sell electricity to Eskom via power purchase agreements.
PetroSA	National oil co.	Extract offshore gas and use it to produce liquid fuels.

Eskom generates electricity and is able to procure electricity from IPPs through various agreements. It is also noted that most of the power stations used to generate electricity are located in the Free State and Limpopo provinces. Eskom sells electricity directly to 2 703 industrial, 51 848 commercial, 81 638 agricultural and 6 million residential consumers. (Department of Energy, 2019)

2.1.3 Current energy generation sources

The current South African energy supply is dominated by coal and crude oil as indicated in the diagram below.

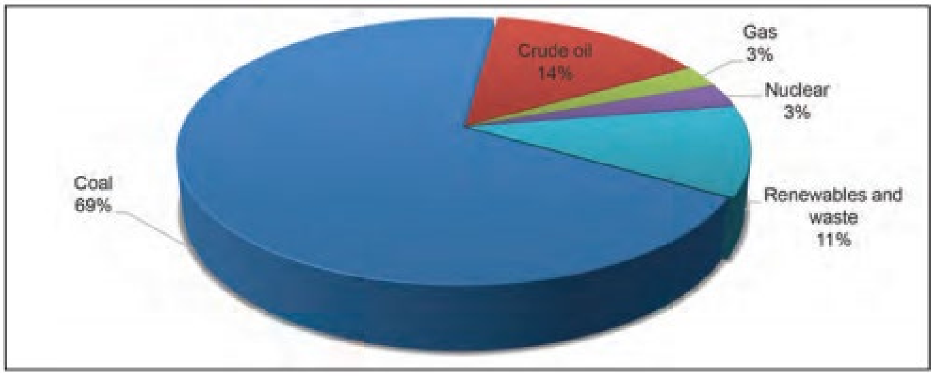

Figure 24: South Africa's primary energy supply (2016)

(Department of Energy, 2019)

The diagram above highlights the reliance of the production of electricity from coal, as well, as highlights that renewables and waste comprises a relatively small component of energy supply mix. Water to energy projects presents the opportunity to increase the generation of energy from renewables and waste as energy supply options.

2.2 Energy consumers

The largest consumers of energy in South Africa are the industrial, transport, commerce and public services sector. This illustrated in the diagram below.

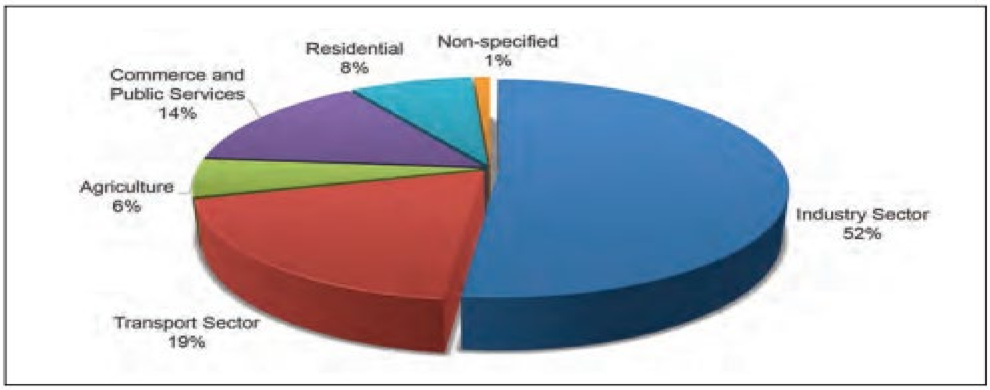

Figure 25: Energy demand by sectors (2016)

Department of Energy (2019)

There are various subsectors within each of the sectors indicated in the diagram above. These are further detailed in the sections within this chapter of the report.

2.2.1 Industrial

Industry accounts for 52% of energy consumed in South Africa. The industrial energy demand by subsector is presented in the diagram below.

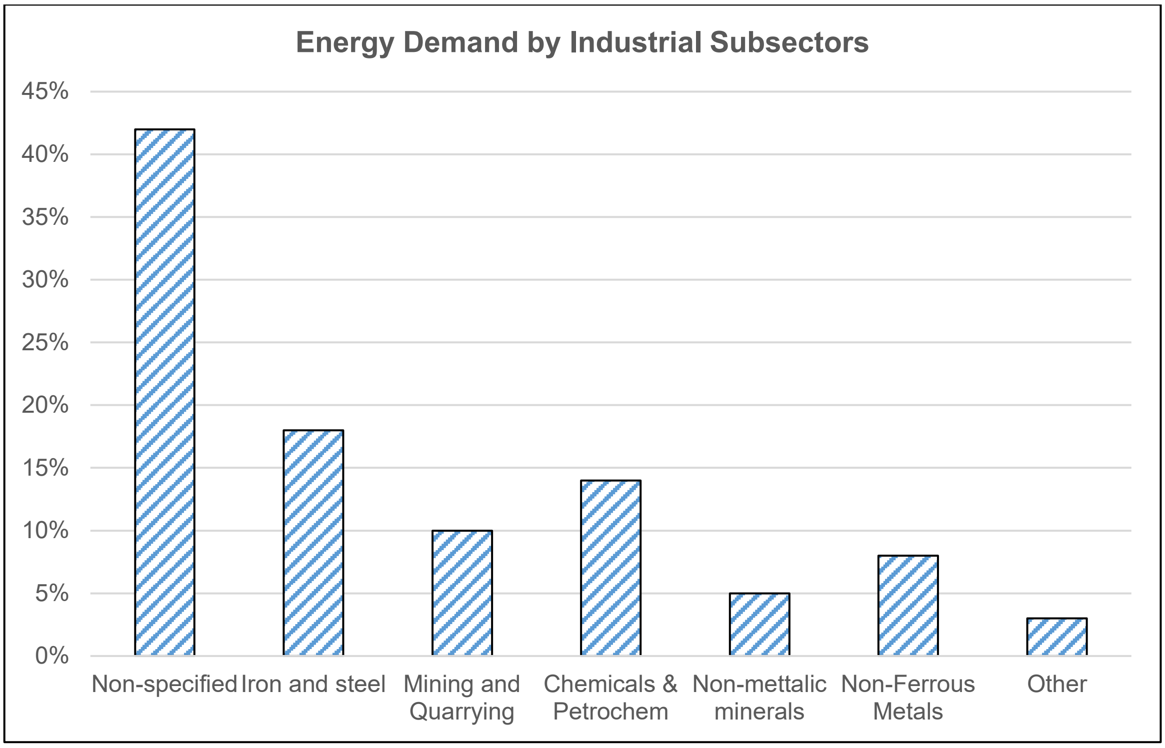

Figure 26: Energy demand by electrical subsector

Source: Department of Energy (2019)

The diagram above highlights non-specified consumers are the largest customer segment in the industrial sector, iron and steel, mining and quarrying and chemicals and Petrochemicals are also amongst the larger consumers of electricity within the sector. This is aligned to the South Africa being a major producer and supplier of primary ferrous minerals and alloys. Coal, Platinum Group Minerals and Gold are three of the larger sub-customer segments within the mining segment. (Department of Energy, 2018)

2.2.2 Transport

The Transport sector accounts for 19% of South Africa's energy consumed. The energy demand within the transport sector relates to South Africa's modern and well-developed transport infrastructure. Road transport is the largest consumer of energy within this subsector with Petroleum products accounting for 99% of the energy demanded. (Department of Energy, 2018)

2.2.3 Commerce and Public Services Sector

The commercial and public services sector consumes 14% of energy in South Africa. This sector comprises the following sub-sectors: (Department of Energy (2019)):

- Financial services;
- Information Technology;
- Retail;
- Tourism;
- Services; and
- Government and quasi government services that provide goods and services to the public for free.

2.2.4 Residential sector

The residential sector consumer is a relatively large consumer of energy at 8% of the overall energy demand. This is attributed to 86% of households in South Africa having access to electricity. Coal is used in areas where access to electricity is not available, and in areas that are located close to coal mines. This is due to coal being a relatively cheap and the fuel source that can be used for cooking and heating purposes. (Department of Energy, 2018).

2.2.5 Agricultural Sector

Agriculture accounts for 6% of the overall energy consumed. This sector can be separated into the well-developed commercial farming sector, as well as the subsistence based farming practices that occur within the rural areas. It should be noted that the bulk of the energy requirements (66%) within the agricultural sector is liquid fuels for the transportation of raw materials, intermediary products and final products. Electricity accounted for 32% of the energy demand within this subsector. (Department of Energy, 2018)

2.2.6 Energy Intensive User Group

The Energy Intensive Users Group of Southern Africa (EIUG) was formed in 1999 as a voluntary, non-profit organisation whose members account for over 40% of electricity consumed in South Africa. The contribution of the current members to the different sectors of the South African economy is presented below. (Energy Intensive Users Group of Southern Africa, 2020)

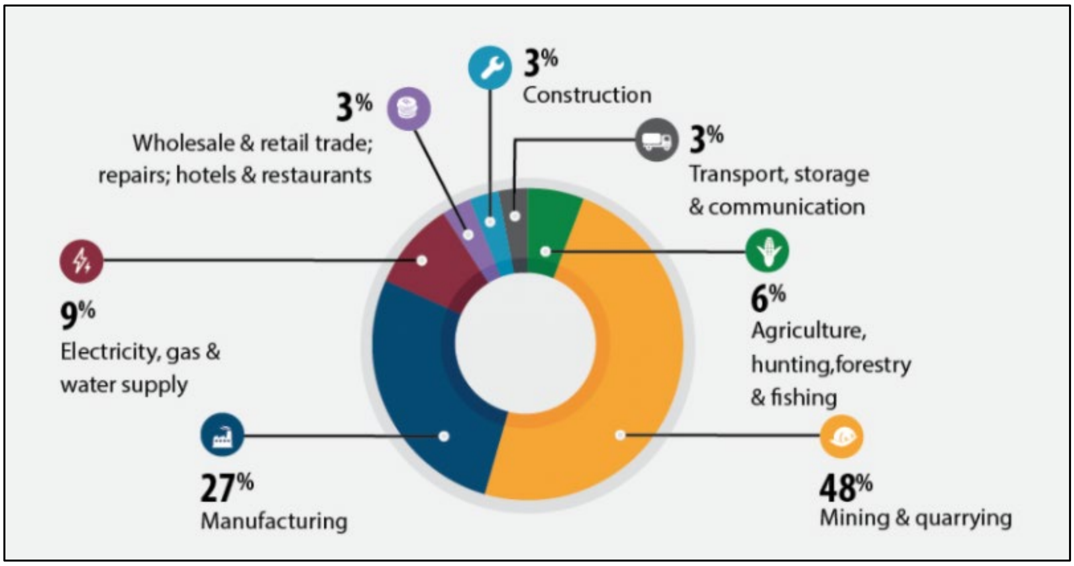

Figure 27: Contribution of EIUG members to different sectors

Source: EUIG (2020)

Manufacturing, mining and quarrying are seen to have the highest consumption within EIUG members. This highlights that there could be significant impact on the water to energy market if this sector could be targeted and unlocked.

It should also be noted that Rand Water is a member of the EIUG. Rand Water is a member of EUIG and is seen to be a high energy user. Rand Water is a Water Board that is mandated to provide bulk water services. This highlights the potential to consider other large water boards and bulk water services providers as potential customers in the water to energy market. A list of the members of EIUG is presented in Appendix C: Members of EUIG.

2.3 Challenges experienced in the energy market

Essentially water to energy projects could be a viable renewable energy source that could supply energy to the identified customers. These projects would need to provide a compelling value proposition to these customers. This section of the report highlights the key challenges that these customers face and need to be understood in order to design an appropriate solution.

2.3.1 Quality and reliability of supply

The EUIG focusses on addressing areas that are seen to be material to their members. These focus areas and the link to the challenges in the energy market is presented in the table below.

Table 38: Priority Areas for the EIUG

Priority Area	Comment
Quality of supply	EIUG engages with suppliers to ensure that the supply of energy adheres to the prescribed standards that allow for normal operations to run. This highlights that energy users require a source that is able to provide a consistent quality of fuel. The variation in quality should not materially impact on the operations of the end user.
Reliable supply	The EIUG is dedicated to working with stakeholders to ensure the uninterrupted supply of energy. This highlights that the assurance of supply is very important as unplanned for interruptions will have a material impact on the end user.
Affordable energy	The EIUG aims to ensure internationally competitive energy tariffs that are affordable and sustainable. This highlights the importance of providing energy at a level that is affordable to the end user over a period of time.

The table above highlights key issues that high energy users deem a reliable and cost-effective energy supply an important consideration. However, these issues are also seen to be relevant to domestic customers and other customer categories when considering a suitable energy source.

Affordable and reliable energy supply must also be considered against the backdrop of the current interruptions to electricity supply (load shedding) and the decision by the National Energy Regulator of South Africa (NERSA) to grant Eskom an effective tariff increase of 13.8% for 2019/20. This may result in users seeking out more reliable and cost-effective solutions (Polity, 2019). This could provide an opportunity for water to energy solutions that can provide reliable and cost-effective solutions.

2.3.2 Clean Energy

South Africa largely remains dependent on Eskom for the generation, transmission and distribution of electricity. However, Eskom generates 90% of its electricity from coal. The use of coal as a fuel source to generate electricity is seen to have a negative impact on the environment and public health with air pollution and global warming seen to be the most severe (Union of Concerned Scientists, 2017). IRP2019 has committed to a more diversified energy mix that also aims to reduce the emission of Greenhouse Gasses.

2.3.3 Wheeling

Wheeling is the financial transaction representing the transportation of third-party electrical energy (kWh) over the distribution network which allows for the third party supplier to sell this electrical energy to a customer at that customer's point of supply (South African Independent Power Producers Assosciation, 2019).

There is often an associated fee (wheeling tariff) paid by the user to the infrastructure owner for the use of transmission and/or distribution infrastructure. The main risk with wheeling is the difficulty in establishing the tariff that should be charged for wheeling. A further risk that is noted is the loss of income to the municipality from the customer who is purchasing the electricity through the wheeling process (SALGA, 2018).

NERSA introduced regulations around wheeling in 2011 requiring all electricity generators (public and private) to be licensed to generate and supply the network with electricity. However, the issuing of generation licenses has been a very slow and tedious process. (ESI Africa, 2020).

2.3.4 Challenges for municipalities

Municipalities have a key role within the water to energy market as WSA through the provision of water and electricity services. The key challenges and different scenarios relevant to the water to energy market for municipalities is presented in the table below.

Table 39: Municipal scenarios and challenges

Scenario	Key challenges
Procuring electricity from embedded small-scale generators (SSEG)	Risk of loss of income as a result of increasing numbers of SSEG purchasing less electricity from the municipality. Loss of revenue could be compounded if tariffs are increased to compensate for initial loss of revenue. Safety risk if system is not in place to allow for SSEG to connect to the grid.
Procuring electricity from an IPP	PPA does need to be in place and the tariff escalation should be viable over the duration of the agreement. Capacity constraints in managing the technical and financial complexity associated with these projects. Regulatory challenges regarding the legal approvals that are required including a Section 34 determination in terms of the New Generation Regulations of 2011. There is no guarantee in the outcome of this process.
Generating renewable energy for own use	Primary risk is the upfront capital cost associated with the technology. This will require an assessment of the financial viability of the project over a long-term period.
Generating renewable energy for sale	The capital requirement for these types of projects can be large. Capacity is also required to manage the complex financial, technical and contractual elements associated with projects of this nature

Source: SALGA (2018)

The table above highlights that whilst municipalities are seen to be a key component within the water to energy market. There are several barriers to entry that would need to be addressed.

2.4 The link between the water and energy markets

This chapter of the report has largely focussed on energy demand, but it is important to highlight the link between large energy users and large water users, as this will greatly assist in identifying and segmenting the water to energy market by matching supply to demand. The table below provides an indication of the large water users in South Africa.

Table 40: Large water users in South Africa

Large water users	%
Irrigation	56.9%
Industry	16.3%
Water Supply Service	15.7%
Commercial	5.1%
Mining	4.8%
Other	1.3%

Source: DWS (2020)

The table above highlights that the largest water users in the country is irrigation (agriculture), Industry and water supply services. This aligns to the industrial, residential and agricultural sectors that were seen to be amongst the sectors with the highest energy demand. The diagram below provides an indication of the annual consumption by different water users per catchment in South Africa.

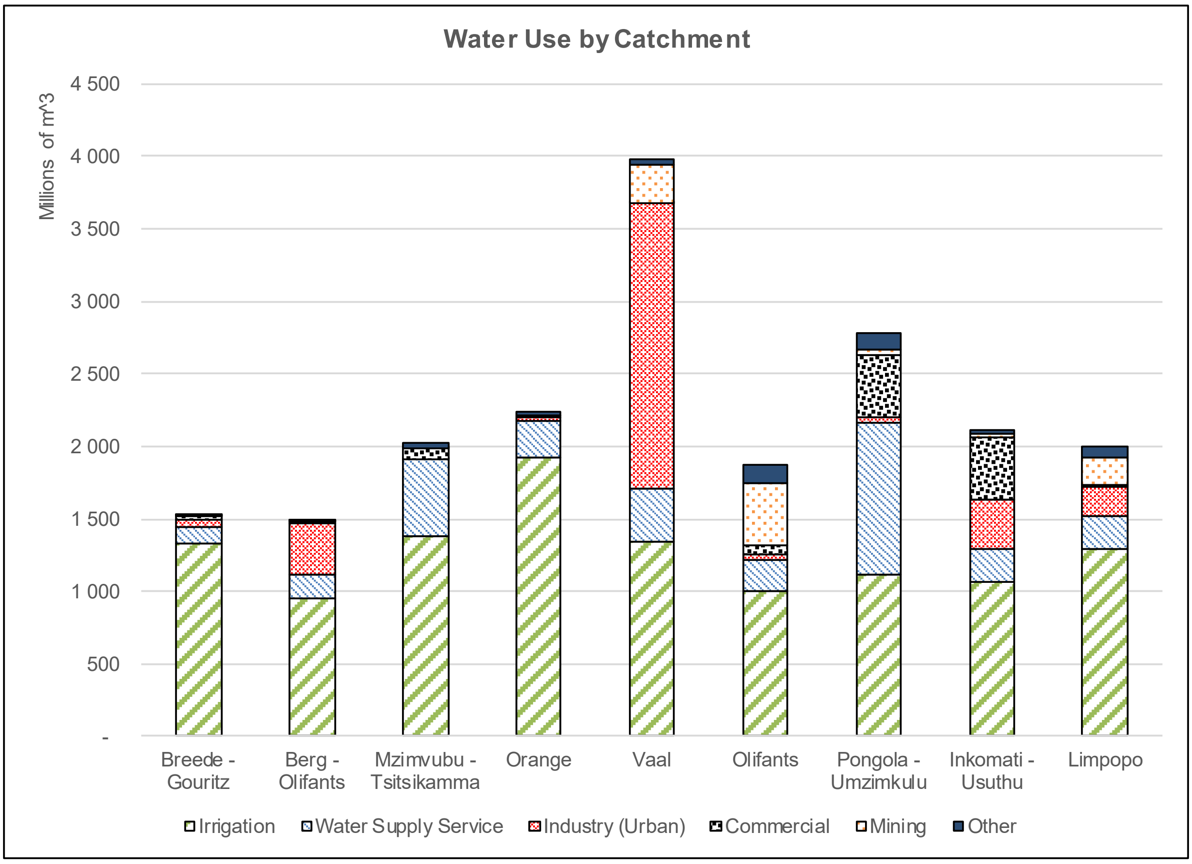

Figure 28: Water User Consumption per catchment

Source: DWS (2020)

The diagram above highlights that agriculture has is a significant consumer of water across all catchments in South Africa with the Vaal catchment having the highest water demand in the country. This demand appears to be driven by the large demand by industry within this catchment.

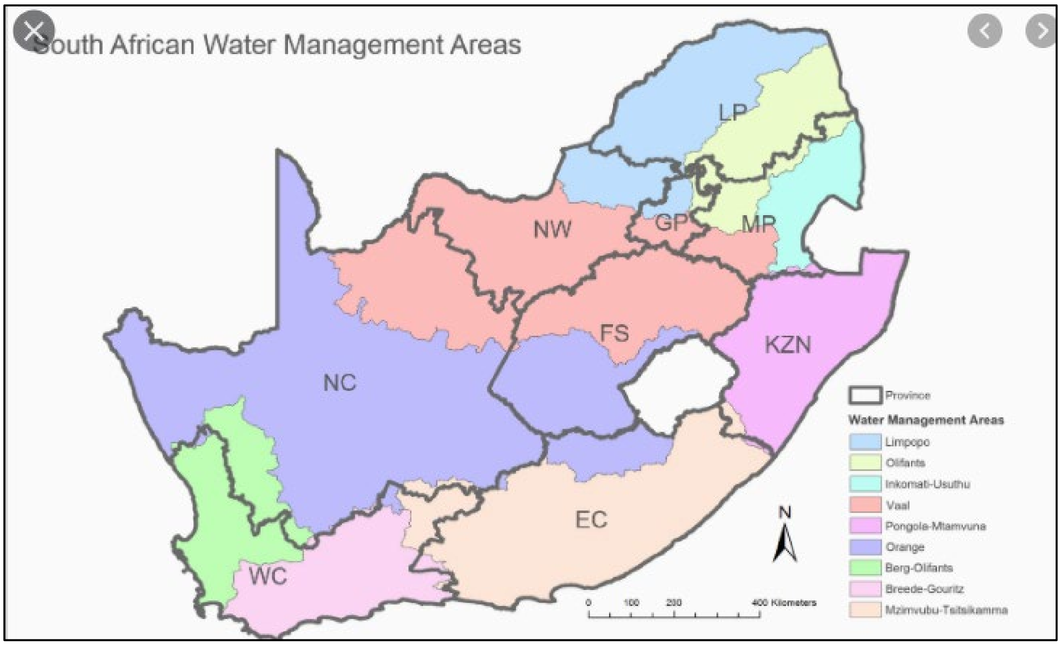

Figure 29: South Africa Water Management Areas

Source: (StatsSA, 2017)

The diagram above provides an indication of the Water Management Areas by geographic location in South Africa. The Vaal CMA covers the North West, Free State, Gauteng and Mpumalanga. The Western Cape has the second highest water use in the country with the bulk of the Berg-Olifants and Breede-Gouritz catchments being located in this province. Thus, the potential agricultural market is seen to have the highest potential in this region.

Figure 28: Water User Consumption per catchment above also highlights the importance of water supply services. It is noted that municipalities have a key role to play in the provision of both electricity and water services to customers. In terms of electricity, municipalities are seen to be involved in the generation and distribution of electricity to consumers, whilst may also be required to perform the role of a Water Services Authority and/or Water Services Provider.

2.5 Conclusion

The energy market in South Africa is large and diverse. However, there is a clear link between water sources that can produce energy to customers that are large energy consumers

2.5.1 Key customer segments

The key customer segments for are presented in the table below.

Table 41: Key customer segments

Market segment	Comment
Industry and Mining	Industry generates the highest demand for energy in South Africa (52%). The EUIG represents 29 members that are seen to consume more than 40% of South Africa's electricity. Industry and Mining are the second highest water users in the country with the largest industrial water use being located within the Vaal catchment.
Agriculture	Irrigation uses the highest proportion of water in South Africa and also consumes 6% of the energy within the country. This represents a potential market segment that has a relatively high-water consumption profile across all catchments in the country.
Domestic	The residential market in South Africa accounts for 8% of energy but 15.7% of water being consumed by water supply services. This is seen to be for the provision of domestic water and sanitation services.
Municipalities	Municipalities are seen to have a key role to play in the provision of water and electricity services to their customers.
Water Boards	Rand Water is listed as on the 29 highest energy users in South Africa. The utility is also the largest Water Board in the country. It is possible that given the scale of operations, Water Boards may be well placed to benefit from Water to Energy interventions.

2.5.2 Challenges within the energy market

Quality of supply, reliability of supply and affordability of energy appear to be key challenges that need to be considered when providing an energy solution. The solution must operate in a manner that ensures that the customer can reliably use the energy supplier on a regular and cost-effective basis.

The use of coal as a fuel source to generate electricity is seen to have a negative impact on the environment and public health with air pollution and global warming seen to be the most severe (Union of Concerned Scientists, 2017). IRP2019 has committed to a more diversified energy mix that also aims to reduce the emission of Greenhouse Gasses.

The recent tariff increases provide a further opportunity as customers a cost effective and reliable energy solution. This coupled with the national drive to move towards a ‘cleaner’ energy solution highlights the value proposition of the opportunity that could be unlocked within the water to energy market.

Municipalities have an important role within the water to energy market. However, there are several barriers to entry that would need to be addressed. These barriers include the high capital requirement, capacity to manage and execute these complex projects and the regulatory challenges.

2.5.3 An opportunity for water to energy projects

The current energy supply market in South Africa is dominated by coal (69%) with renewables and waste having a relatively small market supply share (11%). However, given the focus of IRP2019 there is a clear need to increase the supply from renewable energy sources. This presents the opportunity for water driven energy solutions.

The water to energy projects must provide customers with an attractive value proposition that addresses the challenges being faced by customers. These solutions would thus need to provide reliable and cost-effective energy to the identified customers.

3. THE POTENTIAL FOR WATER TO ENERGY PROJECTS

The preceding Chapter of this report highlighted the different customers that would benefit from sourcing their energy from water sources. There are various technologies that are able to extract the energy inherent in water sources. However, the customer requires a reliable and cost-effective solution. Therefore, emerging innovations would not be able to unlock investment for water to energy projects and the focus must be on mature technologies and processes.

4. THE VARIOUS PROCESSES THAT COULD EXTRACT ENERGY INHERENT IN WATER SOURCES WERE EVALUATED BY UNDERSTANDING THE TECHNOLOGY READINESS LEVELS, MARKET READINESS LEVELS AND EVALUATED USING A MCDA PROCESS. INFORMATION ON THE EVALUATION OF THE TECHNOLOGIES THAT WERE CONSIDERED ARE PRESENTED IN APPENDIX C.

The technologies that were seen to have the greatest potential to unlock the water to energy market were Anaerobic Digestion and Hydropower. The market potential for these technologies and barriers to entry are discussed further within this chapter of the report.

4.1 Anaerobic digestion

Anaerobic digestion has been identified as a process that could be effectively utilised to extract the electrical energy inherent in wastewater sludge. This section of the report details the potential application in the South African water sector.

4.1.1 The market potential in South Africa

There are two broad markets that can be applicable to anaerobic digestion in South Africa. These are installations at wastewater treatment works (WWTW) and installations in rural areas. However, the application in rural areas is seen to be limited due to the relatively high costs and the need for additional feedstock to supplement the wastewater sludge. The focus of this section of the report will apply to the application at municipal WWTW.

A previously completed study highlighted that there are 39 sites that are feasible for CHP projects with the only current CHP pilot project being installed at Northern WWTW at the City of Johannesburg (GIZ, 2016). The table below provides an overall indication of the CHP Potential at the WWTW sites that have been deemed to be viable.

Table 42: Summary of feasible anaerobic digestion for CHP

Parameter	Total Plant Capacity (Ml/day)	Electrical Power (kW_e)	Thermal power (kW_t)	Potential life cycle saving (R million)
Total “sewage’ CHP potential (>10 Ml/day)	5 499	61 370	67 507	
Total existing infrastructure CHP Potential	4 453	33 369	36 706	
Total feasible CHP Potential	3 523	27 145	29 860	2 636

Source: GIZ (2016)

The table above highlights that there is potential 27.1 MW of electrical power and 29.8 MW of thermal power that can be generated at the 39 sites that the study deemed to be feasible with potential savings of R2.6 billion over the life cycle of these projects. 27 145 kWe is the equivalent to 26 421 homes consuming 20 kWh per day.

It is possible that there are additional sites that may now be viable because of the electrical tariff increases or if blended finance is used to reduce the financing costs of these projects. Nevertheless, there is a strong market potential for the generation of biogas from anaerobic digestion at WWTW in South Africa.

4.1.2 Barriers to market entry

Whilst the GIZ study highlighted 39 sites that would be viable for biogas to energy installations, other suggests that sites that are larger than 15 Ml/day are more likely to be financially viable. However, biogas production can vary greatly, and it is therefore recommended that site specific detailed feasibility studies are undertaken. (Sustainable Energy Africa, 2017)

Operational risks need to be managed as the digester is usually at the 'back end' of the wastewater treatment process and the upstream process can negatively affect the quality and quantity of gas produced. Examples of operational risks include poorly functioning Head of Works that results in grit settling in digesters, as well as incorrectly operated primary sedimentation tanks. Both of these examples in a reduced volume and quality of gas produced at the digester. The result of ineffective operations is that engines do not operate optimally and have a higher-than-expected unit operating cost (Sustainable Energy Africa, 2017). This will negatively impact on the financial return of the project.

An additional operational risk that has been noted is that the energy generated at the WWTW is only sufficient to meet a portion of the site's energy requirements. Thus, the site will still require a grid connection to supply the remainder of the electricity requirements. Whilst there are engineering solutions that are available to mitigate against this risk, it does have the potential to cause synchronisation challenges and impact on the stability of the electrical network within the site.

It must also be noted that there are inherent challenges within the municipal wastewater sector. The Green Drop Report indicated that that almost half of the wastewater treatment works in South Africa were not functioning properly in 2013 and recent studies state that there is an excessive amount of raw sewage in the Vaal River (Toxopeus, 2019). There has been no data provided to suggest that the performance in the sector has since improved. The inherent challenges within the sector suggest that the inclusion of an additional unit operating process could add further complexity.

4.2 Hydropower

Hydropower or hydroelectricity refers to the power that derives from the force of energy from moving water (Van Dijk, 2017). It is considered a renewable energy source because the water cycle is constantly renewed by the sun and the process is seen to be constant, dependable and predictable (Van Dijk, 2017).

4.2.1 The market potential in South Africa

There are different applications of hydropower in South Africa. The market potential for the different applications of hydropower development is presented in the table below.

Table 43: Urban and rural opportunities in hydropower development

Application	Generation Capacity (MWh/annum)	MW	Equivalent no. of HH	Annual Revenue (ZAR)
Refurbishment/upgrading of existing plants in ownership of municipalities of DWA	70 000	10	9 722	98 000 000
Hydropower sets to existing (new) dam	500 000	71	69 444	700 000 000
Inter-basin Water Transfer Schemes	300 000	43	41 667	420 000 000
Municipal/Water Utility Distribution systems	375 000	54	52 083	525 000 000
"Greenfield" Hydropower sites	5000	0.71	694	7 000 000

Source: (Barta B., 2015)[2]

The table above highlights that there is significant Hydropower potential that has been identified in South Africa. The shaded cells in the table above provide a high-level indication of the electrical potential that has been identified in South Africa and the equivalent number of homes that could benefit at an average electricity consumption of 20 kWh per day.

Hydrokinetic power is seen to be a comparable energy generation option for rural electricity schemes when compared to other renewable energy sources (wind, PV and diesel generation (Kusakana & Vermaak, 2013). The implementation of small hydro plants is seen to be a cost-effective off-grid solution as capacity factors are high and generation costs can be relatively low (International Renewable Energy Agency, 2015).

There is a view that there are numerous hydropower opportunities in South Africa urban areas and these solutions are seen to be economically viable especially in existing water infrastructure is required (Van Dijk, 2017). This view is supported when considering that mini- and micro hydro offer cost effective-solutions as compared to distributed power generation

[2] The revenue generation potential is based on a tariff of R1.40 per kWh.

requirements, particularly at a household or village level (International Renewable Energy Agency, 2015).

City of Cape Town

The City of Cape Town (CoCT) has previously installed conduit hydropower turbines to provide electricity for the bulk water treatment works. The details of these installations are provided in the table below.

Table 44: Conduit hydropower in CoCT

Location	Turbine Capacity (kW)	Total turbine production / annum (kWh)
Wemmershoek WTW	130 x 2	2 163 720
Blackheath WTW	712	5 825 400
Faure WTW	1 475	12 274 950
Steenbras WTW	179 x 2	2 829 480
Total	**2 775**	**23 093 550**

Source: Sustainable Energy Africa (2017)

The technical and financial feasibility study of additional conduit hydropower in the City was completed in 2011. The report indicated that the CoCT could generate 35 GWh per annum at an average levelized cost of R0.38 /kWh. (Sustainable Energy Africa, 2017)

eThekwini Metropolitan Municipality

The table below provides an indication of the hydropower potential that has been identified in eThekwini Metropolitan Municipality.

Table 45: eThekwini conduit hydropower generation potential

Location	Size of hydro turbine (kW)
Theomore reservoir	71
Stone Bridge reservoir	104
Umhlanga Rocks reservoir	Between 26 and 177
Yellowfin and Escolar reservoir	Between 26 and 177
Avocado and Pomegranate reservoir	Between 26 and 177

Rand Water

Rand Water had identified four sites for the within their hydraulic network that would be able to produce 16 MW of electricity. The water supply to turbines will be tapped from the existing water supply pipelines and fed back to the pipeline. These plants were expected to be commissioned in 2014/15 (Rycroft, 2014). However, subsequent investigations suggest that

13 MW can be generated at these sites, and this has been identified as high priority projects (Rand Water, 2019).

4.2.2 Hydropower capacity in deep mining installations

There is opportunity to generate hydropower from either operating or defunct mining installations. The potential typology of power sourcing arrangements for mines are provided in the table below.

Table 46: Typical power-sourcing arrangements for mines

		Intermediate options						
	Self-supply	*Self-supply + CSR*	*Self-supply + sell to the grid*	*Grid supply + self-supply backup*	*Mines sell collectively to the grid*	*Mines invest in the grid*	*Mines serve as anchor demand for IPP*	*Grid supply*
Description	Mine produces its own power for its own needs	Mine provides power to community through mini-grids or off-grid solutions	Mine produces its own power and sells excess power to the grid	The mine is first connected to the grid and is moving into own-generation when more economical	Coordinated investment by a group of mines, producers, and users in one large power plant off-site connected to the grid	Mine invests with government in new, or in the upgrading of, power assets under different arrangements	Mine buys power from an IPP and serves as an anchor customer	Mine does not produce any power, but buys 100% from the grid
Main generation drivers	Diesel, HFO	Diesel, HFO	Coal, Gas, Hydro	Diesel, HFO	Diesel, HFO, Solar	Hydro, Gas	Any	Any
Presence	Mali and Guinea (hydro) Sierra Leone and Liberia (oil)	Guinea, Madagascar	Zimbabwe Mozambique, Cameroon	Congo, Dem. Rep. Tanzania	Ghana	Niger Congo, Dem. Rep.	South Africa	Mozambique Zambia

Source: Africa Power–Mining Database 2014, World Bank, Washington, DC.
Note: CSR = corporate social responsibility; HFO = heavy fuel oil; IPP = independent power producer.

The table above indicates that Hydropower solutions can be used by mines for their own power requirements, as well as, to supply to the grid. The benefit of sharing the power generation potential of a resource results in the full economies of scale being realised. The optimal sharing of power between the mine and the grid can be realized by determining the energy yield for the resource to the mine with the surplus to be sold to the grid at a cost-recovery tariff to the grid. (Banerjee et al., 2015)

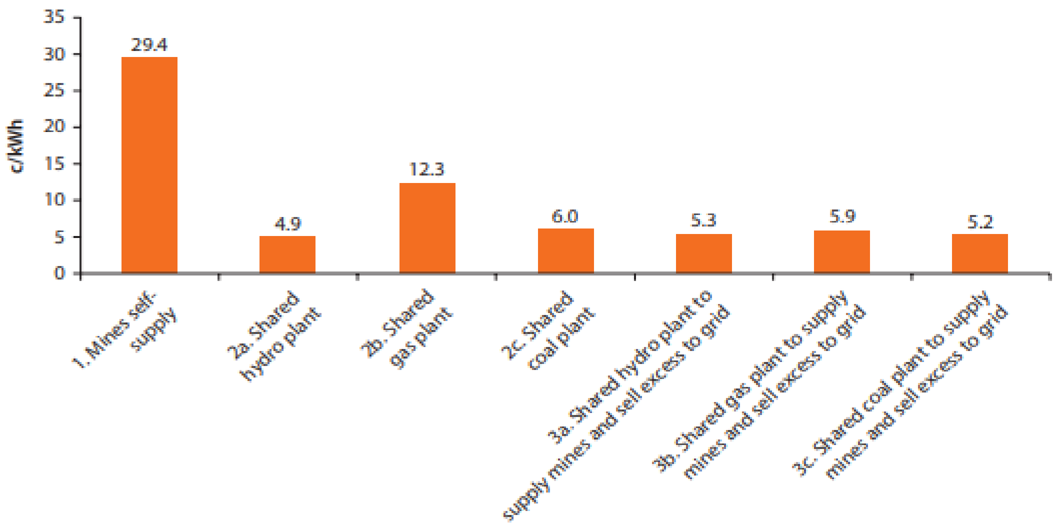

Figure 30: LCOE estimates for scenarios in Tanzania

The diagram above highlights the benefits of the different power sourcing arrangements for mines in Tanzania. This diagram highlights the reduced cost of electricity that economies of scale are able to provide.

It is possible to arrange a hydropower reticulation system depending on the layout of the mine and overall water balance. The costs associated with the hydropower appear to be favourable and the potential savings of electricity from external sources and reduction in peak demand requirements are considerable (Barta B., 2002)

Underground pumped storage hydro schemes can be developed from defunct mining undertakings. The mines that have suitable bedrock located at appropriate depths over 1 km can be developed in this way. Most of the deep gold mines in Gauteng can provide sufficient depth for this development and it has been estimated that this can produce capacity of 1 200 MW in Gauteng. (Barta B., 2002)

Underground pumped hydroelectric energy storage could have potential significance on South African gold mines that are suffering from power cuts. It has been noted that the mines in the Far West Rand gold fields in South Africa have the potential to generate between 0.5-1.5 GW per plant. The study found that these systems is both technically and economically viable and has recommended that a more detailed follow-up study is conducted as a base for establishing the world’s first reference plant in South Africa. (Winde, Kaiser, & Erasmus, 2017)

4.2.3 Barriers to market entry

The unclear policy framework from an electricity use perspective has been a barrier for the development of hydropower projects in South Africa has been the unclear policy framework from an electricity use perspective. REIPP has assisted in increasing policy certainty but developing grid feeding hydro schemes outside REIPP has become virtually impossible (Rycroft, 2014). However, this would need to be revaluated in the light of the decision to allow municipalities would be able to procure electricity from independent power producers (The Presidency, 2020).

A further barrier to market entry is the relatively high capital expenditure that may be required for hydropower projects as compared to the relatively low electricity yields. Each potential hydropower site is unique with approximately 75% of the development costs being determined by the location and site conditions. The remaining 25% of the costs are relatively fixed and comprise the cost of manufacturing the electromechanical equipment. (Sustainable Energy Africa, 2017).

The increased capital cost to transfer the electricity generated to the site that it would be used, particularly in rural areas, may also limit the uptake of the technology. Operational risks are a further challenge as installations may be subjected to theft and vandalism particularly in remote applications.

The City of Cape Town, eThekwini Municipality and Rand Water have identified potential sites at which hydropower could be implemented. However, this indicates that the have delays with the execution of projects that are deemed to be technical and financially viable. Further support may be required to ensure the successful execution of these projects.

4.3 Financial Viability

Anaerobic digestion and hydropower are deemed to be technical viable solutions. The next item that would need to be addressed is the financial viability of the solution. The financial viability of a solution would need to be considered on a case-by-case basis as site conditions will have an impact on the capital expenditure required.

A financial viability assessment was completed to compare the financial implications of three different hydropower solutions. This assessment compared a 28kW, 50kW and 500kW systems.

The following assumptions were utilised to complete the financial viability assessment:

- Tariff – R1.40 /kWh;
- Inflation – 6.79%;
- Production factor – 0.9;
- Weighted Average Cost of Capital (WACC) – 9.59%; and
- Operating costs – 3% of capital expenditure.

The table below provides an indication of the modelled financial returns for different capacities.

Capacity (kW)	28	50	500
Capital requirements (R 000s)	2 184	4 920	31 043
Project NPV (R 000s)	1 009	189	30 585
Project IRR	13.35%	9.93%	17.1%
Payback Period	8.46	10.4	6.10
Discounted payback period	13.08	19.7	10.74

Figure 31: Financial returns for three types of systems[3]

The table above indicates that the financial viability of the solutions is driven by the capital cost and the volume of energy that can be sold at a particular price point. The table indicates

[3] The capital cost for the 28 kW and 50 kW systems were based on data provided by Sustainable Energy Africa (2017) and this was escalated by inflation to the base financial year. The capital cost of the 500 kW system was adjusted from the 28 kW and 50 kW systems.

that relatively longer payback periods for the smaller systems are due to the quantum of energy being produced.

4.3.1 Impact of increasing capital cost

The impact of increasing the capital cost of the selected projects by 20% on the baseline capital costs are presented in the table below. The impact of increasing the capital costs reduces the financial returns and increases the payback period.

Table 47: Financial returns with increase capital costs

Capacity (kW)	28	50	500
Capital requirements (R 000s)	2 621	5 904	37 252
Project NPV (R 000s)	318	(1 366)	20 774
Project IRR	10.63%	7.45%	14.1%
Payback Period	10.90	12.6	8.81
Discounted payback period	17.03	14.9	13.93

The table above highlights the marginal nature of these types of projects that a slight increase in capital costs can result in the projects not being financially viable. The larger projects are less susceptible to the increased capital costs.

4.3.2 Impact of increasing the tariff

The impact of increasing the tariff to the baseline financial model is presented in the table below. The impact of the increased tariff reduces the payback period of the investment, as well as, the renders the projects more attractive to investors.

Table 48: Financial returns with increase capital costs

Capacity (kW)	28	50	500
Capital requirements (R 000s)	2 184	4 920	31 043
Project NPV (R 000s)	1 901	1 782	46 514
Project IRR	16.33%	12.58%	20.5%
Payback Period	7.79	8.0	5.21
Discounted payback period	10.11	14.1	8.88

Increasing the tariff by 20% has a significant positive impact on the financial returns. This can be attributed to the higher sales in addition to the tariff increasing by inflation over the tenure of the investment (20 years)

4.4 Conclusion

The potential to generate electricity from water sources have been identified with several institutions considering implementing projects of this nature. This includes the potential to generate 27.1 MW of electrical power and 29.8 MW of thermal power that can be generated at the 39 WWTW that are deemed to be feasible with potential savings of R2.6 billion over the life cycle of these projects. 27 145 kWe is the equivalent to 26 421 homes consuming 20 kWh per day.

Hydropower has potential application in the municipal, water board and mining markets. The potential application of hydropower projects are indicated in the table below.

Table 49: Urban and rural opportunities in hydropower development

Application	Generation Capacity (MWh/annum)	MW	Equivalent no. of HH	Annual Revenue (ZAR)
Hydropower sets to existing (new) dam	500 000	71	69 444	700 000 000
Municipal/Water Utility Distribution systems (Hydropower)	375 000	54	52 083	525 000 000
Inter-basin Water Transfer Schemes (Hydropower)	300 000	43	41 667	420 000 000
Refurbishment/upgrading of existing plants in ownership of municipalities or DWA (Hydropower)	70 000	10	9 722	98 000 000
"Greenfield" Hydropower sites	5 000	0.71	694	7 000 000

Source: (Barta B., 2015)[4]

The mining sector could contribute a potential 1 200 MW in Gauteng from mining applications. However, there is a need to confirm the practical application of hydropower solutions in mining applications.

Several studies have been completed by Municipalities and Water Boards and there appears to be delays conduit hydropower projects despite being considered fairly attractive. This indicates that further support will be required to address the barriers to market entry and ensure that these projects can be successfully implemented.

A financial viability assessment would need to be undertaken on a site specific basis as the capital expenditure required to implement a project will vary. This could include the distribution infrastructure to transport the electricity to a customer.

[4] The revenue generation potential is based on a tariff of R1.40 per kWh.

5. STRUCTURING A BANKABLE PROJECT

The purpose of the study is focussed on unlocking investment for water to energy projects. A market exists for projects of this nature, whilst several potential projects have been deemed as technically and financially viable. However, the challenge has been in the execution of the project. This section of the report presents the requirements for a bankable project.

5.1 What is a bankable project?

In the UK, the Five Case Model methodology is used across government departments and the private sector to develop business cases. The model provides a framework that is around the following: (Barker & Barton, 2019)

- The **Strategic Case** demonstrates why the project is needed and how it fits with relevant infrastructure and development strategies;
- The **Economic Case** provides an analysis of all available options, including making better use of existing assets, and demonstrates the value for money of the preferred way forward;
- The **Commercial Case** demonstrates commercial viability and project 'bankability';
- The **Financial Case** demonstrates affordability and how the project will be funded over its life-cycle; and
- The **Management Case** demonstrates whether the project is deliverable and how risk will be managed.

The review of literature around hydropower and biogas projects suggest that at the right scale and size, these projects have the potential to be commercially viable but there has been limited uptake. It is therefore important to understand the key risks that would need to be addressed in order to unlock these opportunities.

5.2 Bankability and risk

The bankability of an infrastructure project is determined at the project development stage. The entity responsible for executing the project aims to attract private capital and must decide on the key risk-sharing protocols of the project. Failure to allocate risks to the correct party will result in the project being unable to find investors and lenders. (Rana, 2017)

Appropriate risk management is essential to financiers, developers and investors (Wing & Jin, 2015). The main categories of risks that are associated with the renewable energy sector are presented in the table below.

Table 50: Risk type and sources of risk

Risk type	Sources of risk
Credit risk (borrower will default by failing to repay principal and interest in a timely manner	Default of renewable energy projects. Non-performance on renewable energy projects Low capacity factor
Market risk (potential losses due to market movements)	Low connection rate Low dispatch priority Discontinuous electricity output
Operational risk (risks resulting from the breakdown in people, systems and internal processes)	Volatile electricity output Outdated operating paradigm of the grid
Liquidity risk (capability of a firm to access financing and capital sources, as well as, to trade and realize its asset at fair value)	Non-existence of secondary market Long payback period
Political risk (risk of investment loss in a given country caused by changes in policy or political structure)	Unstable renewable energy policy

Source: Wing & Jin (2015)

Risks and barriers can threaten investment in renewable energy projects and thus prevent the uptake of desirable technologies (Lindlein & Mostert, 2005). An indication of some of these barriers are presented in the diagram below.

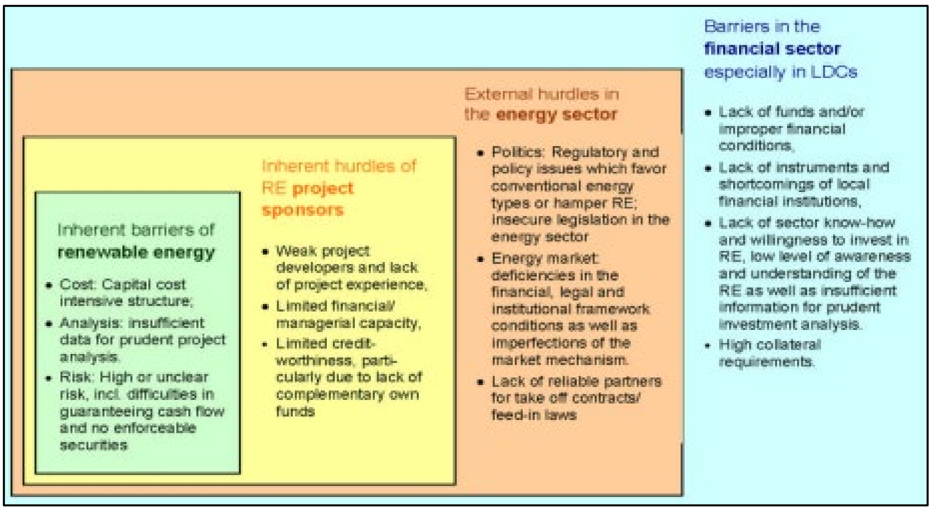

Figure 32: Barriers for RE in achieving financial closure

Source: Lindlein & Mostert (2005)

The diagram above highlights the challenges around financing and the ability of the Project Sponsor or Developer to execute the project. The Developer needs to have a sound understanding of the processes required to reach financial close. The diagram above also highlights that access to financing may be a challenge. However, engagements with funders suggest that the issue may be that the projects presented to funders are not bankable and therefor unable to attract funding.

Typical challenges that were identified by Funders for water to energy projects during the stakeholder phase of the project included:

- Concerns around the accuracy of the information provided in the business plan, particularly around the financial information;
- Poor business plans with unrealistic value propositions and overly optimistic cashflow projections;
- Lack of credible off-takes to provide reliable cash flow to the project and ensure that the project was financially sustainable;
- Poor understanding of legal; and
- Concerns about the ability of the developer to fund the equity component of a project.

5.3 Project development cycle

The project development cycle typically results in the development of an asset and operation and maintenance over an Expected Useful Life. The project development cycle of an infrastructure asset is presented in the diagram below.

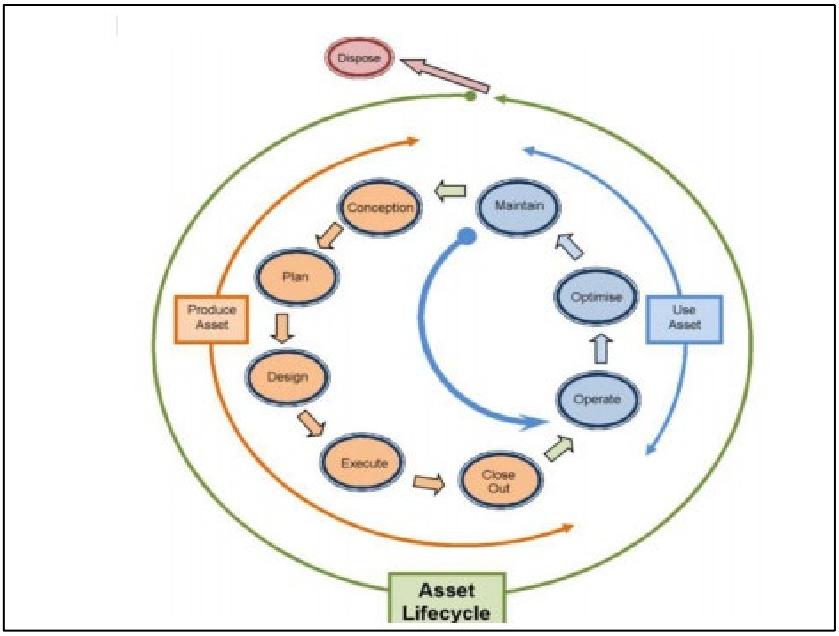

Figure 33: Asset lifecycle

Source: ECSA (2019)

The diagram above highlights the typical produce of a conventional engineering project from concept and design, through to implementation, operation and maintenance (ECSA, 2019). Thus, it is expected that a water to energy project would need to follow a similar process if the opportunity is to be unlocked.

The maybe different role players that are involved during the different elements of the project development cycle. This could include consulting engineers during the concept and planning phases, followed by contractors during the construction phase. However, the project owner or developer is involved through all the development phases and is crucial in ensuring the successful implementation of the project.

The project owner would need to take responsibility for the project and be able to identify the appropriate parties that need to be included on the project during the different phases. The Developer could contract appropriate parties to execute the required phases of the project.

Typically, funders from Development Finance Institutions (DFIs) would require a prefeasibility report and business plan to evaluate the potential to further develop the project. A prefeasibility report would include: (Sustainable Energy Africa, 2017)

- Site description and data;
- Design concept;
- Modelled design results (e.g. plant output);
- Grid connection details (location, cost, line length, etc.);
- Infrastructure costs;
- Financial modelling (capital and operating expenditure, funding, interest, energy produced, etc.); and
- Conclusions and recommendations.

In the case of limited-recourse financing, the lender would wish to exercise tight control over the project, including contracting and insurance, amongst others. They would require an independent technical report of the project; will check any power purchase agreements (PPAs), operating and shareholder agreements; and would prefer contractors with a good track record. Risk can be reduced by using a contractor working on a turnkey fixed-price basis or signing long-term PPAs with secure off-takers. Lenders may step in to operate the project if it is not paying its debts. (Sustainable Energy Africa, 2017)

5.4 Conclusion

This section of the report highlights that there are several elements that need to be considered before a project can be considered bankable. These elements are more than the technologies that are being utilised and will need to be addressed to ensure that projects are bankable.

The broad requirements for a bankable project water to energy is presented in the diagram below.

Risk	Conception	Design	Build	Operate & Maintain
Political	Political support Regulatory environment that supports the implementation of WTE projects			
Financial	Ensure projects are financially viable	Cashflow to fund project development	Necessary agreements to execute projects	
	Usually funded by the Developer	Certainity that the costs are accurate		Sufficient cashflow can be collected and used to service debt
Operational	Necessary skills to execute each phase			

Figure 34: Water to energy project requirements

It is noted that the there is also a need to address the technology and legislative risk to ensure a project is bankable. This has been discussed in the relevant sections of this report. The framework presented above is used to develop the recommendations for the opportunities that have been identified.

6. OPPORTUNITIES MAP AND RECOMMENDATIONS

A review of applicable water and electricity regulations, policies and plans indicated that there is a strong alignment between legislation and the implementation of water to energy technologies. This is evidenced by the Integrated Resources Plan 2019 (IRP2019) which confirms hydropower and biogas to be predominantly featured as part of the proposed energy mix by 2030 which is aligned to the findings of this study.

6.1 Opportunities map

The diagram below provides an indication of the potential water to energy opportunities that funders may have an interest in.

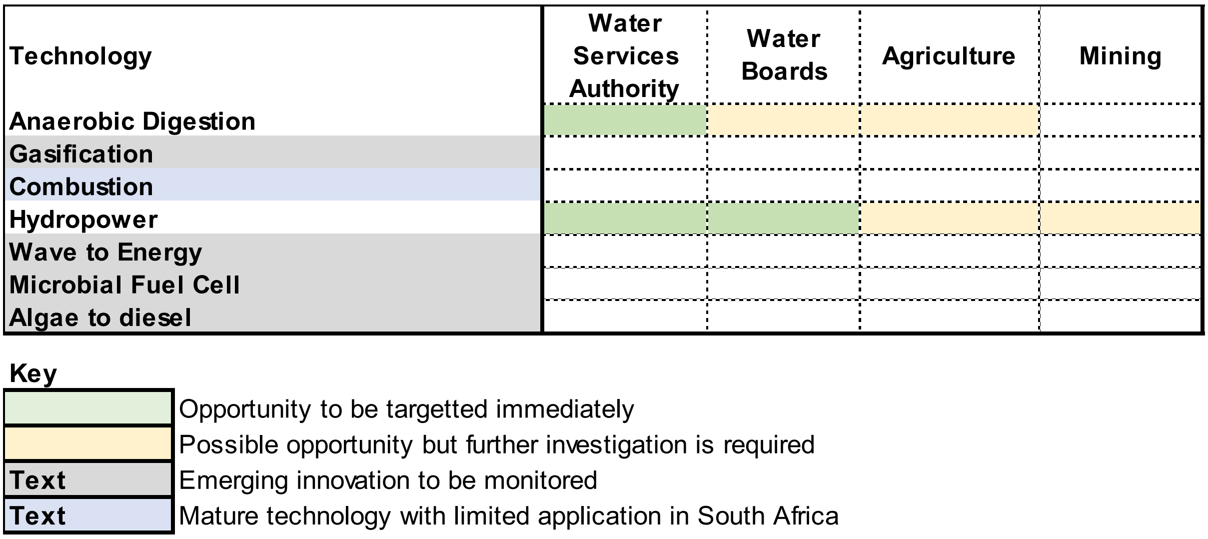

Figure 35: Opportunities map

The diagram above indicates that anaerobic digestion and hydropower provides clear opportunities for water to energy projects. These could be implemented in partnerships with WSA and Water Boards. Anaerobic digestion in agriculture markets may have application but would require an additional feed stock beyond sludge. Hydropower in agriculture may also be possible but this is expected to be site specific and is discussed further below.

It is expected that most of the electricity generated by the water to energy projects would be for onsite use or supply into the municipal grid. This reduces the risk of non-payment for the electricity generated from these projects. This also reduces the requirements to engage with additional parties for off-take agreements and/or the use of transmission infrastructure.

The mining sector could contribute a potential 1 200 MW in Gauteng from mining applications. However, there is a need to confirm the practical application of hydropower solutions or energy recovery in mining applications. It is possible that this electricity could be used on site or supplied directly to industry or the electrical grid depending on the location of the project or operational state of the mine.

Emerging water to energy innovations in should be monitored as these are at varying levels of technology development. There may be potential application of these technologies over the medium term once the value proposition has been confirmed.

6.2 Biogas projects in municipalities

There have been studies that have been completed that highlight the potential of generating biogas from wastewater sludge with 39 sites having been viewed as viable and have the ability to produce 27.1 MW of electricity. However, a high-level assessment of the potential sites indicates that installations at ten sites have the potential to generate 52% of the energy potential and save 63% of the savings that was identified. These sites are presented in the table below.

Table 51: Sites with biogas potential

No	Province	Site	Municipality	Plant capacity (Ml/day)	Potential electrical power (kWe)	Potential savings (R mill)
1	Gauteng	Northern Works	CoJ	450	1 848	243
2	Western Cape	Cape Flats	CoCT	200	2 551	215.2
3	Gauteng	Bushkoppies	CoJ	200	1 489	192.8
4	Gauteng	Olifantsvlei	CoJ	200	1 489	192.8
5	Gauteng	Rooiwal North	TSH	150	1 592	192.8
6	Gauteng	Waterval	EKH	155	1 591	189.6
7	Western Cape	Athlone	CoCT	120	1 042	127.3
8	Western Cape	Goudkoppies	CoCT	150	985	127.1
9	KZN	Kwa Mashu	ETH	80	772	89.4
10	KZN	Northern Works	ETH	70	713	83.6
				1 775	**14 072**	**1 654**

The process at each municipal WWTW is seen to be unique. It is for this reason that it is important to understand and assess the detail in the wastewater treatment process at each WWTW. It should also be noted that the availability and condition of existing infrastructure at the WWTW will have a significant impact on the capital requirements to generate biogas from electricity. It is therefore recommended that detailed feasibility studies be conducted at each of these sites to confirm the feasibility of the projects using site specific data.

The operating model to deliver these projects should be carefully considered. Wastewater treatment works is an integrated process, and the generation of biogas is linked to other processes within the system. The project boundary should be positioned at a site level should the delivery model be a PPP as this will ensure that integrated operations can be managed by one party.

6.3 Hydropower in municipalities and Water Boards

It has been noted that there has been interest shown by WSAs and Water Boards in the implementation of hydropower projects. Rand Water, City of Cape Town and eThekwini

Metropolitan Municipality have completed feasibility projects that confirm these projects are viable.

However, each potential hydropower site is unique with approximately 75% of the development costs being determined by the location and site conditions. The remaining 25% of the costs are relatively fixed and comprise the cost of manufacturing the electromechanical equipment. (Sustainable Energy Africa, 2017). This suggests that there is a need to update the feasibility studies and confirm the financial parameters, as well as, the operating model to ensure successful implication.

The hydropower opportunity exists at the micro, mini and small categories. However, it can be expected that the development costs for the micro categories could be prohibitive hence the recommendation to focus on municipalities and water boards as these institutions could benefit from aggregation that would then allocate the development costs across several sites.

It should also be noted that a large cost of hydropower projects could be the electrical connection that transfers the electricity produced to the location of the consumer. Proximity to use is expected to be closer in urban areas, whilst the distance to connect the production of electricity to the consumer in rural areas may render these projects unviable.

6.4 Other recommendations

These recommendations apply to biogas and hydropower installations and should be considered to ensure that these projects can be successfully implemented.

6.4.1 Political support and willingness

Political support and alignment will be required from all key stakeholders. This will have to be driven from Central Government by ensuring appropriate legislation and incentives are in place.

Incentives should also be introduced and aligned within the different institutions involved in the projects. These incentives should apply to staff that are involved in the different aspects of delivering and operating projects and promote increasing the use of renewable energy.

6.4.2 Financial

Studies have been completed that highlight the biogas and hydropower opportunities in municipalities. These should be updated to reflect the current cost structure and revenue stream.

The focus should be on water to energy projects in the larger metropolitan municipalities and Water Boards as they have the credibility and ability to service debt. These municipalities would usually be paying Eskom for the bulk electricity purchases. It may be possible on certain projects for the municipalities to realise a tariff that may be lower than the NERSA approved tariff for Eskom in the longer term. This could represent a savings for the municipality.

There is a need to consider allocating funding from Investors for the conception, design and build phase of WTE projects as municipalities have competing priorities on constrained budgets. This funding could be used to develop the PFS and level of design required to reach financial close and access debt funding for project implementation. This could increase the pace at which WTE projects are developed.

There may be the opportunity to consider blended finance in projects that are seen to be marginal. Blended finance leverages development funds and expertise to mobilize private investment is a crucial element in the increasing support for water projects. Blended financing interventions should be considered at an aggregated level.

Leading governments are providing financial incentives, streamlining investments approval procedures and developing more effective regulations and penalties that encourage investment in WTE projects. DFIs, foundations and impact investors can provide financial support and technical expertise to develop projects, create strong businesses cases and structure financing deals. (WWF, n.d)

DFIs and other development organisations can provide support in several ways. These include: (WWF, n.d)

- Providing concessional finance on below-market terms;
- Funding the early-stage development of a project (and taking on the risk that it fails);
- Accepting the initial tranche of project losses; and
- Providing finance guarantees that are then used to attract private capital.

In addition to the items identified above, financiers from the public and private sectors should collaborate and pool expertise to develop projects and mobilize capital at scale.

6.4.3 Operational

It is important to ensure that the resources with the requisite skills are included at the various phases of the project. It is often stated that public sector institutions experience challenges in operating and maintaining existing assets. This suggests that the operation and maintenance component could be outsourced either through contracting or using the Public-Private Partnership model.

The alternative delivery model is to consider establishing specialised units within the institutions to operate and maintain the facility. These units would need to ensure that adequate funding is provided for maintaining the facility and attracting resources with the required skills.

It should be noted that the PPP process would shift a significant portion of the design and development costs to the private sector. However, there would be a requirement to identify a credible off-taker for the electricity that would be willing to pay for the electricity generated over a period of time.

6.4.4 Development impact of water to energy projects

The impact of implementing water to energy projects have to be viewed beyond the financial benefits that may accrue to the Develop and other investors. The potential impact of implementing the water to energy opportunities that have been identified are significant in that:

- It contributes to enhancing South Africa's electricity supply;
- It could assist municipalities in obtaining electricity at a lower price than that provided by Eskom;
- Job creation benefits through each phase of project implementation;
- Economic and environmental benefits through investment in renewable energy and reduction on the reliance of coal; and
- It stimulates innovation and the implementation of circular economy principles.

7. REFERENCES

Adu, D., Zhang, J., Fang, Y., Suoming, L., & O. Darko, R. (2017). A Case Study of Status and Potential of Small Hydro-Plants in Southern African Development Community. *Energy Procedia*, 352-359.

African Union Commission. (2015). *Africa 2063: The Africa We Want.*

Banerjee, S., Romo, Z., McMahon, G., Perrine, T., Robinson, P., & Arroyo, I. (2015). *The Power of the Mine: A Transformative Opportunity for Sub-Saharan Africa.* World Bank.

Barker, S., & Barton, A. (2019). Project Preparation – how do you translate a concept into a bankable project? Global Infrastructure Hub.

Barta, B. (2002). *Baseline study – Hydropower in South Africa.* Department of Minerals and Energy.

Barta, B. (2015). Small hydropower opportunities in urban and rural water supply.

Business Tech. (2015). *Who is using all the water in South Africa*. Retrieved from Business Tech: https://businesstech.co.za/news/trending/104441/who-is-using-all-the-water-in-south-africa/

Department of Energy. (2018). 2018: South African Energy Sector Report.

Department of Energy. (2019). Integrated Resources Plan (IRP2019).

Department of Energy. (2019). The South African Energy Sector Report – 2019.

Department of Science and Technology. (2019). White Paper on Science, Technology and Innovation.

Department of Trade & Industry. (2018). Industrial Policy Action Plan 2018/19-2020/21.

Department of Trade and Industry. (2016). *The path to technology commercialisation.*

Department of Trade and Industry. (2017). *The Green Economy Sector in South Africa.*

Deutsche Geselschafr fur Internationale Zusammenarbelt. (2016). Biogas Potential: A Survey of South African Wastewater Treatment Works.

Do, M. H., Ngo, H. H., Guo, W. S., & Liu, Y. (2018). Challenges in the application of microbial fuel cells to wastewater treatment and energy production: A mini review. *Science of the Total Environment*.

ECSA. (2019). Discipline-specific training guidelines for Candidate Engineers in Civil Engineering.

Energy Intensive Users Group of Southern Africa. (2020). *About*. Retrieved from Energy Intensive Users Group of Southern Africa: https://eiug.org.za/

Engineering News. (2018, May 15). Government releases its tenth Industrial Policy Action Plan.

Engineering News. (2019). *Pioneering 1 MW wave-energy pilot project being built in Hermanus*. Retrieved from Engineering News:

https://www.engineeringnews.co.za/article/pioneering-1-mw-wave-energy-pilot-project-being-built-in-hermanus-2019-06-13/rep_id:4136

ESI Africa. (2020, February 29). *Op-Ed: Is power wheeling a solution to South Africa's energy crisis?* Retrieved from ESI Africa: https://www.esi-africa.com/industry-sectors/generation/op-ed-is-power-wheeling-a-solution-to-south-africas-energy-crisis/

Eskom. (2020). *Wave Power*. Retrieved from Eskom: http://www.eskom.co.za/AboutElectricity/ElectricityTechnologies/Pages/Wave_Power.aspx

Fleischman, N., Botha, M., & Germanis, J. (2014). Sewage sludge and biomass incineration in South Africa using a fluidized bed reactor. *South African Journal of Chemical Engineering*, 35-47.

GIZ. (2016). Biogas Potential: A survey of South African Wastewater Treatment Works. GIZ.

Gnude, V. G. (2016). Wastewater Treatment in Microbial Fuel Cells – An Overview. *Journal of Cleaner Production*, 289-303.

György Szabó, I. F. (November 2014,). THE CARBON FOOTPRINT OF A BIOGAS POWER PLANT. *Environmental Engineering and Management Journal – Technical University of Iasi, Romania*, Vol.13, No. 11, 2867-2874.

Hasenauer, R., Gschopf, A., & Weber, C. (2016). Technology Readiness, Market Readiness and the Triple Bottom Line: An empirical analysis of Innovating Startups in an Incubator. *2016 Proceedings of PICMET '16: Technology Management for Social Innovation.*

International Renewable Energy Agency. (2015). Africa 2030: Roadmap for a Renewable Energy Future.

International Renewable Energy Agency. (2015). *Renewable Energy Capacity Statistics.*

International Renewable Energy Agency. (2017). *Biogas for Domestic Cooking: Technology Brief.*

Investment and Infrastructure Office. (2020). Sustainable Infrastructure Development Symposium.

Kusakana, K., & Vermaak, H. (2013). Hydrokinetic power generation for rural electricity supply: Case of South Africa. *Renewable Energy*.

Lindlein, P., & Mostert, W. (2005). Barriers for RE in the steps towards financial closure. KfW.

Lo, C. (2019). Algal biofuel: The long Road to commercial viability.

Lyon, S., Ahmadzadeh, H., & Murry-Ewers, M. (2015). Algae-Based Wastewater Treatment for Biofuel Production: Processes, Species and Extraction Methods.

Msibi, S., & Kornelius, G. (2017). Potential for domestic biogas as household energy supply in South Africa. *Journal of Energy in South Africa*.

Mukumba, P., Makaka, G., & Mamphweli, S. (2018). Biogas technology in South Africa, Problems, Challenges and Solutions. *International Journal of Sustainable Energy and Environmental Research*, 58-69.

Musvoto, E., Mgwenya, N., Mangashen, H., & Macintosh, A. (2018). Energy recovery from Wastewater Sludge – A review of emerging and established technologies for the South African Industry. Water Research Commission.

Muvhiwa, R., Hildebrandt, D., Chimwani, N., Ngubevana, L., & Matambo, T. (2017). The impact and challenges of sustainable biogas implementation: moving towards a bio-based economy.

Nanotechnology Public Engagement. (2017). *Hydrogen South Africa – HySA.*

National Treasury. (2020). *Budget Review 2020.*

Others, D. (2000). Greenhouse Gas (GHG) Inventory for South Africa.

Polity. (2019). *News*. Retrieved from https://www.polity.org.za/article/electricity-tariff-increases-will-have-severe-economic-ramifications-for-south-africa-2019-03-08

Pretoria, G. K.-U. (October 2016). *Potential for biogas as domestic energy supply in South Africa.* Pretoria: University of Pretoria.

Rana, F. (2017). Preparing bankable infrastructure projects. World Bank.

Rand Water. (2019). 2019 Integrated Annual Report.

Rasimphi, T., & Tianrwo, D. (2019). Relevance of biogas technology to Vhembe district of the Limpopo province in South Africa. *Biotechnology Reports*.

Rice University. (2015). Algae from wastewater sources solves two problems: Biofuel and clean-up. ScienceDaily.

Rycroft, M. (2014). The potential of small hydro power plants in southern Africa. *Energize*, 18-22.

Rycroft, M. (2018). Microbial Fuel Cells: A new approach to waste-water treatment. *EE Publishers*.

SALGA. (2018). Renewable Energy Scenarios for Municipalities in South Africa.

Schnell, M., Horst, T., & Quicker, P. (2020). Thermal Treatment of Sewage Sludge in Germany: A review. *J Environ Manage*.

South African Independent Power Producers Association. (2019). *AMEU: Legal Framework and Wheeling of Electricity.*

StatsSA. (2017, February 2). *Four facts about our rivers that you probably didn't know*. Retrieved from StatsSA: http://www.statssa.gov.za/?p=9490

Stevens, A. P. (2019). Ocean energy could be the wave of the future. *Science News for Students*.

Sustainable Energy Africa. (2017). Sustainable energy solutions for South African local government.

Sustainable Energy Africa. (2017). Sustainable energy solutions for South African local government: A practical guide.

The Presidency. (2020). 2020 State of the Nation Address.

Toxopeus, M. (2019, February). *The state of sanitation and wastewater treatment services in South Africa*. Retrieved from Helen Suzman Foundation: https://hsf.org.za/publications/hsf-briefs/the-state-of-sanitation-and-wastewater-treatment-services-in-south-africa

U. S. Energy Information Administration. (2019, October). *Hydropower explained – Wave power*. Retrieved from U.S. Energy Information Administration: https://www.eia.gov/energyexplained/hydropower/wave-power.php

Umwelt Bundesamt. (2019). Sewage sludge management in Germany.

Union of Concerned Scientists. (2017, December 19). *Coal and Air Pollution*. Retrieved from Union of Concerned Scientists: https://ucsusa.org/resources/coal-and-air-pollution

Van Delft, J. (2017). Brandkop Conduit Hydropower Plant.

Van Dijk, M. (2017). Energy Recovery in Pipelines (Micro-turbines).

Winde, F., Kaiser, F. K., & Erasmus, E. (2017). Exploring the use of deep level gold mines in South Africa for underground pumped hydroelectric energy storage schemes. *Renewable and Sustainable Energy Reviews*, 668-682.

Wing, L. C., & Jin, Z. (2015). Risk management methods applied to renewable and sustainable energy: A review. *Journal of Electrical and Electronic Engineering*, 1-12.

Wlodarczyk, P., & Wlodarczyk, B. (2019). Wastewater Treatment and Electricity Production in Microbial Fuel Cell with Cu-B Alloy as the Cathode Catalyst. *Catalysts*.

WWF. (n.d). Seizing the water opportunity.

8. APPENDIX A: METHODOLOGY

To meet the project objectives, the study will be carried out in **four** main phases:

1. Inception;
2. Market Segmentation Analysis;
3. Opportunities map and Recommendations; and
4. Journal article and project close out.

8.1 Phase 1: Inception

The inception meeting was convened on 26 February 2020 with the Water Research Commission (WRC) Research Manager. The purpose of this meeting was to discuss the proposal and confirm that all elements met with the requirements of the PMU. The salient points of the discussion were captured and presented in the Phase 1 report

8.2 Phase 2: Market Segmentation Analysis

A market segmentation analysis of the water to energy sector was conducted during Phase 2 of the study. This was largely desktop based, with directed engagements with identified stakeholders and included the following:

8.2.1 Planning Framework in South Africa

The desktop review included a high-level review of applicable policy documents, national regulations and guidelines. Documents included in the review included:

- National Development Plan 2030
- Integrated Resources Plan
- Industry Policy Action Plan
- Renewable Energy Independent Power Production Programme (REIPP)

This approach ensured the outputs of the study are aligned to the national objectives stated in the abovementioned documents. As an example, the Integrated Resources Plan 2019 (IRP2019) states that *the generation of electricity and heat from biogas holds huge potential in South Africa at both a large and small scale*.

Hydropower has also been identified as an area that will need to be included into the preferred energy mix (Department of Energy, 2019). Therefore, to ensure that the study is relevant and not merely a theoretical exercise, the opportunities and recommendations that emerge from the study should be linked to strategic national objectives.

8.2.2 Review of other studies

The literature review also included studies that have been completed on the potential for the water to energy sector in South Africa. This included studies that have been commissioned by the WRC, other stakeholders (GIZ, CSIR, etc.) and Bosch Projects. Where practical, the study drew from lessons learnt from international research and/ or projects, especially where there were similarities with South Africa (if any) on areas of fiscal policy, legislation and governance for the water and energy sectors. This ensured that the study built on the current body of work that is available in the sector.

This review shall also include a scan of wastewater to energy and mini-hydro projects that have been completed locally and internationally. This will provide an indication of the criteria that is required to successfully implement projects of this nature.

The implications of the following items mentioned by the South Africa President, Mr Cyril Ramaphosa, at the State of the Nation Address on 13 February 2020 were also explored:

- A Section 34 Ministerial Determination will be issued to give effect to the IRP2019, enabling the development of additional grid capacity from renewable energy, natural gas, hydro power, battery storage and coal;
- Bid window 5 of the REIPP will be opened and projects from bid window 4 will be completed;
- Measures will be put in place to enable municipalities in good financial standing to procure their own power from independent power producers; and
- The Infrastructure Fund will invest in areas such as independent water production and municipal bulk infrastructure.

8.2.3 Technology Mapping

A high-level literature review of the existing technologies within the water to energy sector formed the basis of the technology mapping exercise. Appropriate journals were also reviewed during this phase of the study. The following technologies were identified and was assessed during this phase of the study:

1. Anaerobic digestion;
2. Gasification;
3. Combustion;
4. Hydropower;
5. Wave to energy;
6. Microbial fuel cell; and
7. Algae to diesel.

The technology mapping exercise did not include technologies that may be established on water resources and which may not necessarily generate energy from the water source, such as solar panels on water sources and wind turbines in the ocean.

The technology mapping assessed the technology's functionality, level of maturity using the TRLs, and identify factors that may impact the successful marketisation of the technology, i.e. the scale at which the technology may be able to generate energy, the geographic location of the plant/technology, regulatory and institutional arrangements, etc.

8.2.4 Technology Readiness Levels

The target audience of the study are investors and the focus on mature technologies was seen to remove the technology risk associated with emerging technologies. It is unlikely that the targeted investors would be interested in technologies that have been not yet sufficiently developed and still have a relatively high technology risk. The framework that was used to assess the maturity of technologies is presented in the table below (Department of Trade and Industry, 2016).

Table 52: Technology Readiness Levels

	Definition	Comment
TRL 9	Actual system is proved by long-term use in the business system	Actual technology proved through successful deployment in an operational setting. The technology is applied in its final form under real-life conditions, such as those encountered in operational tests and evaluations. This includes using the invention under operational conditions.
TRL 8	Actual system completed and approved through test and demonstration	Actual technology completed and qualified through tests and demonstrations. This technology has been proven to work in its final form and under expected conditions. The prototype is tested and evaluated to see whether it meets operational requirements.
TRL 7	System prototype demonstration in an operational environment	Prototype ready for demonstration in an appropriate operational environment. The prototype should be near operational and ready for demonstration of an actual prototype in an operational environment. Activities include prototype field testing.

The study focussed on technologies that are at commercialisation stages (TRL9) in South Africa, or other parts of the world. This was used as the first filter to determine the technologies that will be considered during the market evaluation. Consideration was given to the inclusion of technologies at TRL7 & TRL8 during the literature review but these were not seen to sufficiently mature for commercialisation and thus the focus remained on mature technologies (TRL9).

It was also noted that TRL consists of the following three components: (Hasenauer, Gschopf, & Weber, 2016)

- Intellectual property;
- Integration readiness; and
- Manufacturing readiness.

Relevant international applications of the technologies have been included in the review to assist in detailing the successes and failures in implementation of these technologies in South Africa. The technology scan was based on existing information and was not seen to the focal point of the study. The focal point of the study is understanding the market potential and developing a strategy that could unlock the high potential segments.

The output of the technology scan resulted in three technologies being at TRL9. These technologies are:

- Anaerobic Digestion;
- Hydropower (Micro, Mini and Small); and
- Thermal Sewage Sludge Treatment.

8.2.5 Market Evaluation

The study aims at determining the potential market for generating and consuming energy from water sources in South Africa thus making the market evaluation a critical element in the study. After the technology mapping, exercise the market evaluation component was performed. The process outlined below was applied:

1. Evaluation and assessment of the current and potential availability of a commercial market for water to energy technologies, size[5] of the current and potential market value (in Rands) of the technology for commercialisation;

[5] At this stage, the market size can be quantified as potential energy capacity supplied to the grid, related services (O&M), capital investment required, revenue generation potential based on an applicable tariff. This will be explored further during the study. All assumptions made will be clearly specified.

2. The Market Readiness Level (MRL) of each of the technologies was assessed. Potential barriers to implementation, and the required interventions, will be identified;
3. The potential customers, buyers, facilitators and users shall be identified. Both the private and public sectors shall be included in the market evaluation; and
4. Identify market drivers, opportunities and risks for market penetration.

8.2.6 Market Readiness Levels

Market Readiness Level (MRL) measures the maturity of a given need in the market considering the potential obstacles (Hasenauer, Gschopf, & Weber, 2016). An indication of MRL is provided in the table below.

Table 53: Indication of MRL

MRL	Comment
1	Unsatisfied needs have been identified
2	Indication of potential social business opportunities
3	System analysis and social environment impact analysed
4	Market research
5	Target defined
6	Industry analysis with respect to social and environmental impact
7	Competitor's analysis and positioning
8	Value proposition defined
9	Product/service defined
10	Business model defined coherently

Source: Hasenauer et al. (2016)

MRL consists of four components:

- Supply readiness – to what degree are competitors' products available?
- Demand readiness – what is the demand for the product?
- Customer readiness – is the customer ready to use and adopt the product?
- Product readiness – is the product ready for widespread use?

The MRL for each of the technologies that are deemed to be at TRL9 was assessed using the framework above. The barriers to entry to the market were considered during Phase 3 of the study.

8.2.7 Multi-Criteria Decision Analysis

The outcomes of the research were evaluated using the Multi Criteria Decision Analysis (MCDA) method. This enabled the research team to compare, evaluate and score the different elements of each technology in order to determine which technologies have the strongest potential to be implemented in the water sector. This process will ensure that the market for each technology is evaluated holistically.

The study team shall imposed a minimum score that would need to be achieved in order for the technology to be considered during the next phase of the study. At this stage, the minimum score to be achieve is expected to be 70% to be considered during Phase 3.

8.2.8 Phase 2 Deliverable

The deliverable for Phase 2 was the Market Segmentation Analysis Report. This report highlighted the technologies that are seen to have the greatest market potential as well the potential customers that could benefit from projects generating energy from water sources.

8.3 Phase 3: Opportunities map and recommendations

Phase 3 of the study merged the outcomes of the technology mapping and market evaluation to develop a competitive framework from which recommendations and implementation plans were derived.

8.3.1 The Risk Approach

The objective of the study is to catalyse investment into the water to energy sector by mapping the market opportunities. Investments are often based on the identification and mitigation of risks towards appropriate parties to ensure that a transaction is structured in a manner that can attract funding from investors.

The PESTEL (Political, Environmental, Social, Technology, Economic, Legislative) framework shall be used as the basis for the risk identification and mitigation of risks associated with the technologies that achieved greater than 70% during phase 2 of the study. Forming part of this framework as well, was the technology’s potential market ability to address key national strategies such as the promotion of women, youth and Small, Medium and Micro Enterprises (SMMEs), as well as, promoting localized manufacturing of equipment.

The risk approach assisted in the development of strategies and recommendations pertaining to each market. These will serve as a useable guide to catalyse investment within the sector and lead to the successful commercialisation of promising technologies.

8.3.2 *Financial Viability Assessment*

In addition to the MCDA, it will be practical to perform a high level financial viability assessment for the technologies identified, using indicative financial assumptions, in order to rank these opportunities financially. The financial viability assessment would be determined using a discounted cash flow (DCF) model, and would include the determination of an IRR, NPV, Pay Back Period and other financial viability metrics used by investors and funders in making investment decisions. The key assumptions required to perform such a viability assessment would include the following:

- An estimate of the indicative capital costs to implement the innovation;
- An estimate of the indicative operating costs to manage and operate the innovation;
- The revenue earned, determining using the prevailing average price of the energy solution multiplied by projected units to be sold (e.g. R/kWh);
- A weighted average cost of capital, assuming an assumed capital structure; and
- Indicative capital structure, comprising commensurate debt and equity structures for funding similar projects.

The financial returns shall be based on a high-level financial modelling exercise that will be based on indicative capital and operating expenditure estimates provided by the technical team on the project. This will be based on the optimal sizing of mature technology options and the associated indicative revenue streams to generate returns that are attractive to the market.

Hydro and wastewater to energy solutions represent a large opportunity that could be unlocked as a result of this study. The project team interrogated data sets such as the Green Drop and Blue Drop reports to determine the potential sites at which projects of this nature can be implemented based on the criteria that is identified. Sites within Metropolitan, Local and Districts Municipalities were also considered.

8.3.3 *Opportunities map and recommendations*

The findings from Phase 3 of the study shall be synthesised and presented as an opportunities map with recommendations. The recommendations from the study will be based on information gathered from previous stages and be separated into short, medium and longer term interventions. Recommendations also include key stakeholders that will need to be engaged with in order to unlock the water to energy market opportunities.

8.3.4 *Stakeholder engagement*

The preliminary findings of the study was presented at a stakeholder workshop. This will provided an opportunity for key stakeholders to engage with the outputs of the study.

Feedback from the stakeholder engagement workshop was consolidated and presented in the final report from Phase 3.

Individual stakeholders were also identified and engaged during the course of the study. Their inputs have been consolidated in this report.

8.3.5 Phase 3 Deliverable

The deliverable for Phase 3 is this report.

8.4 Phase 4: Journal article and project close out

The findings from the study was summarised and presented as an article for publication in a relevant journal. The article could also be presented at an appropriate water to energy dialogue forum. This article has been completed and submitted.

9. APPENDIX B: THE NATIONAL LEGISLATIVE, PLANNING AND POLICY FRAMEWORK

This section of the report details the overarching legal framework and various national policy positions that are applicable to water to energy projects.

9.1 National Legislation

This section of the report outlines links to key South African regulations that are relevant to the water to energy sector.

9.1.1 National Water Act

The National Water Act (Act No. 36 of 1998) (NWA) was promulgated to ensure that the nation's water resources are protected, used, developed, conserved, managed and controlled in ways which take into account amongst other factors: promoting equitable access to water; redressing the results of past racial and gender discrimination; promoting the efficient, ***sustainable and beneficial use of water in the public interest***; facilitating social and economic development; protecting aquatic and associated ecosystems and their biological diversity; and meeting international obligations.

The National Government, acting through the Minister, has the power to regulate the use, flow and control of all water in South Africa. Therefore, the Department of Water and Sanitation (DWS) is the lead regulatory agent and manages all areas of the Act that pertains to water use and disposal. In terms of the NWA, water use licenses will be required where water is being used in instances as typically indicated below.

Table 54: Typical Water Use Checklist

	Water Uses
1	Taking water from a water resource
2	Storing water
3	Impeding of diverting the flow of water in a watercourse
4	Discharging waste or water containing waste into a water resource through a pipe, canal, sewer or other conduit
5	Disposing of waste in a manner which may detrimentally impact on a water resource
6	Disposing in any manner of water which contains waste from, or which has been heated in, any industrial or power generation process
7	Altering the bed, banks, course or characteristics of a watercourse

9.1.2 Water Services Act

The Water Services Act (Act No. 108 of 1997) provides for the right to basic services, which includes the right to have access to clean potable water and basic sanitation. The WSA applies to all users of water, without exception. Key definitions and clauses from the Act, pertinent to water to energy projects are noted below.

“industrial use” means the use of water for mining, manufacturing, ***generating electricity***, land-based transport, construction or any related purpose;

Section 7. Industrial use of water

Subject to subsection (3), no person may obtain water for industrial use from any source other than the distribution system of a water services provider nominated by the water services authority having jurisdiction in the area in question, without the approval of that water services authority.

Section 11. Duty to provide access to water services

Every water services authority has a duty to all consumers or potential consumers in its area of jurisdiction to progressively ensure efficient, affordable, economical and sustainable access to water services.

Affordable and economical access to water is aligned with national strategy objectives and could therefore encourage the pursuit of water to energy options in order to reduce the cost of treating and transporting water to consumers.

9.1.3 Guidelines for the Utilisation and Disposal of Wastewater Sludge Water Treatment Residues

The purpose of the Guidelines for the Utilisation and Disposal of Wastewater Sludge (TT 261/06) and Guidelines for the Utilisation and Disposal of Water Treatment Residues (TT 559/13) was to assist the relevant institutions to:

- Select appropriate sustainable management options for the specific waste streams whilst using and disposal of waste safely;
- Implement the requirements pertaining to the specific management option(s) selected. These include the operational and legal requirements; and
- Implement the monitoring requirements for the selected option(s).

DWS stipulates that waste generated should follow the Utilisation and Disposal Guidelines (TT 261/06 and TT 559/13) and that the Guidelines are therefore legally binding documents and not just recommendations.

The Guidelines consider thermal sludge management practices (sludge to energy) amongst other uses such as on-site and off-site disposal of sludge (i.e. stockpiles, landfills); the agricultural application of sludge (i.e. utilising useful constituents such as carbon and nutrient content in composts and fertilisers, soil conditioning) for both non-profit and as a “saleable product”; beneficial use of sludge (i.e. high-rate usage on agricultural land and capping of landfills) and beneficial use of sludge (i.e. bricks, cement).

9.1.4 Electricity Regulation Act

The generation, transmission, and distribution of energy in South Africa is governed by the Electricity Regulation Act (Act 4 of 2006). In cases where there is electricity to be generated, transmitted, distributed, traded, imported and exported, registration of the facility with the NERSA along with a license to generate are required under this Act.

The legislation does allow for any facility that intends to generate up to 1 MW of electricity for internal use only and is not connected to the national or municipal network to operate without a generation license.

A draft regulation amending the electricity regulations on new generation capacity was published for comment on 5 May 2020. The revised regulation, if promulgated, will permit a municipality to apply to the Minister to establish new generation capacity. The application will need to be accompanied by a detailed feasibility study, sound financial standing demonstration of the Municipality and be aligned to the Integrated Development Plan of that Municipality. The draft regulation amendment also notes that, before the buyer concludes a power purchase agreement, the buyer or the procurer must, subject to any approvals required in terms of the PFMA, Municipal Finance Management Act and Municipal Systems Act.

This provides an opportunity to change the energy landscape as it is expected to unlock the electricity market by encouraging the municipalities to invest into energy sources that are more cost effective and hopefully renewable and cheaper to the end user, and therefore it is also expected to stimulate private investment. There appears to be no specific biogas policy which may prohibit the full potential of the commercialisation of biogas projects in the market.

9.1.5 National Environmental Management Act

The National Environmental Management Act (Act 107 of 1998) (NEMA) provides for cooperative environmental governance by establishing principles for decision-making on matters effecting the environment. NEMA requires that the potential impact of listed activities on the environment must be considered, investigated, assessed (often referred to as the Environmental Impact Assessment (EIA) and reported on, and that these listed activities may not commence without authorisation.

Typical listed activities pertinent to the Water to Energy opportunities are noted in the table below.

Table 55: Triggers for EIA

	Typical Listed Activities
1	The construction of facilities or infrastructure for the generation of electricity where: the electricity output is more than 10 megawatts but less than 20 megawatts; the output is 10 megawatts or less, but the total extent of the facility covers an excess of 1 hectare.
	The construction of facilities or-infrastructure exceeding 1 000 metres in length for the bulk transportation of water, sewage or storm water: with an internal diameter of 0,36 metres or more; or with a peak throughput of 120 litres per second or more, excluding where: a. such facilities or infrastructure are for bulk transportation of water, sewage or storm water or storm water drainage inside a road reserve; or b. where such construction will occur within urban areas but further than 32 metres from a watercourse, measured from the edge of the watercourse.
	The construction of facilities or infrastructure for the transmission and distribution of electricity – outside urban areas or industrial complexes with a capacity of more than 33 but less than 275 kilovolts; or inside urban areas or industrial complexes with a capacity of 275 kilovolts or more.
	The construction of facilities or infrastructure for the off-stream storage of water, including dams and reservoirs, with a combined capacity of 50000 cubic metres or more, unless such storage falls within the ambit of activity 19 of Notice 545 of 2010;
	Construction or earth moving activities in the sea, an estuary, or within the littoral active zone or 100 metres inland of the high-water mark of the sea or an estuary, whichever is the greater, in respect of- (i) fixed or floating jetties and slipways, etc.
	The release of genetically modified organisms into the environment, where assessment for such release is required by the Genetically Modified Organisms Act, 1997 (Act No. 15 of 1997) or the National Environmental Management: Biodiversity Act, 2004 (Act No. 10 of 2004).

9.1.6 National Environmental Management: Air Quality Act

The Air Quality Act (No. 39 of 2004) denotes the minimum emission standards for various types of combustion installations. The Act also addresses monitoring requirements which may be relevant to particular water to energy technologies. It is worth noting that this Act does not deal with Greenhouse Gases (GHG) or the Greenhouse Gas Effect (Others, 2000). The impact that GHG, such as carbon dioxide and methane would have on the earth in terms of climate change/global warming has been documented since the late 1900s.

9.1.7 National Environmental Act: Waste Act, 2009

As of August 2019, sludges that contain a solids content of less than 60% may not be disposed of at a landfill site. As such, conventional dewatering technologies are currently not adequate to meet the required minimum solids content and there has been a need to investigate options that are able to achieve a dryer sludge content.

This specific legislated requirement is expected to encourage re-use, recovery and recycling of waste streams before disposal, in order to offset high costs associated with dewatering, drying and disposal of waste to landfill.

9.1.8 National Environment Management: Waste Amendment Act (2014)

The National Environment Management: Waste Amendment Act (2014) seeks to amend the National Environmental Management: Waste Act, 2008, so as to substitute and delete certain definitions amongst many other objectives and includes for the provision of waste management plans. The National Environment Management: Waste Amendment Act (2014) places an emphasis on the re-use, recovery and recycling of waste before disposal (Department of Trade and Industry, 2017).

9.2 National Development Plan 2030

The South African National Development Plan 2030 (NDP) aims to eliminate poverty and reduce inequality by 2030. In order to achieve this, the economy must grow faster and in a manner that benefits all South Africans, particularly young people and promotes gender equality.

9.2.1 Electricity

The NDP aims to provide 90% of South Africans with access to the electricity grid by 2030, with non-grid options for the rest. The country is forecasting a build capacity of additional 40 000 MW with at least half of the new capacity being provided by renewable energy sources.

9.2.2 Water

The NDP aims to ensure that all people have access to clean, potable water and recognises the need for sufficient water for agriculture and industry. The plan aims to several new irrigation schemes in the Umzimvubu river and Makhatini flats. The NDP also promotes the creation of regional water and wastewater utilities.

9.2.3 Climate Change

The NDP notes the negative impact of emissions of carbon dioxide and other greenhouse gases could have on the availability of potable water and food production. The reduction in the impact of climate change will be managed by moving towards renewable energy sources, amongst others.

9.2.4 Technological change

The NDP promotes the use of Science and Technology to recognise the way goods and services are produced and traded in South Africa. South Africa will use its knowledge and innovative products to compete. This applies to traditional sectors and new industries.

9.3 A review of the 2020 National Budget

This section of the report details the relevant points contained in the 2020 National Budget as this highlights the focus areas for the South African government over the medium term. (National Treasury, 2020)

9.3.1 Energy

The Department of Mineral Resources and Energy continue to support the renewable energy market in line with the national commitment to transition to a low-carbon economy. Government remains committed to procuring renewable energy from independent power producers through REIPP. Private sector investment in the programme is valued at R210 billion of which R42 billion has been sourced from international investors and funders.

9.3.2 Water

Government has allocated R117 billion to water and sanitation over the next three years. This accounts for 14.4 per cent of public sector infrastructure expenditure. The Water Infrastructure Development Programme is allocated R41 billion over the medium with the majority of the being transferred to the Water Trading Entity, Regional Bulk Infrastructure Grant and the Water Services Infrastructure Grant.

9.3.3 Infrastructure Fund

R100 billion has been committed to the Infrastructure Fund. This includes R10 billion over the next three years. The Fund will focus on blended finance projects and will include new funding, guarantees and the repackaging of existing projects. The Fund's implementation unit will be located within the Development Bank of South Africa (DBSA) and will use the Budget Facility for Infrastructure to evaluate proposals. National Treasury is also in the process of developing a national appraisal and evaluation guideline. This will assist stakeholders to understand how projects can be packaged and enable the successful implementation of projects.

9.3.4 Municipal initiatives

A Municipal Investment Programme Project Preparation Facility will be introduced to support metropolitan municipalities establish effective and efficient programme management and project preparation facilities for their capital investment programmes. The Cities Preparation Support Fund will provide co-financing from the 2020/21 financial year which will decline as these municipalities increase their capacity.

The Cities Support Programme shall also support cities in climate resilience and low-carbon development through targeted technical assistance to strengthen project design, packaging and preparation.

9.4 Other relevant positions

This section of the report details other initiatives that are to be relevant to the water to energy study.

9.4.1 Industry Policy Action Plan

The Industrial Policy Action Plan 2018 (IPAP2018) has a focus on deepening industrial development, speeding up radical economic transformation and increasing the ability to produce higher value-added products (Engineering News, 2018).

The White Paper on Science Technology and Innovation focusses on the use of Science, Technology and Innovation (STI) to accelerate economic growth, contribute to a more competitive economy and improve people's daily lives. The White Paper also focusses on the exploitation of new sources of growth, such as, the Fourth Industrial Revolution (4IR), the circular economy and Information, Communication and Technologies.

The White Paper also states that the mandates of Development Finance Institutions (DFIs) will be expanded to scale up funding for industrial innovation activities. The Paper also notes the need for the for increased commercialisation funding. Thus, a Sovereign Innovation Fund will be established to leverage co-investment by the public and private sectors. (Department of Science and Technology, 2019)

9.4.2 Integrated Resources Plan 2019

The Integrated Resources Plan 2019 (IRP2019) is aligned to the National Development Plan 2030 and is the South African electricity infrastructure development plan. The current energy mix based on generation options are presented in the table below. (Department of Energy, 2019)

Table 56: SA current installed energy mix

Source	Installed capacity (GW)	% of Total
Coal	38	73.5%
Diesel	3.8	7.4%
Renewable energy	3.7	7.2%
Pumped storage	2.7	5.2%
Nuclear	1.8	3.5%
Hydro	1.7	3.3%
Total	51.7	100%

The potential long term energy mix based on a variety of criteria is indicated in the table below.

Table 57: Proposed Energy Mix

	Coal	Coal (Decommissioning)	Nuclear	Hydro	Storage	PV	Wind	CSP	Gas & Diesel	Other (Distributed Generation, CoGen, Biomass, Landfill)
Current Base	37 149		1 860	2 100	2 912	1 474	1 980	300	3 830	499
2019	2 155	-2373					244	300		Allocation to the extent of the short term capacity and energy gap.
2020	1 433	-557				114	300			
2021	1 433	-1403				300	818			
2022	711	-844			513	400 1000	1600			
2023	750	-555				1000	1600			500
2024			1860				1600		1000	500
2025						1000	1600			500
2026		-1219					1600			500
2027	750	-847					1 600		2000	500
2028		-475				1000	1 600			500
2029		-1694			1575	1000	1 600			500
2030		-1050		2 500		1 000	1 600			500
TOTAL INSTALLED CAPACITY by 2030 (MW)	33364		1860	4600	5000	8288	17742	600	6380	
% Total Installed Capacity (% of MW)	43		2.36	5.84	6.35	10.52	22.53	0.76	8.1	
% Annual Energy Contribution (% of MWh)	58.8		4.5	8.4	1.2*	6.3	17.8	0.6	1.3	

Installed Capacity
Committed / Already Contracted Capacity
Capacity Decommissioned
New Additional Capacity
Extension of Koeberg Plant Design Life
Includes Distributed Generation Capacity for own use

The table above highlights that Hydro, pumped storage, as well as, other renewable energy sources remain part of the national energy mix over the longer term. In terms of other renewable energy sources, IRP2019 notes that the generation of electricity and heat from biomass and biogas holds great potential in South Africa. Other relevant policy positions to be noted from IRP2019 are presented in the table below.

Table 58: Relevant policy positions from IRP2019

Relevant Policy position	Comment
Policy position 1: Immediately initiate a medium-term power purchase programme (MTPPP) to assist with creating reserve capacity.	A MTPPP similar to that adopted after IRP2010 should be considered. Development of generation for own use should also be encouraged.
Policy position 4: Convene a team to assemble a 'just transition' plan within a year in consultation with all social partners.	Attention has to be given to the path adopted to give effect to the energy mix and the preparation work necessary to execute the retirement and replacement of these plants.
Policy position 9: South Africa must support strategic power projects in neighbouring countries that enable the development of cross-border transmission power needed for the regional power pool.	IRP2019 used the commercial parameters that was submitted for the Inga and 2 500 MW of hydropower was selected on its own merits.

The above table highlights the mechanisms that are in place in order to ensure implementation of potential water to energy solutions that emerge from the study.

It was also noted during the South African National State of the Nation Address that Sectorial 34 Ministerial Determination will be issued shortly to enable the development of additional grid capacity from renewable energy, natural gas, hydro power, battery storage and coal. Measures will also being put in place to enable municipalities that are in good standing are able to procure their own power from independent power producers.

IRP2019 notes that SA still has 3-million households without access to grid-based electricity. Whilst non-grid connections have been effective in providing lighting and small power, however a significant thermal load for cooking, space and water heating is still required.

Distributed generation through biomass, biogas and municipal waste holds great potential for improving municipal revenue. Technologies are available for these areas to be added to the generation mix at sub-utility scale. IRP2019 already makes provision for distributed generation and therefore allows municipalities to diversify their supply base.

IRP2019 promotes a varied energy mix in order to enhance South Africa's electricity supply. The plan highlights that hydropower, pumped storage and biogas are part proposed energy mix by 2030. Municipalities are encouraged to diversify the energy supply. The plan also highlights that access to electricity for over 3 million households remain a challenge and the issue is not just the provision of energy for lighting but also energy is required for cooking, space and water heating. Research on the hydrogen economy and Hy-Sa should be supported.

9.4.3 Renewable Energy Independent Power Procurement Programme

The Renewable Energy Independent Power Procurement Programme (REIPPPP) was developed to contract with private producers to supply energy to the national grid. The programme has been able to attract private sector investment valued at R210 billion, of which R42 billion has been sourced from international investors and funders (National Treasury, 2020).

It is noted bid window 5 of the programme will be opened whilst work with producers to accelerate the completion of window 4 projects will be undertaken. Measures will also be put in place to enable municipalities in good financial standing to procure their own power from independent power producers. (The Presidency, 2020)

9.4.4 Africa Agenda 2063

Agenda 2063 is Africa's blueprint and master plan for transforming Africa into the global powerhouse of the future. Agenda 2063 aspires to ensure that all people across the continent shall have access to the necessities of life such as, water, sanitation and energy. Agenda 2063 also aims to harness all African energy resources to ensure renewable and environmentally energy to all African households, businesses, industries and institutions through building the national and regional energy pool and grids (African Union Commission, 2015)

9.4.5 The Green Economy

The Department of Trade & Industry (2017) has noted that there are significant opportunities for innovation such as industrial development and employment creation in the recycling sector. The commitment to invest in waste-management projects that divert waste from landfill sites through employment-creating initiatives is further emphasised in the National Development Plan 2030. The waste economy is seen to offer exciting opportunities in small-scale waste to energy projects such as biogas. (Department of Trade and Industry, 2017).

10. APPENDIX C: MEMBERS OF EUIG

List of companies that form part of the EUIG:

- AECI
- AFROX
- Air Liquide
- Anglo American
- AngloGold Ashanti
- ASSMAG
- Columbus Stainless
- Consol
- EXXARO
- GLENCORE
- Gold Fields
- Harmony
- Hulamin
- IMPLATS
- Kumba Iron One
- LONMIN
- Mondi
- Mongonese Metal Co
- PPC
- Rand Water
- Richards Bay Minerals
- SAMANCOR
- SASOL
- SCAW Metals Group
- Sibanye Stillwater
- South32
- Tongaat Hulett
- Transalloys
- TRANSNET

11. APPENDIX D: ESTABLISHED TECHNOLOGIES

11.1 Anaerobic Digestion

This section of the report provides additional information on anaerobic digestion.

11.1.1 The Process

Anaerobic digestion (AD) comprises of two distinct processes, where in the absence of oxygen and provision of adequate storage time, complex organic compounds are broken down into simpler compounds (volatile acids) through micro-organisms. Methane-forming bacteria convert theses acids into stable organic forms whilst releasing carbon dioxide and methane. Methane (biogas) has a high calorific value and can be converted to heat and electricity. The key components associated with the anaerobic digestion process and conversion to electricity and heat is detailed in the diagram below.

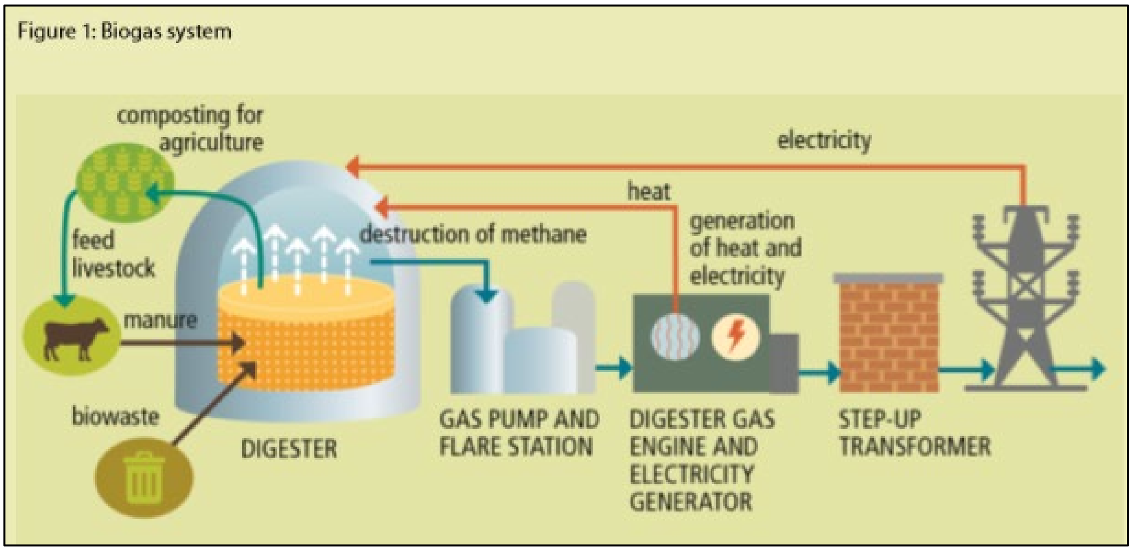

Figure 36: Typical Biogas to Energy diagram

Sustainable Energy Africa (2017)

Wastewater treatment processes contribute more than 20% of the total municipal electricity consumption (Sustainable Energy Africa, 2017). The biogas produced at Wastewater Treatment Works (WWTW) within the South African context is typically flared to the atmosphere. The larger WWTW (>10 Ml/d) normally use the methane gas to heat the sludge entering the mesophilic digesters.

The performance of anaerobic digesters can be enhanced through the use of thermal hydrolysis for sludge pre-treatment Thermal hydrolysis (TH) is the most widely applied sludge pre-treatment method in advanced anaerobic digestion systems, with over 60 plants installed worldwide. The process involves injecting steam at high temperature and pressure to rupture cells and improve the conversion of organic matter to biogas in the digestion process. Performance data comparing seven sludge pretreatment methods indicates that sludge pretreated using TH achieves the highest destruction of volatile solids (and hence biogas yield) during anaerobic digestion. (Musvoto, Mgwenya, Mangashen, & Macintosh, 2018). This process is seen to be at TRL9 outside of South Africa but has not been entrenched in the South African market.

11.1.2 Technology Readiness

There are currently 38 large scale commercial projects that are in operation in South Africa. The details of seven of these operations are presented in the table below.

Table 59: Examples of Commercial Anaerobic Digestion applications in SA

Project Name	Capacity	Description
Bronkhorstspruit Biogas and CHP Plant	5MW	The plant utilises approximately 120 000 tonnes of feedstock a year, the bulk being manure with additional supplements from the abattoir along with food wastes (Sean Thomas, 2015).
Uilenkraal Biogas Project	500 kW	Cape Advanced Engineering (CAE) located on a dairy farm. The feedstock comprises of manure, urine and wastewater slurry. The plant is currently meeting 95% of the farm's electricity demand (200kWh's daily) supplying power to the farm's dairy, animal-feed milling and crop irrigation activities.
Elgin Fruit Juice Biogas Project	526 KW	The anaerobic digester is fed with the by-products (pomace and waste fruit) of the juice extraction process for which damaged or sub-standard fruit pulp is used. The anaerobic digester is also fed cow manure from the Groenland Meat Traders (1-2tonnes per day) as well as chicken litter from Elgin Free Range (<1 ton per week) (Mostert, 2015). The company owns and operates an onsite anaerobic digester which has an installed capacity of 526kW of electricity for own consumption during the operating season i.e. for 6 months from January to June.
Northern Wastewater Treatment Works	1.2 MW	With an installed capacity of 1.1MW (3 x 376kW engines), providing roughly 10 - 15%14 of the Works electricity demand (Odendaal, 2013).
Morgan Springs Biogas Project	400 kW	The digester will be largely run on abattoir wastes which includes paunch manure (stomach contents), manure, blood and guts. The plant has an installed capacity of 0.4MW, generating approximately 50% of the abattoir's own electricity needs as well as 90% of the abattoir's heat/warm water needs used for cleaning and sterilisation processes (BiogasSA, 2015).
Jan Kempdorp Abattoir Biogas Project	135kW	The plant runs completely on abattoir waste which includes animal manure and slaughter waste. The digester utilises roughly 2020 tonnes of abattoir waste per year and has an installed capacity of 135kW, generating 650kWh/day (iBert, 2015).
New Horizons Waste-to-Energy Facility	4 MW	Clean Energy Africa. Digester food source is organic matter.

The table highlights that the use of anaerobic digestion to generate biogas that can be converted to electricity is a viable option. This technology has also been successfully implemented international as indicated by the table below.

Table 60: International references for the generation of biogas using anaerobic digestion

Country	Biofuel Comments
Germany	A total of 4 GW of total biogas power installed (Wagner, 2015), ranging from agricultural wastes to wastewater treatment plants.
USA	Over 240 livestock farm, 630 landfill gas projects and 1 200 wastewater treatment projects (U.S.D.o. Energy, 2014).
China	China was the highest investor in, and generator of, renewable energy world-wide in 2014 (IRENA, 2015). There are approximately 100 000 large-scale and 43 million rural household digesters.
India	India has an estimated 4.75 million household bio-digesters (IRENA, 2015). Household digesters are common in India as approximately 68% of the population live in rural areas.
Hungary (György Szabó, November 2014)	In 2013, at the 54 biogas power plants in Hungary, with a total of 111 million m^3 of biogas being utilized energetically (Fazekas et al., 2013). Until 2003, the extraction and utilization of biogas occurred exclusively at a few sewage-treatment plants and newly built regional communal landfills.

The table above indicates that there has been widespread of anaerobic digestion as a technology to generate biogas. A scan of international markets also suggest that developed nations tend to have larger scale anaerobic digestion for commercial utilisation, agriculture, landfill gas and wastewater treatment, whilst developing nations tend to have smaller scale rural and household digesters.

Biogas generated in small sized digesters can be used for cooking and lighting in households. Wastewater sludge can be used as a feedstock for the digester, along with other feedstocks such as, manure, food processing residues and energy crops. Biogas is commonly used in rural areas of China and India with the African Biogas Partnership having installed over 46 000 digesters. (International Renewable Energy Agency, 2015). In South Africa, there are approximately 700 biodigesters in South Africa with about 50% of these being small scale installations (Muvhiwa, Hildebrandt, Chimwani, Ngubevana, & Matambo, 2017). The table below provides an indication of the small-scale biogas projects that have been undertaken in South Africa.

Table 61: Examples of small scale biogas projects

Project Name	Location	Comment
iLembe District Biogas Project	KwaZulu-Natal	Khanyisa Projects, a renewable energy developer, was responsible for training several local builders to construct the 26 x 6 m^3 digesters
Mpfuneko Biogas Project	Limpopo	Project is currently in progress and will involve the installation of 55 digesters
Various	Various	BiogsaPro Agama has installed 320 units to date for various clients including include, bush camps, wine and game farms, rural households and schools.

The table above highlights that several small scale biogas projects that has been completed in rural areas. The technology utilised to generate electricity from biogas is therefore seen to be at **TRL9** for large scale commercial applications, as well as small scale domestic applications in rural areas.

However, 2.3 million households utilise firewood and charcoal to meet their energy requirements (Muvhiwa et al., 2017). This presents a large opportunity to utilise biogas from anaerobic digestion to provide energy for cooking to these households. However, it would appear that sludge would need to be supplemented with an additional organic feedstock such as cattle manure. It has been estimated that a national cost savings of R1 billion could be realised annually by replacing fuel-wood with biogas (Rasimphi & Tianrwo, 2019)

There are several developers and governmental programmes working to implement biogas projects within the rural sector.

11.1.3 *Market readiness Levels – Large scale*

The table below provides an overview of the MRL for anaerobic digestion at WWTW.

Table 62: MRL for AD at WWTW

MRL Component	Comment
Supply readiness – to what degree are competitor products available?	There are equipment suppliers that are available to supply to this particular market. This is evidenced by the several commercial operations in South Africa. There are also several existing digester installations at WWTW. The ability to procure skills and services locally, as opposed to importing the supply requirements will need to be confirmed in subsequent studies.
Demand Readiness – what is the demand for the product?	There is a clearly a demand for the product (Heat and Power) by municipalities as evidenced by several studies.
Customer Readiness – is customer ready to use and adopt the product?	It would appear that is a challenge as despite high potential of this solution. There has been limited uptake in the public wastewater sector.
Product readiness – is the product ready for widespread use	The product in the case of anaerobic digestion is seen to be heat and power. There are mature applications for utilising these products either onsite or for supply to a grid connection.

Therefore, Anaerobic Digestion at WWTW is seen to be at **MRL9** as there has been widescale commercial application and the product has been clearly defined. There has been interest for implementing the technology at selected WWTW but it appears that the customer readiness component of the market does need to be addressed.

11.1.4 Market readiness Levels – Small scale

The table below provides an overview of the MRL for anaerobic digestion at smaller scales in rural applications.

Table 63: MRL for AD in rural applications

MRL Component	Comment
Supply readiness – to what degree are competitor products available?	There are several developers and governmental programmes working to implement anaerobic digestion projects in rural areas as evidenced by the projects that have been completed.
Demand Readiness – what is the demand for the product?	There is an inherent demand in the market as there are large numbers of households that currently use wood or coal as fuel sources for cooking.
Customer Readiness – is customer ready to use and adopt the product?	There has been an indication of interest by the WSA but there has been limited implementation. This is a possible area of limitation.
Product readiness – is the product ready for widespread use	The production of biogas from anaerobic digestion for use in rural areas is thus seen to be mature as evidenced by applications in China and India.

Therefore, Anaerobic Digestion at smaller scales in rural areas are seen to be at **MRL9** as there has been widescale application internationally, with some application locally and the product has been clearly defined. There has been interest for implementing the technology in some rural areas but it appears that the customer readiness component of the market does need to be addressed, as well as, the identification of other suitable feedstocks to the digester. It should also be noted that this technology is not seen to be viable only with the use of sludge but will require an alternative feedstock.

11.1.5 Barriers to market entry – smaller scale

The costs for the installation and use of biogas digesters for urban peripheral and rural communities are usually high and subsidies are applied to encourage their use. As an example, a subsidy of €240 per plant is provided whilst in Cameron, 30% of the digester cost is subsidised. It is suggested that the absence of subsidies or innovative financing mechanisms will inhibit the use biogas facilities in rural areas. (International Renewable Energy Agency, 2015)

Identifying sites with a suitable supplementary feedstock is crucial as it is considered unfeasible to operate a domestic biodigester solely with either chicken waste, human waste or food waste due to insufficient feedstock. However, installation of non-sewered households generate sufficient greywater to mix with organic waste for feeding digesters for cooking purposes at a community level. (Msibi & Kornelius, 2017)

A lack of technical construction and maintenance expertise and shortcomings in energy markets also inhibit the implementation of biogas for cooking solutions. Increasing local production capacity and reducing high import tariffs could reduce costs and improve the performance of installed units. (International Renewable Energy Agency, 2017)

The overarching problems and challenges to biogas technology expansion in South Africa can be attributed to: (Mukumba, Makaka, & Mamphweli, 2018)

- High initial investment costs and subsequent operations of the unit;
- The availability of biogas substrates and the effective yields as compared to conventional fuels;
- Cheaper electricity from coal fired thermal power stations; and
- Lack of user education on biogas production and its usage results in biogas digester failures.

11.1.6 Conclusion

The generation of biogas through the use of anaerobic digestion and the conversion to electricity at large WWTW is seen to have high potential for commercialisation as evidenced by a score of 88% as a result of the MCDA exercise. This is due to the technology been seen to be mature as evidenced by commercial applications in other industries.

The market also appears to be interested in the use of this technology as evidenced by institutions having identified sites that may be well suited to the application of the technology. It appears that despite the considerable potential and interest of anaerobic digestion there has been limited uptake.

The generation of biogas through the use of small scale anaerobic digesters is seen to have high commercial application within South Africa as evidenced by a score 80% from the MCDA exercise. This is due to the technology been seen to be mature as evidenced by several applications internationally. The local market also appears to be interested in the use of this technology as evidenced by several projects being completed.

However, there are limitations in rural applications include a relatively high capital requirement and the need for a supplementary feedstock to ensure that these projects are viable. There are also concerns around the operating model and the skills requirement to operate these facilities in rural areas. Small scale applications in rural areas on wastewater sludge is not seen to be viable and will require a primary feedstock.

11.2 Hydropower

Hydro plant facilities can be categorized into various sizes as indicated in the table below. It is noted that there is a large diversity of definitions across countries regarding categorization of hydro plants, but the table below shows the most widely accepted categories.

Table 64: Hydropower Categories

Hydro Category	Power Range
Pico	0-5 kW
Micro	5-100 kW
Mini	100-1 MW
Small	1-10 MW
Medium	10-100 MW
Large	100 MW+

As per the terms of reference for this study, investigation was restricted to the micro hydro to small hydro categories, so from 5 kW to 10 MW power output. Each of these categories are further detailed below.

11.2.1 The process

Modern hydro plants produce electricity using turbines and generators, where mechanical energy is created when moving water spins rotors on a turbine. The turbine is connected to an electromagnetic generator, which produce electricity when the turbine spins

There are four main types of hydro plants:

- Impoundment (Dam) facilities are the most common technology which uses a dam to create a large reservoir of water. Electricity is made when water passes through turbines in an outlet from the dam;

- Pumped storage facilities are similar but have a second reservoir below the dam. Water can be pumped from the lower reservoir to the upper reservoir, storing energy for use at a later time. The turbine is usually at the base of the conduit linking the two dams;
- Run-of-river facilities rely more on natural water flow rates, diverting just a portion of river water through turbines, sometimes without the use of a dam or reservoirs. Since run-of-river hydro is subject to natural water variability, it is more intermittent than dammed hydro; and
- A more recent trend is the use of turbines in bulk water distribution pipelines (conduit hydropower) where there is excess head in the system to drive the turbines.

11.2.2 Technology Readiness

Micro Hydro power is seen to be highly site specific in order for the technology to be commercially viable. Therefore Eskom (2020) has concluded that micro hydro is not a feasible option for South African circumstances as this is not economically viable at scale. However, the Brandkop Conduit Hydropower Plant (96 kW) was launched in 2015, and as of December 2016, the plant was supplying Bloemwater Head Office with renewable energy. This plant provides the blue print that could be used for other municipalities and utilities to implement Conduit Hydropower projects. (Van Delft, 2017)

Small-scale hydropower is one of the most cost-effective technologies for electrification as it is seen to have low environmental impacts and can have significant benefit if implemented in rural areas. There are currently small hydropower installations in 148 countries or regions around the world. (Adu, Zhang, Fang, Suoming, & O. Darko, 2017). It is also noted that Africa has a capacity of 525 MW from hydro plants with individual capacities of less than 10 MW.

Generally, conventional hydropower (dams, run-of-river and pumped storage) appear to be well established and have been proven in various sites around the world at the appropriate scale. However, conduit hydropower is seen to be a recent intervention in the South African water sector, but all hydropower technologies appear to be at **TRL9**. The application of the technologies at the appropriate scale and availability of locations may be a challenge but this will be investigated further during the next phase of the study.

11.2.3 Market readiness levels

The table below provides an indication of the MRL as related to hydropower.

Table 65: MRL for Hydropower

MRL Component	Comment
Supply readiness – to what degree are competitor products available?	This is seen to be established in South Africa with the presence of several large schemes. The availability of supply readiness for mini hydro applications would need to be confirmed in subsequent studies.
Demand Readiness – what is the demand for the product?	There is an inherent demand in the market for rural and urban applications
Customer Readiness – is customer ready to use and adopt the product?	This is a possible area of limitation as WSA may have concerns around synchronisation on existing sites, as well as, the operations and maintenance of multiple small sites within their water network.
Product readiness – is the product ready for widespread use	Electricity can be produced from hydropower technologies and this is seen to be ready for widespread use.

Therefore the hydropower segment is seen to be at **MRL9** as the product or service is well defined. Although the potential business model and method of delivery still needs to be confirmed. The delivery model is clear for the large scale schemes but there appears to be limited uptake for small, micro and mini schemes despite the clear potential.

The future for small hydropower in South Africa could possibly be seen through three tracks: (Rycroft, 2014)

- Grid-connected projects that will feed into the national grid;
- Small scale systems for private use; and
- Isolated systems for rural electrification

However, the cost of the infrastructure required to deliver the energy generated to the customer may results in projects being not viable from a financial perspective. Also the development costs of the smaller projects may be prohibitive.

11.2.4 Conclusion

Hydropower has potential application in the municipal, water board and mining market. Several studies have been completed by Municipalities and Water Boards and there appears to be delays conduit hydropower projects despite being considered fairly attractive.

The mining sector could contribute a potential 1 200 MW in Gauteng from mining applications. However, there is a need to confirm the practical application of hydropower solutions in mining applications.

11.3 Combustion of sewage sludge

Combustion, or burning, is a high-temperature exothermic organic oxidation chemical reaction between a fuel (e.g. biomass) and an oxidant, usually atmospheric oxygen that produces oxidized, often gaseous fuel products. Further combustion of these gaseous fuels will be able to produce electricity and/or heat.

11.3.1 The process

Incineration, which is the combustion of organic material such as waste with energy recovery, appears to be the most common waste to energy (WtE) process to be implemented. All new WtE plants incinerating waste are required to meet strict emission standards, including those on nitrogen oxides (NOx), sulphur dioxide (SO_2), heavy metals and dioxins. Hence, modern incineration plants are vastly different from old types, some of which neither recovered energy nor materials. Modern incinerators reduce the volume of the original waste by 95-96 percent, depending upon composition and degree of recovery of materials such as metals from the ash for recycling.

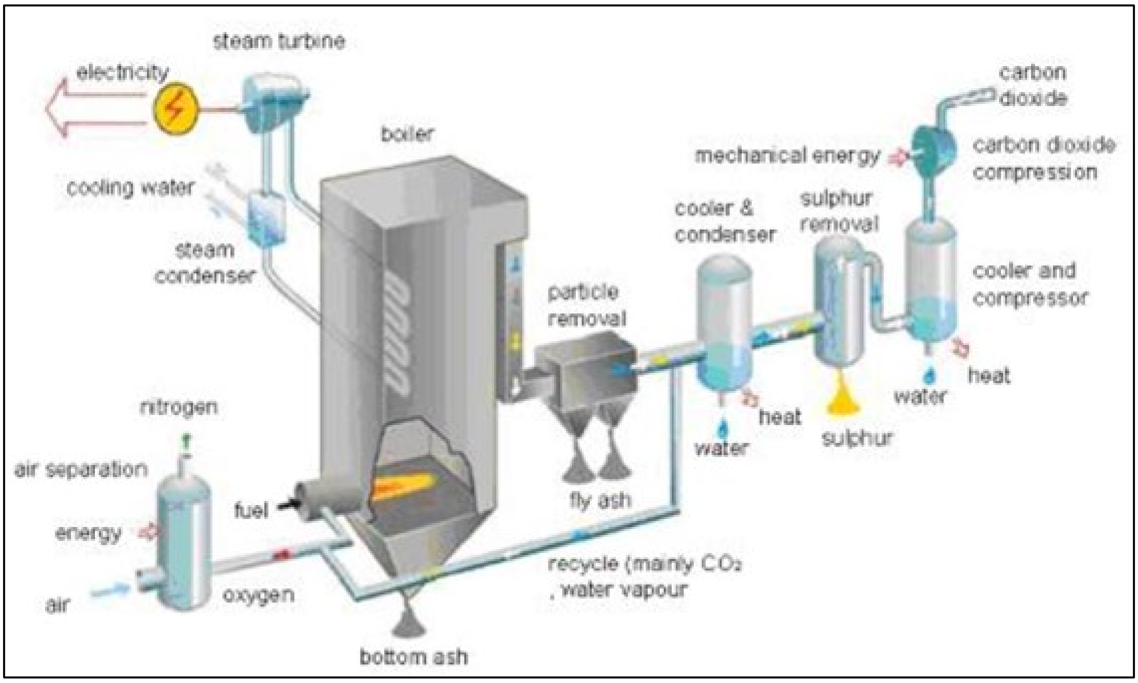

Figure 37: Typical Combustion Waste to Energy Process

The diagram above highlights the potential to generate electricity, and heat that could be generated using the combustion process. The following types of combustion systems are used for sewage sludge mono-incineration plants: (Umwelt Bundesamt, 2019).

- Fluidized bed furnaces;
- Multiple-heart furnaces;
- Multiple-hearth fluidized bed furnaces; and
- Cycloid furnaces.

11.3.2 Technology Readiness

According to the International Solid Waste Association (ISWA) there are 431 WtE plants in Europe (2005) and 89 in the United States (2004). It is also noted that most of sewage sludge in Germany is incinerated mostly in fluidized beds with some in coal fired power plants, cement kilns and waste incineration plants (Schnell, Horst, & Quicker, 2020).

eThekwini Municipality has utilised a sewerage sludge incinerator at Kwa Mashu WWTW. The facility was operated on a 24/7 basis and produced a stable ash that greatly reduced the volume of material that needed to be disposed at a suitable landfill site. (Fleischman, Botha, & Germanis, 2014). Therefore, based on this and the items discussed above, combustion technology is seen to be at **TRL9**.

11.3.3 Market Readiness Levels

The table below provides an indication of the MRL as related to combustion.

Table 66: MRL for Combustion

MRL Component	Comment
Supply readiness – to what degree are competitor products available?	There appears to be suppliers of combustion technologies in South Africa as this is commonly used in other industries.
Demand Readiness – what is the demand for the product?	There appears to be limited demand from WSAs for combustion technologies.
Customer Readiness – is customer ready to use and adopt the product?	Customers may not appear to be ready for the use of the technology despite been proven internationally, there has been limited successful application in wastewater treatment.
Product readiness – is the product ready for widespread use	Electricity can be produced from combustion and this is seen to be ready for widespread use.

Therefore the combustion is seen to be at MRL8 as the value proposition seems to be defined for a limited number of sites but the potential business model and method of delivery still needs to be confirmed. There also appears to be limited appetite for the application of these technologies.

11.3.4 The market potential in South Africa

It has been estimated that approximately 1 488 MW of power can be generated from wastewater sludge in South Africa. However, a subsequent study highlights that this was overestimated as not all energy available in wastewater would be available for conversion (Musvoto, Mgwenya, Mangashen, & Macintosh, 2018).

The market potential is thus seen to be slightly lower than that of anaerobic digestion at wastewater treatment works given the higher capital costs associated with the additional infrastructure that would be required for the combustion of wastewater sludge.

11.3.5 Barriers to market entry

One of the biggest challenges to the combustion of sewage sludge is that whilst certain technologies have been implemented internationally, there has been limited demonstration within South Africa. There is a concern that technology designs may not be well suited to the South African context particularly in terms of operation and maintenance (Musvoto et al., 2018)

Combustion plants are located at the ‘back-end’ of the wastewater treatment works process and require unit operations that are located within the process stream to be optimally operated to generate the desired quantum of electricity. This may prove to be a challenges within a wastewater operations environment that experiences challenges with existing mature operations.

It is also noted that the operations at Kwa-Mashu WWTW experienced challenges with the quality of the feedstock to the unit. The feedstock was not at the desired quality and thus needed to be supplemented with a supplementary feedstock. This raises concerns around the sustainability and cost of operating this infrastructure.

11.3.6 Conclusion

Combustion of wastewater sludge is not seen to have a high commercialisation potential as evidenced by a score of 52% as an outcome from the MCDA. This is due to there being limited application in South Africa despite the technology being mature outside South Africa. There also appears to be a reluctance on the part of WSA to operate a technology that is not seen to be locally proven, has a high capital cost and possible operation and maintenance risks.

12. APPENDIX E: EMERGING INNOVATIONS

This section of the report details the emerging innovations that were considered during Phase 2 of the study. These innovations are seen to have high potential but are not yet sufficiently mature to be commercialised on at a large scale. These innovations should be monitored as they are further developed and consideration to commercialisation should be given once these are seen to be at TRL9.

12.1 Wave to energy

Wave power is seen to be a sustainable energy resource that is created as wind blows across the ocean surface (Eskom, 2020). Wave energy systems converts the energy inherent in the water's movement to electricity. Wave energy is seen to be a more sustainable source of renewable energy due to the availability to produce electricity on a consistent basis and not only at specific times of the day (baseload power) (Stevens, 2019).

The oceans represent a vast natural energy resource with the World Energy Council estimating that 2 Trillion Watts of energy could be harvested. This is the equivalent of twice the world's electricity production (Eskom, 2020). A further example of the high potential of wave power is that the theoretical annual energy potential of the waves of the coast of the United States of America is estimated to be the equivalent to 64% (2.64 trillion kilowatt hours) of the country's electricity generation in 2018 (U. S. Energy Information Administration, 2019).

There are several methods and technologies under development for the capturing and conversion of wave energy to electricity. These include placing devices on or below the surface of the water, as well as, the anchoring of devices to the floor of the ocean (U. S. Energy Information Administration, 2019).

Despite the high potential of wave to energy, there are several key issues that still need to be addressed: (Stevens, 2019)

- Location of the devices;
- Suitability of technology components (corrosion and damage of equipment); and
- Environmental impact of the technology.

12.1.1 Technology Readiness

Wave to energy technologies is in a developmental phase with Eskom currently exploring the availability of wave power along the east and western coastline in South Africa. The utility expects to conduct laboratory scale tests to determine the most suitable technology once the resource assessment is complete and if the results are positive. This is expected to be completed in the next two to three years. (Eskom, 2020)

A pilot 1 MW wave to energy facility is currently being developed in South Africa. This is based on a patented process and is expected to supply clean electricity to a large-scale abalone farm in Hermanus, Western Cape. The full-scale facility is expected to be 3.5 MW and will be developed once the pilot project has been successfully installed and operated. (Engineering News, 2019)

Wave to energy is seen to have great potential but is seen to be at **TRL7** with further work required to prove that the technology can be successfully implemented at a commercial scale. Wave to energy solutions are also site-specific and further work is required to identify potential sites and the development of an appropriate solution at each site.

12.2 Microbial fuel cell

A microbial fuel cell (MFC) is a bio-electrochemical device that harnesses the power of respiring microbes to convert organic matter in wastewater directly into electrical energy. The MFC is a fuel which transforms chemical energy into electricity using oxidation-reduction reactions. This process can combine electricity production with wastewater treatment (Wlodarczyk & Wlodarczyk, 2019). An overview of the process in the MFC is presented in the diagram below.

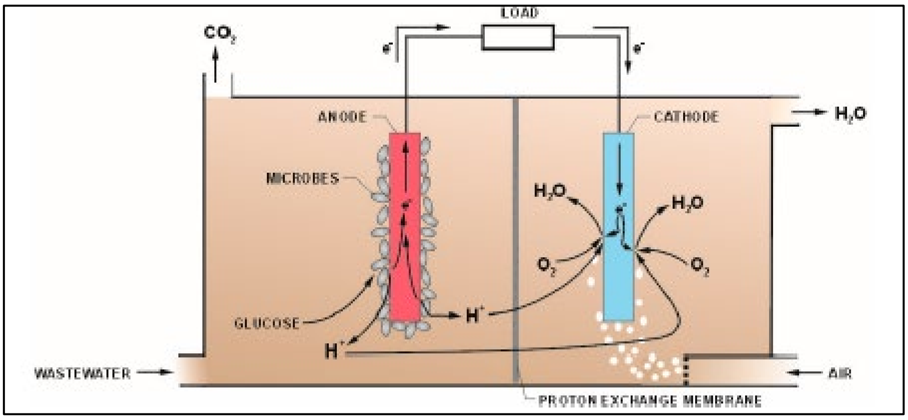

Figure 38: MFC Process
Source: Wlodarczyk & Wlodarczyk (2019)

The diagram above highlights the production of water and carbon dioxide whilst utilising wastewater as a feedstock. The fuel cell is seen to have the potential for high conversion of the organic potential but power output at this stage is low. (Rycroft, Microbial Fuel Cells: A new approach to waste-water treatment, 2018).

12.2.1 Technology Readiness

The use of the microbial fuel cell in wastewater treatment has the potential benefit of reducing operational costs for treating the waste stream, as well as, generating electricity. However, full scale studies are required to determine the real potential of the technology (Gnude, 2016).

However, some of the challenges associated with technology include due high costs and low electricity production (Do, Ngo, Guo, & Liu, 2018). Therefore, progress on this technology should be monitored but it is not at TRL9.

12.3 Generating biofuel from wastewater using algae

Fuel derived from algae holds the potential for higher yields compared to previous systems and includes a diverse range of products including biodiesel, ethanol, jet fuel, etc. (Lo, 2019). The diagram below provides an indication of a hypothetical algae-based wastewater treatment system with the associated products (Lyon, Ahmadzadeh, & Murry-Ewers, 2015).

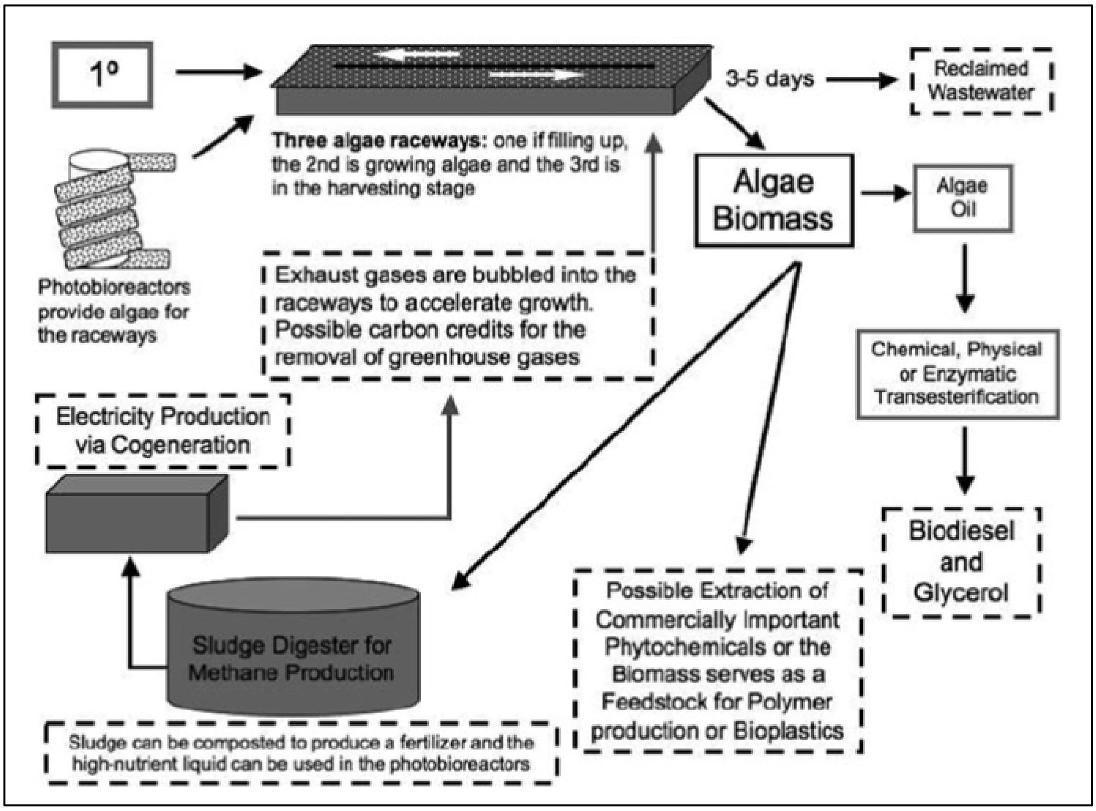

Figure 39: Flow diagram of an algae-based wastewater treatment system[6]

Source: Lyon et al. (2015)

Initial studies suggest that municipal wastewater could be used as a feedstock for the development of high-value strains of algae that could be used as a basis for algae-based biofuels whilst removing more than 90% of nitrates and more than 50% of phosphorus from wastewater (Rice University, 2015). The study also noted that the biofuels were a 'hot topic' in algaculture five years ago but interest cooled as the algae industry moved towards producing higher-value, lower-volume products for the pharmaceutical, cosmetic and other industries.

[6] The boxes with the 'dashed border' indicate the end product or benefit

There was significant investment in the algae based biofuels between 2005 and 2010. However, the industry's ambitious production goals have not yet been achieved. This can be attributed to the extraction of the fuel, cost-competitiveness with fossil fuels. This highlights that the commercial viability of the product is still to be ascertained.

12.3.1 Technology Readiness

An oil from algae trial that is underway at the Kingsburgh WWTW in eThekwini Metropolitan Municipality. This is being completed in collaboration between eThekwini Municipality and Durban University of Technology. It has been noted that several laboratory studies have been completed but there has been limited large-scale testing which has been completed at a large scale facility (Rice University, 2015).

Therefore, the technology available for converting organic material in wastewater to a biofuel is seen to be at **TRL7** as this requires further testing to confirm the technology on a large scale. The long-term effects of utilising oil generated from wastewater also needs to be assessed as this fuel source could negatively impact on the performance of mechanical components.

12.4 Thermal treatment of sewage sludge

This section of the report highlights the potential other applications for the thermal treatment of sludge and the generation of electricity.

12.4.1 Gasification

Gasification is a process that converts organic fuel-based carbonaceous materials into carbon monoxide, hydrogen and carbon dioxide. This is achieved by reacting the material at high temperatures (>700 °C), ***without combustion***, with a controlled amount of oxygen and/or steam. The resulting gas mixture is called syngas (from synthesis gas) or producer gas and is itself a fuel. The power derived from gasification and combustion of the resultant gas is a source of ***renewable*** energy if the gas is derived from biomass.

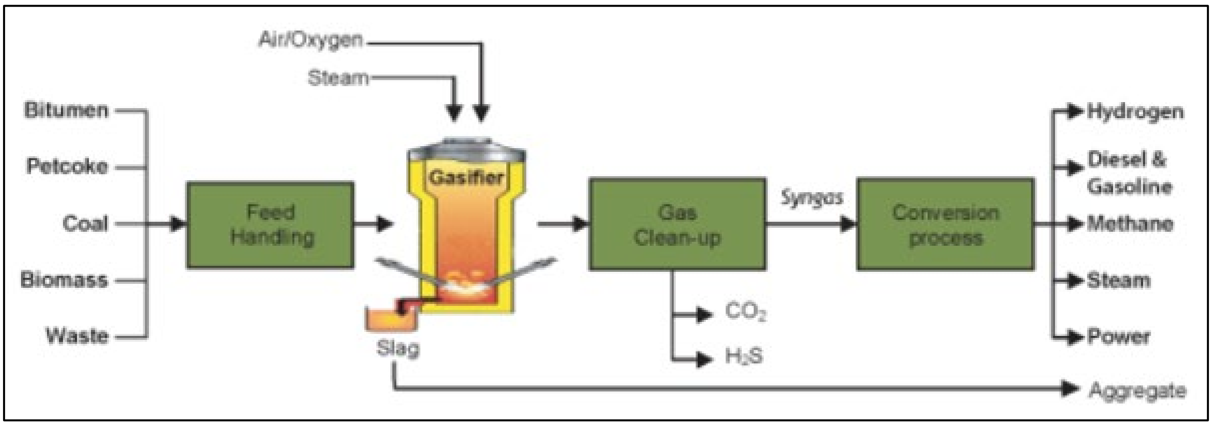

Figure 40: Typical Gasification Diagram

In principle, gasification can be used to process any organic material. Coal and petroleum coke are used as primary feedstocks for many large gasification plants worldwide. Additionally, a variety of biomass and waste-derived feedstocks can be gasified, with wood pellets and chips, waste wood, plastics and aluminium, Municipal Solid Waste (MSW), Refuse-derived fuel (RDF), agricultural and industrial wastes, ***sewage sludge***, switch grass, discarded seed corn, corn stover and other crop residues all being used.

Gasification could assist the world both with management of its wastes and production of the energy and products needed to foster economic growth. Most of the commercial projects listed above utilise wood as a fuel source to produce biogas. The concern is that sewage sludges that generally has a high moisture content and would need an alternative fuel source.

Co-feeding the gasifier with sewage sludge appears to be an option but unfortunately it has not been tried and tested in the market although it is noted that there is a sewage sludge gasification plant that has been operational since 2004 whilst another plant that utilised this technology has been shut down (Umwelt Bundesamt, 2019). Schnell et al. (2020) further assert that alternative thermal processes such as gasification and pyrolysis are tested in bench or pilot scale level. Therefore, gasification of sewage sludge is seen to be at **TRL7**.

12.4.2 Emerging Enhanced Hydrothermal Carbonisation Polymeric Carbon Solid (PCS) Technology

Hydrothermal carbonisation (HTC) is a thermo-chemical conversion process that converts wet organic matter, under moderate temperature and pressure, into a high-energy-value hydrochar that can be used as a biofuel. In some cases, the reaction is aided by a catalyst which reduces the temperature and processing time. A wide variety of waste biomass, without regard to moisture content, can be processed using HTC. The process emits no methane and very little Carbon Dioxide. This reduces the amount of GHGs released into the atmosphere. The resulting carbon-neutral solid hydrochar can be burnt in a boiler to produce electricity and heat.

The polymeric hydrochar can also be used in agriculture, the building industry and as an adsorption media. The enhanced HTC technology developed by PCS Biofuels™ is still emerging and has only been applied at full-scale for processing wood chips mixed with bagasse and palm oil. However, laboratory-scale tests in Canada have shown that the technology can process wastewater sludge, on its own and mixed with other biomass, to produce hydrochar with an energy content varying from 17-25 MJ/kg. (Musvoto et al., 2018)

HTC, unlike other thermo-chemical conversion processes (like dry pyrolysis and gasification), involves the conversion of wet biomass under moderate to high temperature and pressure and, in some cases, in the presence of homogeneous or heterogeneous catalysts. The conversion is through complex pathways that include hydrolysis, dehydration, decarboxylation, aromatisation and re-condensation. Fundamentally, the process involves lowering both the oxygen and hydrogen content of the feed (measured in terms of the O/C and H/C ratio) and increasing the carbon content of the subsequent hydrochar. Unlike dry thermo-chemical conversion processes, hydrolysis is the critical and initial step in HTC. Because hydrolysis exhibits lower activation energy, lower temperature HTC reactions have been shown to achieve the same level of conversion efficiency as higher temperature processes. (Musvoto et al., 2018). PSC is seen to be an emerging technology and not yet at **TRL9**.

13. APPENDIX F: OUTCOMES OF THE MCDA EXERCISE

Multi-criteria decision analysis

			AD at WWTW			AD in rural areas			Hydropower in urban areas			Hydropower in rural areas			Incineration		
		Weighting	**Comment**	**Score**	**Overall score**	**Comment**	**Score**	**Overall score**	**Comment**	**Score**	**Overall score**	**Hydropower in rural areas**	**Score**	**Overall score**	**Comment**	**Score**	**Overall score**
1	**Alignment to national plans and strategies**	**10%**	Included in IRP2019 as other.	4	8%	NDP2030 speaks to increasing offgrid access (rural areas). Included in IRP2019 as other.	5	10%	Hydro is specifically mentioned in IRP2019	4	8%	NDP2030 speaks to increasing offgrid access (rural areas). Hydro is specifically mentioned in IRP2019.	5	10%	Included in IRP2019 as other. Alignment of sludge disposal requirements.	2	4%
2	**Regulations**	**10%**	Air emmisions are a concern.	4	8%	Reducing reliance on wood fuel sources therefore a positive environmental impact.	5	10%	Limited concerns	5	10%	Limited concerns	5	10%	Concerns around compliance	3	6%
3	**Maturity of technology in the international space**	**10%**	Mature. Hungary and USA has large commercial scale applications.	5	10%	Mature. High number of domestic users in China, India and other parts of Africa.	5	10%	Mature	5	10%	Mature	5	10%	Mature. Used in Europe and America. Usually with an additional feedstock.	2	4%
4	**Maturity of technology in the local space**	**10%**	GIZ study highlights market potential for commercial application. South Africa already has commercial biogas applications using other organic wastes.	5	10%	Pilot projects have been completed in SA but there are concerns around the long term operation of the plants..	4	8%	Larger schemes are well established but there are concerns around the smaller schemes	4	8%	Larger schemes are well established but there are concerns around the smaller schemes		0%	Limited examples that has highlighed operational challenges.	2	4%
5	**Who are the Customers that could benefit from the application the technology (End User)**	**10%**	Own use at WWTW with possible supply to commercial customers or municipal grid. Not always able to meet full demand requirements.	4	8%	Predominantly domestic customers (largely for cooking and heating).	3	6%	Own use with a possible supply to the municipal grid.	5	10%	Predominantly domestic customers or commercial users	3	6%	Own use at WWTW with possible supply to commercial customers or municipal grid. Not always able to meet full demand requirements.	4	8%
6	**Market size (MW)**	**10%**	27,1	5	10%		5	10%	53,1	5	10%			0%			0%
7	**Market readiness levels**	**10%**	Established in SA but limited appetite for implementation by WSA.	4	8%	Concerns around the willingness of the customer to operating the units and utilising the biogas.	3	6%	Established in SA but limited appetite for implementation by WSA (5kW - 10 MW).	4	8%	Established in SA but limited appetite for implementation by WSA (5kW - 10 MW).		0%	Appears to be limited.	2	4%
8	**Penetration rates (Potential impact)**	**10%**	High in the private sector but limited in the public sector	4	8%	High in international markets but limited in SA.	4	8%	Currently low outside of larger schemes but the potential does exist.	4	8%	High	4	8%	Potential but with additional feedstock	3	6%
9	**Potential for utilising other feedstock (additional fuel sources such as MSW, coal, biomass, etc.**	**10%**	High but is viable at scale without an additional feedstock	5	10%	High (This is a prerequisite as water sources is not expected to be viable without an alternative feedstock. These may be available in rural areas)	3	6%	No additional feedstock	3	6%	No additional feedstock	3	6%	High (This is a prerequisite as water sources is not expected to be viable without an alternate feedstock)	3	6%
10	**Barriers to implementation**	**10%**	Operational risks, bankability and willingness on the part of the implementing agent.	4	8%	High capital expenditure, operating model and access to a suitable feedstock.	3	6%	Operational risks, bankability and willingness on the part of the implementing agent.	3	6%	Need to identify suitable sites, operating risks, vandalism	3	6%	Lack of proof of concept, operating risks, capital expenditure, reliance on additional feedstock.	2	4%
		100%			**88%** 1			**80%** 3			**84%** 2			**56%** 4			**46%** 5

1 Very poor
2 Poor
3 Good
4 Very good
5 Excellent