The State of Waste to Energy Research in South Africa

A REVIEW

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sanedi
South African National Energy Development Institute (SOC) Ltd.

RECORD
renewable energy center of research & development

giz
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

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South African – German Energy Programme (SAGEN)

Hatfield Gardens

333 Grosvenor Street

Pretoria 0028

South Africa

Contact: Marlett Balmer (marlett.balmer@giz.de)

Renewable Energy Centre of Research and Development (RECORD)

PO Box 868

Ferndale

2160

Contact: Dr. Karen Surridge-Talbot (karenst@sanedi.org.za)

Consultant: **Alicia van der Merwe**

PO Box 1387

Wapadrand

0050

Contact: aliciavanderm@gmail.com

List of Abbreviations

ARC	Agricultural Research Council
BBP	Bronkhorstspruit Biogas Plant
BioERG	Bio-resource Engineering Research Group
CAB	Centre for Algal Biotechnology
CBG	Compressed Biogenic Gas
CCT	Clean Coal Technologies
CDP	Cape Dairy Biogas Plant
CeBER	Centre for Bioprocess Engineering Research
CHP	Combined Heat and Power
CPUT	Cape Peninsula University of Technology
CREW	Centre for Renewable Energy and Water
CSIR	Council for Scientific and Industrial Research
DBSA	Development Bank of Southern Africa
DEA	Department of Environmental Affairs
DoE	Department of Energy
DUT	Durban University of Technology
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
EPPEI	Eskom Power Plant Engineering Institute
ERC	Energy Research Centre
FHIT	Fort Hare Institute of Technology
GEEF	Green Energy Efficiency Fund
IDC	Industrial Development Corporation

IEA	International Energy Agency
IEP	Integrated Energy Plan
iFSM	Integrated Faecal Sludge Management
IPAP	Industrial Policy Action Plan
IPP	Independent Power Producer
IREAP	Institute for Research in Electronics and Applied Physics
IRP	Integrated Resource Plan
ISCW	Institute for Soil, Climate and Water
I-WARM	Institute for research in Waste and Resources Management
IWWT	Institute for Water and Wastewater Technology
MaPS	Material and Process Synthesis Unit
MFMA	Municipal Finance Management Act
MRF	Material Recovery Facility
MSA	Municipal Systems Act
MSW	Municipal Solid Waste
MUT	Mangosuthu University of Technology
NDP	National Development Plan
Necsa	South African Nuclear Energy Corporation
NEM:AQA	National Environmental Management: Air Quality Act
NEM:WA	National Environmental Management: Waste Act
NEMA	National Environmental Management Act
NERSA	National Energy Regulator of South Africa
NGP	New Growth Path
NRF	National Research Foundation

NSSD	National Strategy for Sustainable Development and Action Plan
NWMS	National Waste Management Strategy
NWU	North-West University
PEETS	Process, Energy and Environmental Technology Station
PPP	Public-Private Partnership
RDF	Refuse-Derived Fuel
REDISA	Recycling and Economic Development Initiative of South Africa
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
REPP	Renewable Energy Procurement Programme
RU	Rhodes University
SABIA	Southern African Biogas Industry Association
SADC	Southern African Development Community
SANCOOP	South Africa – Norway, Research Co-operation
SANEDI	South African National Energy Development Institute
SAWIS	South African Waste Information System
STG+	Syngas to Gasoline Plus
SU	Stellenbosch University
UASB	Upflow Anaerobic Sludge Blanket
UCT	University of Cape Town
UFH	University of Fort Hare
UJ	University of Johannesburg
UKZN	University of KwaZulu-Natal
UL	University of Limpopo
UNISA	University of South Africa

UniVen	University of Venda
VGB	Vereinigung der Großkesselbesitzer e.V
VP-BPV	Vascular Plant-Biophotovoltaics
VUT	Vaal University of Technology
Wits	University of Witwatersrand
WPG	Waste Process Grease
WRC	Water Research Commission
WtE	Waste to Energy

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Summary

Energy supply and waste management are two challenges that South Africa is faced with due to rapid economic and population growth. In order to meet these challenges in the future and to support the governments drive towards a green economy, innovative strategies are required to produce affordable, clean energy from renewable sources. Here waste to energy (WtE) technologies can provide a dual solution. This review provides an overview of the current waste to energy (WtE) research being carried out at South African Universities, Universities of Technology and other research institutions. Common research themes and priorities were identified as well as possible gaps that are not being covered by current WtE research. This review also includes recommendations on future WtE focal areas for South Africa.

Although the current WtE research landscape in South African is very diverse a specific preference has been shown towards anaerobic digestion for the production of biogas. Furthermore, other fields of interest also included fermentation for the production of bioethanol, gasification for the production of syngas (which is further converted to several liquid fuels), pyrolysis for the production of bio-oil and transesterification for the production of biodiesel. Although research was spread amongst various types of wastes, feedstock most researched included municipal solid waste, agricultural waste (e.g. animal waste, crop residues), industrial waste, wastewater, wood waste, food waste and waste tyres.

Waste to energy research and implementation in South Africa is driven by social and economic factors as well as government directive. Several incentives, policies and programmes have been put into place in order to promote WtE in the country. The alignment of WtE research in South Africa with these policies, incentives and programmes is crucial to its successful implementation. The country's current drive towards the use of biomass waste/residues, municipal waste, industrial waste, waste tyres and small-scale renewable energy projects for the production of biogas, liquid fuels, heat and electricity is well complimented by current research being conducted at South African research institutes. Furthermore although the

uptake of WtE technologies in the county shows promise it is still hindered by several factors and to address some of these problems a few recommendation were presented.

Introduction

The processes of urbanisation and industrialisation are positively correlated with energy consumption and waste generation. This is especially noticeable in metropolitan areas that experience rapid population growth and continuous physical expansion in response to modernisation and globalisation (9). This ultimately leads to greater volumes of commercial, industrial and municipal waste with a diverse complexity and composition. In the past, South Africa favored landfilling due to freely available land with arid conditions and low population density. This has resulted into limited incentive to divert waste streams away from landfill and towards alternative waste management practices. Today this is no longer sustainable due to landfill space constraints and increased competition for land in larger metropolitan areas, necessitating waste recycling and reduction in landfill volumes (3). According to the third national waste baseline assessment, South Africa generated approximately 108 million tonnes of waste in 2011 of which 59 million tonnes were general waste. Only 10% of the general waste was recycled and the remaining 53.5 million tonnes landfilled. However, the extent to which waste is handled, transported, recycled and/or recovered is unknown as reporting is not currently legislated (4). To promote waste minimisation, the South African government has initiated the following:

- A 150% Research and Development tax rebate for the implementation of design principles that incorporate re-use and recycling;
- The National Cleaner Production Centre which aims to reduce the quantity and toxicity of waste during manufacturing processes;
- The Industry Waste Management Plans (formal industry developed plans in consultation with DEA in terms of NEM:WA) are being prepared by the paper and packaging industry, the pesticide industry, the lighting industry and the tyre industry (3).

South Africa currently relies almost entirely on fossil fuels (approx. 90%) to satisfy its energy demand, with coal providing 75% of this energy supply (1). This dependence is due to its vast coal resources, making it an attractive and low-cost source of energy for South Africa (2). The majority of total greenhouse gas (GHG) emissions in the country (85% in 2010) are produced by the Energy sector (11), with 0.99 kgs of carbon dioxide emitted per kWh of electricity generated for 2012 (12). It was therefore important for South Africa, as a signatory of the Kyoto Protocol, to focus on ways to reduce CO_2 emissions (10). Furthermore, delays in the construction of additional power stations (3) and the approval by NERSA (National Energy Regulator of South Africa) of a 12.69% electricity tariff increase for 2015 (7), necessitates alternative means of generating electricity.

Waste to energy (WtE) offers a feasible solution to not only mitigate South-Africa's electricity constraints and reduce CO_2 emissions, but to also extend current landfill lifespan. WtE is defined by the Environmental Protection Agency (EPA) as: "The conversion of non-recyclable waste materials into useable heat, electricity, or fuel through a variety of processes, including combustion, gasification, pyrolization, anaerobic digestion, and landfill gas (LFG) recovery". The successful implementation of WtE projects are currently hindered by several factors such as: low gate fees at landfills (thereby still making it the preferred disposal route), complexity of waste supply, relatively low electricity prices (3), high capital costs of most WtE facilities (8), public perception of WtE (8), lengthy Environmental Impact Assessment (EIA) and governmental approval processes, initiating electricity agreements with municipalities (Regulated by Municipal Finance Management Act and Municipal Systems Act), time consuming carbon financing registration processes, limited opportunity for combined heat and power generation as South Africa has a mild climate, skill shortage and lack of research and development (3). Despite these constraining factors, there are numerous opportunities to be captured, as the country has several strengths which could ensure successful WtE technology implementation, for example: the country has significant quantities of landfill waste and other untapped waste resources, it has relatively advanced banking and financial institutions which can control funding, a developing regulatory and legislative system, shortages in electricity supply, greenhouse gas reduction initiatives, etc. (3).

The South African government has shown an increased commitment to a more environmentally sustainable economy that minimises emissions and maximises the efficient use of energy, through a range of policies and programmes.

The following sections outline the prominent policies and regulations that (in)directly promote the development of the WtE industry in the country.

General government policies applicable to the waste to energy industry

The National Development Plan (NDP) 2030, 2011

- The National Development Plan sets targets and outlines actions to ensure the country's development challenges are addressed.
- The NDP aims to change the South African energy system to reduce greenhouse emissions and alter the country's heavy reliance on fossil fuel. A target was set to procure 20 000 MW of electricity from renewable energy and establish an economy-wide carbon price by 2030.

The Energy Efficiency Strategy, 2008 – First review

- The strategy aims to guide the development and implementation of novel technologies and energy efficiency practices, at residential and industrial locations, thereby reducing energy demands. Here, on-site energy production using waste already at the site could fall into this classification.

New Growth Path (NGP) Framework, 2010

- The New Growth Path was adopted by government, as the framework for economic policy development and driver of job creation strategies in the country.

- The NGP identified Green economy as a facilitator for employment creation, and called for the promotion of greater investment by the private sector in this area. A targeted 400 000 additional jobs could be created by 2030.
- The NGP framework requested the development of codes for commercial buildings to reduce energy use and waste production.

New Growth Path: Accord 4. Green Economy Accord, 2011

- The Green Economy Accord is a result from shared dialogue on the NGP Framework and is a signed commitment by government, business, organised labour and community constituents.

National Strategy for Sustainable Development and Action Plan (NSSD), 2011 – 2014

- The NSSD is a proactive strategy that calls for the diversification of the country's energy sources and implementation of energy efficiency programmes. It ultimately aims to encourage investment in renewable energy.
- The NSSD regards sustainable development as a continuing commitment, which combines social equity, environmental protection and economic efficacy with the vision and values of the country.
- The strategy endorses the employment of green cities and towns, event greening and tourism.

Municipal Systems Act 2000 (Act No. 32 of 2000) (MSA)

- Provide fundamental principles, mechanisms and processes to municipalities, thereby enabling a progressive move towards social and economic enhancement of local communities, ensuring universal access to important services that are affordable to all.
- The Act includes planning and implementing municipal service delivery, such as waste management, and aims to upgrade, extend and improve on services.

Municipal Finance Management Act No. 56 of 2003 (MFMA)

- An Act to secure comprehensive and sustainable management of the financial affairs of municipalities and other institution in the local scope of government, to establish treasury norms and standards for the local scope of government and to provide for matters connected therewith.
- The Municipal Finance Management Act states requirements for a municipality to enter into a public-private partnership (PPP) agreement. The municipality must demonstrate that the proposed agreement will, (a) provide value for money to the municipality; (b) be inexpensive for the municipality; and (c) transfer suitable technical, operational and financial risk onto the private party.

Industry regulations - General socio-economic policies

Environmental

The National Environmental Management Act (NEMA) 107 of 1998

The National Environmental Management: Waste Management (NEM:WA) Act 59 of 2008

The National Environmental Management: Air Quality Act (NEM: AQA), 2008

- These acts are encompassing all environmental legislation in the country, which covers air, waste, water use and general environmental impact. The acts outline environmental responsible guidelines for operating facilities that pose a potential environmental risk.

Minimum Requirements for Handling, Classification and Disposal of Hazardous Waste, 1998

- List steps required when classifying hazardous waste, as well as its handling and disposal.
- One of the recommended treatment options includes incineration that could be combined with power generation.

White Paper on Integrated Pollution and Waste Management, GN 227 March 2000

- The White Paper emphasises the importance of preventing pollution at the source, thereby minimising the impact on the receiving environmental as well as rehabilitating the degraded environments.

Economic

Industrial Policy Action Plan (IPAP), 2012/2013

- IPAP aims to guide industrial development as well as focus the countries resources on identified critical sectors, thereby ensuring the improvement of the local economy and job market.
- Under Green industries, waste management and the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) exist.

Energy and electricity

Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), 2011

- REIPPPP was initiated in 2011 by the Department of energy, to encourage the private sector to invest in wind, solar photovoltaic, concentrated solar (CSP), biomass and small-hydro-technology. According to this programme, prospective producers of green energy with a capacity over 5MW must place a bid. Therefore, REIPPPP could provide a potential source of financial and operational support for the before mentioned technologies.
- For prospective producers of green energy with a generation capacity of not less than 1 MW but under 5 MW, a separate programme namely The Small Projects IPP Procurement Programme exists. Technologies that shall be considered under this programme include: onshore wind, solar photovoltaic, biomass, biogas and landfill gas.

The Integrated Resource Plan (IRP), 2011

- The IRP forms a subset of the Integrated Energy Plan. The IRP provides a long-term planning framework to supply the countries projected energy demand at the lowest cost. One of the listed potential sources for energy production is Municipal Solid Waste (MSW).

The Integrated Energy Plan (IEP), 2012 (Draft – for public consultation)

- It is a multi-faceted, long term energy framework which was undertaken to determine the best way to meet the current and projected energy service needs of the country in the most efficient and socially beneficial manner, while keeping control over economic costs.

Electricity Regulations on New Generation Capacity, 2010

- Assists planning of new power generation facilities, controls and sets standards for power purchase agreement.

Amended Electricity Regulations Act, 2006

- The Act has the following set goals:
    - Form a national regulatory framework for the electricity supply industry;
    - Make the National Energy Regulator of South Africa (NERSA) the custodian and enforcer of the national electricity regulatory framework;
    - Diversify the countries energy sources;
    - To regulate the generation, transmission, distribution, trading and the import and export of electricity by providing licences and registration.

White Paper on the Renewable Energy Policy, 2004

- The paper states Governments principles, goals and objectives for renewable energy, with a list of enabling actions. Government plans to purposefully develop the renewable energy resources in a methodical way. The challenge is to provide sufficient incentives for renewable energy based industries to develop, grow and be sustainable in the long term.

Waste Management

South Africa's National Policy on the Thermal Treatment of General and Hazardous Waste, GN. R. 777 of 24 July 2009

- The policy states the government's stance on thermal treatment as a suitable waste management strategy, and provides an outline within which the following thermal waste treatment technologies shall be implemented:
  - Incineration of general and hazardous waste in dedicated incinerators or other high temperature thermal treatment technologies, including but not limited to pyrolysis and gasification;
  - Co-processing of selected general and hazardous wastes as alternative fuels and/or raw materials in cement production.

National Waste Management Strategy (NWMS), 2012

- NWMS is a legislative requirement of the NEM:WA. The purpose of the NWMS is to achieve the objects of the NEM:WA. Organs of state and affected persons are obliged to give effect to the NWMS.
- Waste management in South Africa faces numerous challenges and the NWMS provides a plan to address them.

Objective of the review

The objective of the project is to provide an overview of the current WtE research being carried out at South African Universities, Universities of Technology and other research institutions, to identify common themes and priorities in this energy research, to identify possible gaps that are not being covered by current energy research, to compile a profile of the energy researchers actively working in the field and to make recommendations on future research focal areas for South Africa. Ultimately, the information generated during the course of the review will be used in the establishment of a WtE research platform.

Current waste to energy research conducted in South Africa

Universities of Technology

Dr. Vincent Okudoh
Lecturer, Department of Biotechnology

Department of Biotechnology
Faculty of Applied Sciences Building
Cape Town Campus
Corner of Keizersgracht and Tennant Street
Zonnebloem
Cape Town
8000
Tel: +27 21 460 3507
Fax: +27 21 460 3282
E-mail: okudohv@cput.ac.za

Current Waste to Energy Research Themes

- **Biochemical Conversion Technologies**
  - *Process*: Anaerobic digestion
  - *Feedstock*: Food waste, Plant waste, Municipal solid waste, Industrial waste such as winery waste
  - *Product*: Biogas, Biomethane (upgraded biogas), Digestate
  - *Other*: Digester design and construction
    : Digester installation
    : Consultation and advice

Overview of Current Waste to Energy Research

- Research in collaboration with some colleagues focusses mainly on the use of food and plant waste along with some selected energy crops such as cassava, sugar beets, amadumbe etc. The group collaborations cut across countries; Cranfield University, UK; Hamburg University of Applied Sciences, Germany; University of KwaZulu-Natal (UKZN) and Cape Peninsula University of Technology (CPUT), South Africa and Agricultural

Research Council (ARC), Stellenbosch. The Bio-resources Engineering Research Group (BioERG) located at Biotechnology Department at Cape Town Campus of CPUT aims to take anaerobic digestion research more seriously for the benefit of South Africa. However, support is needed from all stakeholders to achieve this aim.

Recommendations on Future Waste to Energy Research Focal Areas for South Africa

- Future research based on multidisciplinary approach involving a team assembled from Agriculture, Chemical Engineering and Microbiology departments;
- Research that utilises a combination of waste and non-food energy crops;
- Research that combines the different technologies;
- More focus needs to be placed on the use of the following feedstock for anaerobic digestion research:
    1. Food (industrial) and plant (agriculture) waste
    2. Municipal solid waste (household)
    3. Slurry and sewage
    4. Selected energy crops like cassava, sugar beet and amadumbe;
- On the government level, separate food waste collection bins by the municipal officials. The average household in South Africa throws away lots of food every month not to mention the wastes from the supermarkets and restaurants. Adopting this strategy will boost recycling rates by 25%, reduce waste that end up in landfills by 30% and save local authorities in South Africa millions of Rand on the cost of disposal. Furthermore, government regulation of the anaerobic digestion industry should also be considered;
- The adoption of cassava in South Africa as an energy crop. This crop provides multiple benefits due to its better water-footprint than most crops. It is currently not a staple food in South Africa and can supplement other wastes due to its high carbohydrate content and can be grown in most parts of the country without much fertilizer input. Educating our

commercial farmers to try this crop could spiral anaerobic digestion research into a big industry as it complements well with other feedstock currently used in South Africa.

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

- The benefits of anaerobic digestion technology to the future South African economy cannot be overemphasised. More experts are needed in this area to tap into this multi-million dollar industry;
- More research on bioresources which includes technologies and processes complimentary to the anaerobic digestion process are also required. These processes will help increase the viability and efficiency of the anaerobic digestion technology. Research into emerging technologies and products from the bioeconomy such as:
    1. Bioplastics made from volatile fatty acids produced during anaerobic digestion will reduce dependence on oil-based plastics
    2. Algal research can be run from heat produced from an anaerobic digestion plant
    3. Improving energy storage from heat and electricity produced from anaerobic digestion plants
    4. Cleaning up biogas for use as vehicle fuel and injection into the national grid
    5. Possible chemical products from long chain fatty acids made during the anaerobic digestion process

Waste to Energy Colleagues

- Prof. Cristina Trois (University of KwaZulu-Natal, troisc@ukzn.ac.za)
- Prof. Stefan Schmidt (University of KwaZulu-Natal, schmidts@ukzn.ac.za)
- Prof. Tilahun Workneh (University of KwaZulu-Natal, seyoum@ukzn.ac.za)
- Mr. Nathaniel Sawyerr (University of KwaZulu-Natal)
- Prof. Paul Scherer (Hamburg University of Applied Sciences, Germany)

- Mr. Frederick Coulon (Cranfield University, UK)
- Dr. SKO Ntwampe (Cape Peninsula University of Technology, ntwampes@cput.ac.za)
- Mrs. Nike Lewu (ARC, Stellenbosch)
- Mr. Reckson Mulidzi (ARC, Stellenbosch)

Prof. Daniel Ikhu-Omoregbe
HoD, Department of Chemical Engineering

Department of Chemical Engineering
Chemical Engineering Building
Bellville Campus
Symphony Way
Bellville
7535
Tel: +27 21 959 6130
E-mail: ikhuomoregbed@cput.ac.za

Overview of Current Waste to Energy Research

- Conversion of municipal solid waste (MSW) to refuse derived fuels (RDF) and solid derived fuels (SDF) to determine their suitability for use in energy plants;
- Analysis of the potentials of landfill gases for energy generation;
- Analysis and modeling of PEM fuel cells, and combined heat and power (CHP) systems.
- Analysis of the gasification of MSW for energy and hydrogen production;
- Studies in energy and chemicals from scrap tyres;
- Biodiesel production from waste vegetable and palm oil using heterogeneous catalyst from waste materials, its viability: both environmentally and economically. The effects of free fatty acids and moisture content on the production of biodiesel;
- Production of gasoline and diesel from wastewater sludge.

Recommendations on Future Waste to Energy Research Focal Areas in South Africa

- Characterisation and quantification of types of waste in South Africa;
- Analysis and adaptation of existing technologies for their suitability for the South African municipal and industrial wastes processing;

- Investigation of the beneficiation of the various types of wastes.

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

- There is a need for collaboration amongst researchers in the various Universities and Research establishments in South Africa;
- Involvement of local and municipal authorities in collaboration with institutions in the handling, treatment and disposal of wastes for energy generation.

Waste to Energy Colleagues

- Mr. A. Rabiu (Cape Peninsula University of Technology, rabiua@cput.ac.za)
- Dr. Yusuf Isa (Cape Peninsula University of Technology, isay@cput.ac.za)
- Dr. O Oyekola (Cape Peninsula University of Technology, oyekolas@cput.ac.za)

Prof. Faizal Bux
Director, Institute for Water and Wastewater Technology (IWWT)

Institute for Water and Wastewater Technology
Steve Biko Campus
Durban University of Technology
Corner of Steve Biko Road and Botanic Gardens Road
Durban
4001
Tel: +27 31 373 2597
Fax: +27 31 373 2777
E-mail: faizalb@dut.ac.za

Current Waste to Energy Research Themes

- **Biochemical Conversion Technologies**
  - *Process*: Dark fermentation
  - *Feedstock*: Crop residues - sugarcane bagasse
  - *Product*: Biohydrogen

  - *Process*: Anaerobic digestion
  - *Feedstock*: Wastewater
  - *Product*: Biogas
  - *Other*: Evolutionary algorithm application

Overview of Current Waste to Energy Research

- Evaluation of biohydrogen production potential of sugarcane bagasse in dark fermentation process;
- Microbial community analysis of an anaerobic baffled reactor enriched for dark fermentative hydrogen producing bacteria;

- Application of an evolutionary algorithm to enhance wastewater degradation and biogas production in an upflow anaerobic sludge blanket (UASB) reactor.

Recommendations on Future Waste to Energy Research Focal Areas for South Africa

- None

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

- None

Waste to Energy Colleagues

- None

Prof. Akash Anandraj
Director, Centre for Algal Biotechnology (CAB)

Centre for Algal Biotechnology
Department of Nature Conservation
Mangosuthu University of Technology
511 Mangosuthu Highway
Umlazi
KwaZulu-Natal
4031
Tel: +27 31 907 7627
E-mail: akash@mut.ac.za

Current Waste to Energy Research Themes

- **Biochemical Conversion Technologies**
  - *Process*: Photo fermentation and Combined dark/photo fermentation
  - *Feedstock*: Wastewater, Industrial wastes, Animal waste, Plant wastes and and by-products
  - *Product*: Biogas, Biohydrogen
  - *Product application*: Biogas converted to electricity and heat in cogeneration units (CHP)
    : Upgrade biogas to natural gas grade for use in fuel cells
    : Biohydrogen purification and use in fuels cells
  - *Other*: Economic, technical and environmental analysis
    : Reactor design and construct

  - *Process*: Fermentation
  - *Feedstock*: Agricultural waste, Municipal solid waste, Green waste
  - *Product*: Biobutanol
  - *Other*: Technical and environmental analysis

: Reactor design and construct

- *Process*: Direct biophotolysis
- *Feedstock*: Landfill leachate
- *Product*: Biohydrogen
- *Product application*: Biohydrogen purification and use in fuel cells
- *Other*: Life-cycle assessment

  : Economic, technical, environmental and socio-economic analysis

  : Reactor design and construct

- **Bioelectrochemical Conversion Technologies**
  - *System*: Microbial fuel cells
  - *Feedstock*: Wastewater, Landfill leachate
  - *Product*: Electricity

- **Thermochemical Conversion Technologies**
  - *Process*: Direct combustion
  - *Feedstock*: Industrial waste

Overview of Current Waste to Energy Research

- Research conducted includes the conversion of several waste feedstock by making use of biochemical, thermal and bioelectrochemical conversion technologies.

Recommendations on Future Waste to Energy Research Focal Areas for South Africa

- Biohydrogen to fuel cells, for a direct piped source of hydrogen

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

- None

Waste to Energy Colleagues

- Dr. Sarah White (Mangosuthu University of Technology, Sez.white@gmail.com)

Prof. Ochieng Aoyi
Director, Centre for Renewable Energy and Water (CREW)

Centre for Renewable Energy and Water
Department of Chemical Engineering
Vanderbijlpark Main Campus
Vaal University of Technology
Andries Potgieter Blvd
Vanderbijlpark
1900
Tel: +27 16 950 9884
E-mail: ochienga@vut.ac.za

Current Waste to Energy Research Themes

- **Biochemical Conversion Technologies**
  - *Process*: Integrated anaerobic digestion and photodegradation
  - *Feedstock*: Wastewater, Industrial waste, Food waste, Sewage sludge, Abattoir waste,
  - *Product*: Biogas

- **Chemical Conversion Technologies**
  - *Process*: Transesterification
  - *Feedstock*: Waste cooking oil, Waste processing grease
  - *Product*: Biodiesel

- **Thermochemical Conversion Technologies**
  - *Process*: Pyrolysis
  - *Feedstock*: Waste tyres
  - *Product*: Bio-oil

- *Process*: Direct combustion
- *Feedstock*: Industrial waste, Refuse-derived fuel

Overview of Current Waste to Energy Research

- Research conducted includes the conversion of several waste feedstock by making use of biochemical, thermal and chemical conversion technologies.

Recommendations on Future Waste to Energy Research Focal Areas in South Africa

- The focus should be in generating region specific data. In this case, the region should be South Africa. Conventional method should be integrated with advanced ones in order to improve systems performance with regard to quality and quantity of the product.

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

- Application of low-cost nano-materials (catalysts) to improve WtE conversion.

Waste to Energy Colleagues

- Dr. Hillary Ruto (Vaal University of Technology, hilaryr@vut.ac.za)
- Prof. Maurice Onyango (Tshwane University of Technology, onyangoms@tut.ac.za)
- Prof. Paul Musonge (Durban University of Technology, paulm@dut.ac.za)

Universities

Prof. Sanette Marx
Associate Professor, School of Chemical and Minerals Engineering

School of Chemical and Minerals Engineering
Potchefstroom Campus
North-West University
11 Hoffman Street
Potchefstroom
2531
Tel: +27 18 299 1995
Fax: +27 18 299 1535
E-mail: sanette.marx@nwu.ac.za

Current Waste to Energy Research Themes

- **Chemical Conversion Technologies**
  - *Process*: Esterification, Transesterification, Catalytic hydrotreatment, Nano-catalysts, Polymerisation
  - *Feedstock*: Waste cooking oil, Animal fat, Waste process grease (WPG), Butter factory effluent, Sweet sorghum bagasse, Water hyacinth, Waste lignin
  - *Product*: Biodiesel, Renewable diesel, Bio-butanol, Diisocyanate, Bio-phenols, Bio-polyurethane foam

- **Bioelectrochemical Conversion Technologies**
  - *System*: Microbial fuel cells
  - *Feedstock*: Wastewater
  - *Product*: Electricity

- **Biochemical Conversion Technologies**
  - *Process*: Fermentation
  - *Feedstock*: Sweet sorghum bagasse, Amaranth stalks and stems, Crude glycerol, Wood waste, Paper waste
  - *Product*: Bioethanol, Biobutanol, Biomethanol, Organic acid, Succinic acid

  - *Process*: Anaerobic digestion
  - *Feedstock*: Municipal solid waste, Industrial wastes, Crop residues, Animal waste, Plant wastes and by-products,

    : Co-digestion (sweet sorghum bagasse, amaranth, water hyacinth and pig manure mixtures)
  - *Product*: Biogas, Hydrocarbons (organic acids)

- **Thermochemical Conversion Technologies**
  - *Process*: Co-combustion
  - *Feedstock*: Coal/biochar (derived through liquefaction blends)

  - *Process*: Co-gasification (GreenCoal), Liquefaction
  - *Feedstock*: Coal/biochar (derived from liquefaction of waste), Industrial waste, Woody weeds, Animal waste, Oil cake, Amaranth stalks, Sweet sorghum bagasse, Municipal Effluent
  - *Product*: Syngas, Biochar, Bio-oil, Biodiesel, Renewable diesel (for petrol, diesel and bio-paraffin production)
  - *Product* application: Syngas for further processing to liquid fuels and chemicals

    - Gasoline, diesel and jet fuel (Fischer-Tropsch process)
    - Gasoline, diesel and jet fuel (STG+ process)
    - Synthetic natural gas
  - *Other*: Biomass-coal kinetics

    : Heat transfer parameters

Overview of Current Waste to Energy Research

- Research conducted include the conversion of several waste feedstock by making use of biochemical, thermal, chemical and bioelectrochemical conversion technologies.

Recommendations on Future Waste to Energy Research Focal Areas for South Africa

- Future WtE research should focus on using the following feedstock: Municipal waste (sewage, grasses and waste plant materials), water effluent from industrial processes, landfill and agricultural and crop residues, fermentation waste;
- Future WtE research should focus on the following processes: Catalytic hydrotreatment, biodiesel production, liquefaction and co-gasification.

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

- Microbial fuel cell research;
- Incorporation of biomass into the upstream processes and not blending at the final stage. Very little is being done in this regard;
- Solar fuels; use of a combination of renewable energy technologies to produce electricity, fuel and chemicals in a single plant.

Waste to Energy Colleagues

- Mr. Corneels Schabort (North-West University, corneels.schabort@nwu.ac.za)
- Dr. Elvis Fosso-Kankeu (North-West University, 24838616@nwu.ac.za)
- Dr. Idan Chiyanzu (North-West University, 240043605@nwu.ac.za)
- Dr. Roelf Venter (North-West University, 13003685@nwu.ac.za)

Prof. Christien Strydom
Director, School of Physical and Chemical Sciences

School of Physical and Chemical Sciences
Building G6, Room E112
Potchefstroom Campus
North-West University
Potchefstroom
2531
Tel: +27 18 299 2340
Fax: +27 18 299 2350
E-mail: christien.strydom@nwu.ac.za

Current Waste to Energy Research Themes

- **Thermochemical Conversion Technologies**
    - *Process*: Thermal gasification
    - *Substrate*: Wood waste, Agricultural waste
    - *Product*: Syngas
    - *Product application*: Syngas for heat production
      : Syngas for power production in gas engines, turbines or fuel cells
    - *Other*: Technical analysis

    - *Process*: Co-gasification
    - *Substrate*: Coal/waste wood blends, Coal/crop residue blends
    - *Product*: Syngas
    - *Product application*: Syngas for heat production
      : Syngas for power production in gas engines, turbines or fuel cells
      : Syngas for further processing to liquid fuels

- *Other*: Technical analysis

- *Process*: Co-pyrolysis
- *Substrate*: Coal/waste wood blends, Coal/crop residue blends
- *Product*: Bio-oil
- *Product* application: Bio-oil as feedstock for synthesis gas production
- *Other*: Technical analysis

Overview of Current Waste to Energy Research

- The influence of selected biomass additions on the co-pyrolysis and co-gasification with an inertinite-rich medium rank C South African coal as well as vitrinite-rich South African coals. The aim is to understand the chemical mechanisms involved in order to control the processes better. Moreover, possible catalytic effects are studied;
- Direct liquefaction of coal using a biomass derived phenol-rich solvent;
- Investigation of the chemical and structural changes of dried biomass, torrefied biomass and torrefied biomass-coal blends during pyrolysis and gasification.

Recommendations on Future Waste to Energy Research Focal Areas for South Africa

- Co-use of coal and waste biomass during thermal processing is important to alleviate the pressure on usage of mined coal and to decrease the environmental impact of waste biomass. Although Clean Coal Technologies and energy efficient strategies are being developed, an alternative carbon supply must be found to augment our coal supply for the future while also improving the carbon footprint associated with gasification.

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

- Extend current research of co-gasification to also include other carbon-rich waste material.

Waste to Energy Colleagues

- Prof. Sanette Marx (North-West University, sanette.marx@nwu.ac.za)
- Prof. John Bunt (North-West University, john.bunt@nwu.ac.za)
- Prof. Ray Everson (North-West University, ray.everson@nwu.ac.za)
- Prof. Hein Neomagus (North-West University, hein.neomagus@nwu.ac.za)

Prof. John Bunt
Associate Professor, School of Chemical and Minerals Engineering

School of Chemical and Minerals Engineering
Building N1, Room 141
Potchefstroom Campus
North-West University
Potchefstroom
2531
Tel: +27 18 299 1376
Fax: +27 18 299 1535
E-mail: john.bunt@nwu.ac.za

Current Waste to Energy Research Themes

- **Thermochemical Conversion Technologies**
  - *Process*: Co-gasification
  - *Feedstock*: Coal/waste tyre blends
  - *Product*: Syngas, Partial gasification-high surface area products
  - *Product* application: Syngas for heat production
    : Syngas for further processing to liquid fuels
  - *Other*: Technical analysis

  - *Process*: Pyrolysis
  - *Feedstock*: Waste tyres
  - *Product*: Chars, gas and bio-oil
  - *Other*: Technical analysis

Overview of Current Waste to Energy Research

- Pyrolysis of used automobile tyres to produce chars, gas and "oil";
- Pyrolysis of coal to produce chars;
- Blending and co-gasification of coal and tyre derived chars.

Recommendations on Future Waste to Energy Research Focal Areas for South Africa

- Blending waste derived products with current mainstream energy products;
- Environmental impact of waste utilisation as a source of energy.

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

- Separation of pyrolysis products into different valuable entities.

Waste to Energy Colleagues

- Dr. Rufaro Kaitano (North-West University, rufaro.kaitano@nwu.ac.za)
- Prof. Hein Neomagus (North-West University, hein.neomagus@nwu.ac.za)

Prof. Carlos Bezuidenhout
Subject Chair and Associate Professor, Microbiology

School of Biological Sciences
Subject Group: Microbiology
Building E6, Room 211
Potchefstroom Campus
North-West University
Potchefstroom
2531
Tel: +27 18 299 2315
Fax: +27 18 299 2330
E-mail: carlos.bezuidenhout@nwu.ac.za

Current Waste to Energy Research Themes

- **Biochemical Conversion Technologies**
  - *Process*: Anaerobic digestion
  - *Feedstock*: Sewage Sludge, Faecal Sludge
    : Co-digestion (Faecal sludge for co-digestion with sewage sludge, Garden waste, Kitchen waste, Grease trap residue)
  - *Product*: Biogas
  - *Product* application: Biogas converted to electricity and heat in cogeneration units (CHP)
    : Upgrade biogas to natural gas grade for use as a natural gas substitute
  - *Other*: Economic, technical and socio-economic analysis

Overview of Current Waste to Energy Research

- Reviewing faecal sludge management practices and policies in South Africa and in particular North-West Province;
- Reviewing available organic waste streams (e.g. faecal sludge from pit latrines, garden refuse) in Tlokwe Local Municipality;
- Reviewing potential beneficial uses of faecal sludge and treatment processes;
- Investigating feasibility of upgrading existing wastewater treatment infrastructure with value-added processes, in particular biogas utilisation;
- Cost-benefit analysis and development of a catalogue of factors that influence feasibility;
- Installing an anaerobic digestion process at a wastewater treatment plant and if applicable modifying it to a mesophilic process;
- Setting up a laboratory to research co-digestion of various substrates;
- Utilising the produced biogas to generate electricity and heat, if applicable;
- Identifying interfaces to other research areas e.g. dry toilets, products from (biogas) process residues.

Recommendations on Future Waste to Energy Research Focal Areas in South Africa

- Integration of WtE research into waste, water, energy nexus;
- Co-digestion of faecal sludge with animal manure;
- Pyrolysis of municipal organic waste for biochar;
- Capturing of municipal organic waste for anaerobic treatment.

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

- There is a strong need for full scale working examples in order to move toward process optimisation and (full scale) co-digestion research;
- Small lab reactors are not enough to promote research in this field.

Waste to Energy Colleagues

- Integrated Faecal Sludge Management (iFSM) Project Team at NWU:
  - Prof. Carlos Bezuidenhout (carlos.bezuidenhout@nwu.ac.za)
  - Senta Berner (23136359@nwu.ac.za)
  - Dr. Jaco Bezuidenhout (jaco.bezuidenhout@nwu.ac.za)
  - Bren Botha
  - Liandi Bothma
- Tlokwe Local Municipality
- SALGA-NW, and national office
- Bauhaus Universitaet Weimar, Germany

Prof. Janice Limson
Director, Biotechnology Innovation and Communication Centre

Biotechnology Innovation Centre
Biological Sciences Building
Prince Alfred Street
Rhodes University
Grahamstown
6140
Tel: +27 46 603 8263
Fax: +27 46 603 7576
E-mail: j.limson@ru.ac.za

Current Waste to Energy Research Themes

- **Bioelectrochemical Conversion Technologies**
  - *System*: Microbial fuel cells
  - *Feedstock*: Wastewater, Brewery wastewater
  - *Product*: Electricity

Overview of Current Waste to Energy Research

- Research focuses on the area of energy from biofuel cells coupled to wastewater treatment.

Recommendations on Future Waste to Energy Research Focal Areas for South Africa

- The need currently is for research in bioenergy to be translated into a pilot scale project;
- The Energy-Water Nexus is a key concern as it buttresses food, health and biodiversity. The issues then of translating wastewater into energy seek to conserve both water and

energy resources which are inextricably linked both to each other and in their impact on the other key sectors.

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

- Surveys on industrial waste

Waste to Energy Colleagues

- Richard Laubscher (Rhodes University, r.laubscher@ru.ac.za)
- Prof Tebello Nyokong (Rhodes University, t.nyokong@ru.ac.za)
- Prof Keith Cowan (Rhodes University, a.cowan@ru.ac.za)

Prof. Johann Görgens
Professor, Department of Process Engineering

Department of Process Engineering
Stellenbosch University
Banghoek Road
Stellenbosch
7600
Tel: +27 21 808 3503
Fax: +27 21 808 2059
E-mail: jgorgens@sun.ac.za

Current Waste to Energy Research Themes

- **Biochemical Conversion Technologies**
  - *Process*: Fermentation
  - *Feedstock*: Any type of lignocellulosic plant materials
  - *Product*: Bioethanol, butanol, jet fuel
  - *Other*: Computer-based process designs
    : Reactor design and construct
    : Life-cycle assessment
    : Economic, technical, environmental and socio-economic analysis

  - *Process*: Anaerobic digestion
  - *Feedstock*: Industrial waste, Food waste, Plant waste and by-products
  - *Product*: Biogas

- **Thermochemical Conversion Technologies**
  - *Process*: Thermal gasification

- *Feedstock*: Any type of lignocellulosic plant materials, Refuse-derived fuel, Waste tyres
- *Product*: Syngas
- *Product application:* Syngas for further processing to liquid fuel
  - Gasoline, diesel, jet fuel (Fischer-Tropsch process)
  - Jet fuel (STG+ process)
  - Ethanol/butanol/methane (Syngas fermentation)
- *Other*: Computer-based process designs
  : Life-cycle assessment
  : Economic, technical and environmental analysis

- *Process*: Co-gasification
- *Feedstock*: Coal/wood waste blends, Coal/crop residue blends

- *Process*: Thermal depolymerisation
- *Feedstock*: Waste tyres, Plastic waste

- *Process*: Pyrolysis
- *Feedstock*: Any type of lignocellulosic plant materials, Waste tyres, Industrial waste, Plastic waste, Municipal solid waste
- *Product*: Pyrolysis products
- *Other*: Computer-based process designs
  : Life-cycle assessment
  : Economic, technical, environmental and socio-economic analysis

Overview of Current Waste to Energy Research

- Biorefineries for co-production of materials, chemicals, fuel and electricity from available plant biomass. Such integration of multiple processes will maximise the economic and environmental benefits derived from available plant biomass, and providing substantial improvements compared to plants dedicated to bio-energy production only;

- Develop technologies for plant biomass conversion and demonstrate the economic and environmental benefits of such processes;
- Integration of experimental technology development with rigorous modelling of conversion processes, both for biorefineries and bio-energy production plants.

Biochemical conversion

- Development of high biomass sugarcane cultivars with improved fibre characteristics for pretreatment-hydrolysis-fermentation to ethanol;
- Conversion of paper sludge from wood pulping or paper recycling into ethanol;
- Integration of cellulosic ethanol from sugarcane bagasse with sugar syrup fermentation in an integrated production plant, involving experimental testing and process modelling.

Thermal conversion

- Pyrolysis process development for sugarcane bagasse; process modelling and economics of incorporating pyrolysis into the energy supply of a sugar mill;
- Sasol co-gasification of biomass with coal, including pyrolysis process development for upgrading of biomass prior to gasification, and thermal degradation kinetics of biomass during co-gasification;
- Thermal degradation kinetics of refuse-derived fuel (RDF) under pyrolysis conditions.

Biorefineries for fuels/chemicals from biomass

- Process modelling for comparison of hydrolysis-fermentation to ethanol, gasification-synthesis and pyrolysis routes for sugarcane bagasse to liquid bio-fuels. Ionic liquids for fractionation of bagasse into hemicellulose, digestible cellulose and lignin streams.

Industrial consultation on new technologies

- Mass and energy balance evaluation on commercial pyrolysis technology;
- Techno-economic evaluation of opportunities for electricity production from biomass;
- Investigation into woody biomass supply for co-firing with coal in electricity supply.

Recommendations on Future Waste to Energy Research Focal Areas for South Africa

- None

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

- None

Waste to Energy Colleagues

- Prof. Emile van Zyl (Stellenbosch University, whvz@sun.ac.za)
- Prof Hansie Knoetze (Stellenbosch University, jhk@sun.ac.za)

Prof. Emile van Zyl
HoD, Department of Microbiology
Senior Chair of Energy Research: Biofuels

Department of Microbiology
JC Smuts Building
Stellenbosch University
De Beer Street
Stellenbosch
7600
Tel: +27 21 808 5854
TeleFax: +27 21 808 5846
E-mail: whvz@sun.ac.za

Current Waste to Energy Research Themes

- **Biochemical Conversion Technologies**
  - *Process*: Fermentation
  - *Feedstock*: Agricultural waste, Crop residues, Wood waste, Green waste
  - *Product*: Bioethanol

Overview of Current Waste to Energy Research

- Genetic manipulation of *Saccharomyces cerevisiae* to utilise cellulose and hemicellulose;
- Isolation and expression of genes encoding cellulases and hemicellulases, as well as enzymes for xylose utilisation in *S. cerevisiae*. This will allow the yeast to utilise an abundant range of polysaccharides for the production of bioethanol;
- Develop next generation recombinant yeast that produces enzymes for efficient fermentation of all hexose and pentose sugars present in cellulose and hemicellulosics (major polysaccharides present in plant material);
- Bioprospect for novel organisms and enzymes capable of lignocellulose degradation as well as characterising them for their potential application in the biofuels industry;

- Expression of commercial important genes in yeast and filamentous fungi for (a) the production of enzymes, (b) the improvement of yeasts for bioethanol production.

Recommendations on Future Waste to Energy Research Focal Areas for South Africa

- None

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

- None

Waste to Energy Colleagues

- Prof. Johann Görgens (Stellenbosch University, jgorgens@sun.ac.za)

Prof. Sue Harrison
Director, Centre for Bioprocess Engineering Research (CeBER)

Centre for Bioprocess Engineering Research
Department of Chemical Engineering
Groote Schuur Campus
University of Cape Town
Rondebosch
7700
Tel: +27 21 650 2518
Fax: +27 21 650 5501
E-mail: sue.harrison@uct.ac.za

Current Waste to Energy Research Themes and Overview

- **Biochemical Conversion Technologies**
  - *Process*: Anaerobic digestion, Dark fermentation, Combined dark and photo fermentation
  - *Feedstock*: Domestic wastewater, Industrial wastewater, Food waste, Sewage sludge, Plant wastes and by-products, Algal residue, Crop residues, Process residues
  - *Product*: Biogas, Biohydrogen
  - *Other*: Life cycle assessment
    : Economic, technical and environmental analysis
    : Reactor design and construct

  - *Process*: Fermentation
  - *Feedstock*: Agricultural waste, Crop residues, Organic municipal solid waste, Process wastes
  - *Product*: Bioethanol, Biobutanol
  - *Other*: Life cycle assessment

: Technical analysis

- **Chemical Conversion Technologies**
    - *Process*: Transesterification
    - *Feedstock*: Waste cooking oil
    - *Product*: Biodiesel
    - *Other*: Life cycle assessment

      : Technical analysis

- **Bioelectrochemical Conversion Technologies**
    - *System*: Microbial fuel cells
    - *Feedstock*: Wastewater, Plant exudates
    - *Product:* Electricity

Overview of Current Waste to Energy Research

- Anaerobic digestion of several waste feedstock;
- Hydrogen production using *Rhodopseudomonas palustris.* Photo fermentation for hydrogen production, using diverse waste resources. This metabolically diverse micro-organism has been demonstrated to perform in a novel immobilised cell system;
- Microbial fuel cells, including the Vascular Plant-Biophotvoltaics (VP-BPV) as well as process of wastewaters. The former is a novel system capable of low cost energy production for essential services in remote locations;
- The development of wastewater anaerobic digestion for greater energy, water and nutrient recovery, WRC Proposal Number 1003933 – under review;
- Wastewater biorefinery – production of biogas, biofuels and commodity bioproducts.

  This forms a current WRC project that seeks to investigate the potential of wastes as resource. Partly this is focussed on energy from waste and it builds on our early work on Energy from Waste (Burton, S. *et al.* 2010. *Energy from wastewater– a feasibility study*.

Essence report. WRC TT 399-09. pp. 38. ISBN 978-1-77005-847-7; Burton, S. *et al*. 2010. *Energy from wastewater– a feasibility study*. *Guide*. WRC TT 400-09. pp. 11. ISBN 978-1-77005-848-4);

- Carbon capture and cycling by algae to reduce carbon footprint of coal-fired power stations – algae can be used for biofuel production or in commodity product production. This project links strongly to an existing research programme on algal biofuels, through both algal oils for biodiesel production and biogas from algal cake;
- Integration of energy recovery with allied processes. Here the focus is on combined energy recovery while processing of wastes or development of industrial ecology processes, allowing energy recovered to offset energy requirements of the process. Examples include the recovery of energy through anaerobic digestion for steam production in breweries and integration of microbial fuel cells into waste treatment processes;
- Modelling and optimisation of fermentation for bioethanol production. In this collaborative project, the modelling approach is used to create optimisation tools towards the integrated optimisation of the bioethanol production process, from both cane juice and molasses as well as bagasse.

Recommendations on Future Waste to Energy Research Focal Areas for South Africa

- Energy from waste - potential for significant contribution to SA;
- Wastewater biorefineries with bioenergy as a lead product;
- Biohydrogen;
- Microbial fuel cells, including the VP-BPV;
- Biobutanol from sugar cane by-products;

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

- Collaboration between different stakeholders, especially across disciplines;
- Appropriate funding vehicles, especially for larger, well integrated projects in which fundamental science and its application are developed together;
- Scale of operation – pilot scale facilities are needed to demonstrate developing technologies;
- Strategies for technology transfer. Many of the new technologies will need to enter the commercial space through technology push. The process towards technology uptake needs to be initiated early in the technology development process to ensure worthy technologies do not remain "on the shelf"

Waste to Energy Colleagues

- Dr. Madelyn Johnstone-Robertson, (University of Cape town, m.johnstone robertson@uct.ac.za)
- Dr. Robert Pott, (University of Cape town)
- Dr. Rob van Hille, Moss Group (rob.vanhille@uct.ac.za)
- Dr. Melinda Griffiths, (University of Cape town, melinda.griffiths@uct.ac.za)
- Prof. Harro von Blottnitz (University of Cape town, harro.vonblottnitz@uct.ac.za)
- Dr. Bothwell Batidzira (University of Cape town, bothwell.batidzirai@uct.ac.za)
- Dr. Niyi Isifiade (University of Cape town)
- Dr. William Stafford (CSIR, wstafford@csir.co.za)
- Dr. Brett Cohen (University of Cape town, brett.cohen@uct.ac.za)

Dr. Amos Madhlopa
Senior Researcher, Energy Research Centre (ERC)

Energy Research Centre
Menzies Building
Upper Campus
University of Cape Town
Library Road
Rondebosch
7701
Tel: +27 21 650 3897
Fax: +27 21 650 2830
E-mail: amos.madhlopa@uct.ac.za

Current Waste to Energy Research Themes

- **Biochemical Conversion Technologies**
  - *Process*: Anaerobic digestion
  - *Feedstock*: Municipal solid waste, Municipal wastewater, Livestock manure
  - *Product*: Biogas
  - *Product* application: Biogas converted to electricity and heat in cogeneration units (CHP)

Overview of Current Waste to Energy Research

- Currently no on-going research projects.

Recommendations on Future Waste to Energy Research Focal Areas for South Africa

- Evaluate the economic viability of capturing and utilising biogas as an energy source;

- Investigate carbon emissions reduction potential associated with applying the by-product of anaerobic digestion as manure to replace the inorganic fertilisers.

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

- Assessment of domestic biodegradable waste as a source of energy.

Waste to Energy Colleagues

- Prof. Harro Von Blottnitz (University of Cape Town, harro.vonblottnitz@uct.ac.za)
- Mr. Sydwell Luvo Vanyaza (luvo.vanyaza@gmail.com)

Dr. Bothwell Batidzirai
Senior Researcher Officer, Energy Research Centre (ERC)

Energy Research Centre
Menzies Building
Upper Campus
University of Cape Town
Library Road
Rondebosch
7701
Tel: +27 21 650 3767
Fax: +27 21 650 2830
E-mail: bothwell.batidzirai@uct.ac.za

Current Waste to Energy Research Themes

- **Biochemical conversion technologies**
  - *Process*: Anaerobic digestion
  - *Feedstock*: Municipal solid waste, Wastewater, Industrial waste, Food waste, Sewage sludge, Animal waste, Plant wastes and by-products, Abattoir waste, Garden waste, Road side grasses
  - *Product*: Biogas
  - *Product* application: Biogas converted to electricity and heat in cogeneration units (CHP)
    : Upgrade biogas to natural gas grade for use as a natural gas substitute
  - *Other*: Economic, technical, environmental and socio-economic analysis

  - *Process*: Fermentation
  - *Feedstock*: Agricultural waste, Crop residues, Wood waste, Green waste
  - *Product*: Bioethanol, Biobutanol

- *Other*: Economic, technical, environmental and socio-economic analysis

- **Thermochemical conversion technologies**
  - *Process*: Direct combustion
  - *Feedstock*: Residual (unprepared) municipal solid waste, Refuse-derived fuel
  - *Other*: Economic, technical, environmental and socio-economic analysis

  - *Process*: Co-combustion
  - *Feedstock*: Coal/wood waste blends, Coal/crop residue blends, Coal/municipal waste blends
  - *Other*: Economic, technical, environmental and socio-economic analysis

  - *Process*: Thermal gasification
  - *Feedstock*: Wood waste, Municipal solid waste, Agricultural waste, Industrial waste, Crop residues
  - *Product*: Syngas
  - *Product application*: Syngas for heat production

    : Syngas for power production in gas engines, turbines or fuel cells

    : Syngas for further processing to liquid fuels and chemicals

      - Gasoline, diesel and jet fuel (Fischer-Tropsch process)
      - Synthetic natural gas
  - *Other*: Economic, technical, environmental and socio-economic analysis

  - *Process*: Co-gasification
  - *Feedstock*: Coal/refuse-derived fuel blends, Coal/crop residue blends, Coal/municipal waste blends
  - *Product*: Syngas
  - *Product application*: Syngas for heat production

: Syngas for power production in gas engines, turbines or fuel cells

: Syngas for further processing to liquid fuels and chemicals

- Gasoline, diesel and jet fuel (Fischer-Tropsch process)
- Synthetic natural gas

- *Other*: Economic, technical, environmental and socio-economic analysis

- *Process*: Pyrolysis
- *Feedstock*: Green waste, Wood waste, Woody weeds, Agricultural waste
  Municipal solid waste
- *Product*: Bio-oil
- *Product application*: Bio-oil for heat production in industrial boilers

: Bio-oil used as a substitute for diesel fuel in stationary engines

: Bio-oil blends with standard diesel fuels or bio-diesel fuel

: Bio-oil as feedstock for synthesis gas production

Overview of Current Waste to Energy Research

- Assessment of potential amounts of waste resources from municipal waste;
- Technical and economic feasibility of biogas digestion using different feedstock;
- Cost supply analysis of agricultural residues for use in power generation.

Recommendations on Future Waste to Energy Research Focal Areas in South Africa

- Sustainability of agricultural and forestry residue harvesting for large scale energy applications;
- Pre-treatment of residues and waste for the energy markets;
- Optimisation of regional WtE scenarios;

- Potential for dry digestion of woody waste.

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

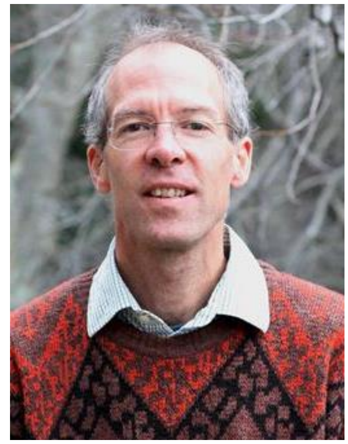
- National resource assessment – last study done in 1998;
- Municipal waste analysis;
- Potential for waste separation and implications (economic, social, environmental);
- Multi product biodigester assessment;
- Digestate volarisation.

Waste to Energy Colleagues

- None

Prof. Harro von Blottnitz
Head, Environmental and Process Systems Engineering

Environmental and Process Systems Engineering
Department of Chemical Engineering
Upper Campus
Corner of Madiba Circle and South Lane
University of Cape Town
Rondebosch
7701
Tel: +27 21 650 2518
Fax: +27 21 650 5501
E-mail: harro.vonblottnitz@uct.ac.za



Current Waste to Energy Research Themes

- **Biochemical Conversion Technologies**
  - *Process*: Anaerobic digestion, Dark fermentation
  - *Feedstock*: Roadside slaughter waste, Abattoir waste, MSW, Wastewater, Industrial waste, Food waste, Crop residues, Animal waste, Plant waste and by-products
  - *Product*: Biogas, Biohydrogen
  - *Product application*: Biohydrogen production for cooking
  - *Other*: Innovation studies
    : Life cycle sustainability analysis of biohydrogen and biomethane options
    : Optimisation of bio-refineries, focusing on utilisation of sugarcane bagasse
    : Economic, technical, environmental and socio-economic analysis

- **Thermal Conversion Technologies**
  - *Process*: Direct combustion, Plasma arc gasification

- *Other*: Life-cycle assessment studies

  : Economic, technical, environmental and socio-economic analysis

- **Chemical Conversion Technologies**
  - *Process*: Transesterification
  - *Other*: Life-cycle assessment studies

    : Economic, technical, environmental and socio-economic analysis

Overview of Current Waste to Energy Research

- Industrial systems analysis and optimisation for sustainable development. Analyses and optimisation work focus on environmental and economic performance of technologies;
- WtE research is strongly focused on biofuels and bioenergy applications;
- Study how decisions for novel urban infrastructure, including WtE, are made and what constraints municipalities face in this regard.

Recommendations on Future Waste to Energy Research Focal Areas for South Africa

- At some stage, mainstream general waste incineration with energy recovery will need to be seriously considered in South Africa. But these will be mega-projects, by municipal capital works experiences to date. The metros which will need to drive such projects will need significantly beefed up knowledge support and project management systems;
- In other words, nothing new technologically, we can import this technology, but a new level of competency and capacity will be needed in local government.

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

- Chemically treated waste timber.

Waste to Energy Colleagues

- Green-cape
- Dr. Bothwell Badzirai, (University of Cape town, bothwell.batidzirai@uct.ac.za)

Dr. Sampson Mamphweli
Senior Researcher, Fort Hare Institute of Technology (FHIT)

Fort Hare Institute of Technology
Alice Campus
University of Fort Hare
1 King Williams Town Road
Alice
5700
Tel: +27 40 602 2311
Fax: +27 40 653 0665
E-mail: smamphweli@ufh.ac.za

Current Waste to Energy Research Themes

- **Biochemical Conversion Technologies**
  - *Process*: Anaerobic digestion
  - *Feedstock*: Animal waste
    : Co-digestion (cowdung, donkey dung, pig manure, chicken litter)
  - *Product*: Biogas
  - *Product* application: Biogas converted to electricity and heat in cogeneration units
    : Upgrade biogas for use as a natural gas substitute
  - *Other*: Digester design and construct
    : Digester installation
    : Predictive computer models
    : Technical analysis

- **Thermochemical Conversion Technologies**
  - *Process*: Gasification, Co-gasification
  - *Feedstock*: Wood waste, Agricultural waste

- *Product*: Syngas
- *Product* application: Syngas for heat production

  : Syngas for power production in gas engines, turbines or fuel cells
- *Other*: Technical pre-feasibility study

  : Life-cycle assessment

  : Economic and socio-economic analysis

  : Gasifier design and construct

Overview of Current Waste to Energy Research

Biochemical Conversion:

- Demonstrate the biogas digester technology as a low-cost energy production and renewable energy technology;
- Design and monitor the performance of highly efficient biogas digester technologies;
- Develop computer models for prediction of performance of various types of biogas digesters in various weather conditions in South Africa;
- Installation and performance monitoring of rural household digesters in communities;
- Investigate the possibility of co-digestion of various substrates and associated challenges.

Thermal Conversion:

- Undertake feedstock analysis and characterisation;
- Undertake kinetic studies on biomass and biomass/coal blends for gasification;
- Demonstrate biomass gasification as an alternative renewable energy source;
- Design, install and monitor the performance of biomass gasifiers in order to develop strategies for enhancement of process efficiency;

- Develop data acquisition systems that can be used for data collection in biomass gasifiers;
- Develop computer models for predicting the performance of biomass gasifiers and process optimisation;
- Undertake feasibility studies for project development using biomass gasifier technologies.

Recommendations on Future Waste to Energy Research Focal Areas for South Africa

- The development of efficient WtE technologies;
- Piloting and performance evaluation of WtE technologies at industrial scale;
- Detailed analysis of the available waste in relation to existing technologies requirements;
- Techno-economic analysis of WtE technologies.

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

- The biggest gap is piloting and project development with a view to collect data that can be used to prove the viability of the various technologies. South African technologies need to be proven in the country through pilot projects preferably at industrial scale.

Waste to Energy Colleagues

- Prof. Edson Meyer (University of Fort Hare, emeyer@ufh.ac.za)
- Dr. Golden Makaka (University of Fort Hare, gmakaka@ufh.ac.za)
- Dr. Christy Manyi-Loh (University of Fort Hare, cmanyi-loh@ufh.ac.za)

Prof. Edison Muzenda
Research and Postgraduate Coordinator, Department of Chemical Engineering
Head, Environmental and Process Systems Engineering Research Unit

Department of Chemical Engineering
John Orr Building
Doornforntein Campus
University of Johannesburg
Corner of Siemert and Beit Street
Doornfontein
2028
Tel: +27 11 559 6817
Fax: +27 11 559 6430
E-mail: emuzenda@uj.ac.za; emuzenda@yahoo.co.uk

Current Waste to Energy Research Themes

- **Biochemical Conversion Technologies**
  - *Process*: Anaerobic digestion
  - *Feedstock*: Municipal solid waste, Wastewater, Industrial waste, Food waste, Crop residues, Sewage sludge, Animal waste, Plant wastes and by-products, Abattoir waste
    : Co-digestion (various substrates including market vegetable and fruit waste
  - *Product*: Biogas
  - *Product application*: Compressed biogenic gas (CBG) as vehicle fuel
  - *Other*: Techno-economic and socio-economic analysis
    : Digester design and construct
    : Predictive computer models

- **Thermal Conversion Technologies**
  - *Process*: Co-combustion
  - *Feedstock*: Coal/refuse-derived fuel, Coal/wood waste, Coal/crop residue Coal/animal waste, Coal/municipal waste, Coal/industrial waste blends

  - *Process*: Pyrolysis
  - *Feedstock*: Waste tyres, Plastic waste
  - *Product*: Bio-oil
  - *Product application*: *Bio*-oil for heat production in industrial boilers
    : Bio-oil used as a substitute for diesel fuel in stationary engines
    : Bio-oil blends with standard diesel fuels or bio-diesel fuel
  - *Other*: Economic, Technical, Environmental and Socio-economic analysis

  - *Process*: Thermal depolymerisation
  - *Feedstock*: Plastic waste
  - *Product*: Light crude oil processed into gasoline

Overview of Current Waste to Energy Research

- Conduct basic and applied research to prove the application, adaptability and scalability of various biogas technologies for production of biogas for an alternate vehicle fuel in the form of CBG. This programme is designed to be part of and to support the national initiative for Renewable Fuels for the Transport Sector, under the leadership of SANEDI;
- Evaluate technologies for enriching raw biogas to a grade suitable as a vehicle fuel in the form of CBG;
- Conduct a techno-economic survey to evaluate the economic viability for utilising biogenic waste streams to CBG, focusing on the municipal waste sector;

- Build capacity in the biowaste sector through undergraduate and postgraduate training and skills development within the structure of the University's normal teaching, learning and research activities;
- Design and build an instrumented bio-digester for conducting experiments on various biodegradable wastes and operating parameters to optimise production of biogas;
- Conduct a detailed technical, socio-economic and scientific study of a sustainable business process for the possible utilisation of municipal biowaste;
- Research novel technologies in the waste utilisation value chain.

Recommendations on Future Waste to Energy Research Focal Areas for South Africa

- Cultural, social, political and economic studies to promote the use of biogas;
- Municipal or community biogas pilot plants.

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

- Thermochemical conversion of biomass into energy;
- Waste tyre and other waste rubber utilisation for energy and material recovery e.g. pyrolysis;
- Integrated green energy policy studies with biomass focus.

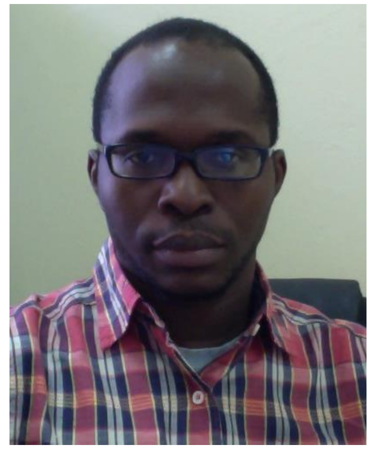
Waste to Energy Colleagues

- SANEDI
- CoJ - City Parks
- CoJ - PIKITUP
- SABIA – Eddie Cook
- IDC

- Prof. Harold Annegarn (University of Johannesburg, hannegarn@gmail.com)
- Dr. Ludger Eltrop (University of Stuttgart)
- Mr. Mansoor Mollagee (University of Johannesburg, mmollagee@uj.ac.za)
- Dr. Wale Aboyade (University of Johannesburg, aaboyade@uj.ac.za)

Dr. Akinwale Aboyade
Energy and Sustainability Specialist: Process, Energy and Environmental Technology Station (PEETS)

Process, Energy and Environmental Technology Station
Makhulong Building
Doornfontein Campus
Beit Street
University of Johannesburg
Doornfontein
2028
Tel: +27 11 559 6430
E-mail: aaboyade@uj.ac.za



Current Waste to Energy Research Themes

- **Biochemical Conversion Technologies**
  - *Process*: Anaerobic digestion
  - *Feedstock*: Municipal solid waste, Wastewater, Industrial waste, Food waste, Crop residues, Sewage sludge, Animal waste, Plant wastes and by-products, Abattoir waste
    : Co-digestion of mixes of the above feedstock
  - *Product*: Biogas, Biohydrogen
  - *Product application*: Biogas converted to electricity and heat in cogeneration units
    : Upgrade biogas for use as a natural gas substitute
    : Upgrade biogas for use as CG vehicle fuel
    : Biohydrogen purification and use in fuel cells
  - *Other*: Life-cycle assessment
    : Economic, technical, environmental and socio-economic analysis

- **Thermochemical Conversion Technologies**
  - *Process*: Co-combustion
  - *Feedstock*: Coal/RDF, Coal/wood waste, Coal/crop residue, Coal/animal waste, Coal/municipal waste and Coal/industrial waste blends
  - *Other*: Life cycle assessment

    : Economic, technical, environmental and socio-economic analysis

  - *Process*: Thermal gasification
  - *Feedstock*: Waste wood, Plastic waste, Aluminum waste, Municipal solid waste, Refuse-derived fuel, Agricultural waste, Industrial waste, Sewage sludge, Crop residues, Waste tyres
  - *Product*: Syngas
  - *Product application*: Syngas for heat production

    : Syngas for power production in gas engines, turbines or fuel cells

    : Syngas for further processing to liquid fuels

    - Gasoline, diesel and jet fuel (Fischer-Tropsch process)
    - Ethanol/butanol/methane (syngas fermentation)
  - *Other*: Life cycle assessment

    : Economic, technical, environmental and socio-economic analysis

    : Gasifier design and construct

  - *Process*: Co-gasification
  - *Feedstock*: Coal/RDF, Coal/wood waste, Coal/crop residue, Coal/animal waste, Coal/municipal waste and Coal/industrial waste blends
  - *Product*: Syngas
  - *Product* application: Syngas for heat production

    : Syngas for power production in gas engines, turbines or fuel cells

: Syngas for further processing to liquid fuels

- Gasoline, diesel and jet fuel (Fischer-Tropsch process)

- *Other*: Life-cycle assessment

  : Economic, technical, environmental and socio-economic analysis

  : Gasifier design and construct

- *Process*: Pyrolysis
- *Feedstock*: Waste tyres, Industrial waste, Plastic waste, Green waste, Sewage sludge, Wood waste, Woody weeds, Agricultural waste, Animal waste, Municipal solid waste
- *Product*: Bio-oil
- *Product application*: Bio-oil for heat production in industrial boilers

  : Bio-oil used as a substitute for diesel fuel in stationary engines

  : Bio-oil blends with standard diesel fuels or bio-diesel fuel

  : Bio-oil as feedstock for synthesis gas production

- *Other*: Life-cycle assessment

  : Economic, technical, environmental and socio-economic analysis

  : Gasifier design and construct

Overview of Current Waste to Energy Research

- Research conducted includes the conversion of several waste feedstock by making use of biochemical and thermal conversion technologies.

Recommendations on Future Waste to Energy Research Focal Areas for South Africa

- Decentralised bioenergy production as a clean alternative to waste management, policy and economics of biogas as vehicular fuel.

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

- Commercialising modular small scale bioenergy systems;
- Anaerobic digestion application in small scale wastewater treatment plants.

Waste to Energy Colleagues

- Prof. Edison Muzenda (University of Johannesburg, emuzenda@uj.ac.za)
- Dr. Sampson Mamphweli (University of Fort Hare, smamphweli@ufh.ac.za)
- Prof. Harro von Blottnitz (University of Cape Town, harro.vonblottnitz@uct.ac.za)

Prof. Cristina Trois
Dean and Head, School of Engineering

School of Engineering
UNITE/School of Engineering Building
Howard College Campus
King George V Avenue
University of KwaZulu-Natal
Glenwood
Durban
4041
Tel: +27 31 260 3055
E-mail: troisc@ukzn.ac.za

Current Waste to Energy Research Themes

- **Biochemical Conversion Technologies**
  - *Process*: Anaerobic digestion
  - *Feedstock*: Food waste, Farm waste
  - *Product*: Biogas

Overview of Current Waste to Energy Research

- Conduct research on production of energy from waste, biogas-to-energy, biomass-to-energy;
- Two WtE projects, one initiated in 2010 (under IREAP Integrated Renewable Energy Advancement Programme) with Don't Waste Services as industrial partner for the production of 0.5-1MW of electricity from food waste and a second for energy production from biodigestion of food waste from the Agrizone of Dube Trade Port;
- Bioenergy production in a deep rural area (Northern kwaZulu-Natal);
- Mapping the potential of bioenergy-projects in KZN to realise Green Economy (for KZN-DEDT, 2012-2013);

- A future plan is to establish and direct an Institute for research in Waste and Resources Management (I-WARM), with particular focus on biohydrogen and biogas production.

Recommendations on Future Waste to Energy Research Focal Areas for South Africa

- Waste to Energy with particular focus to biodigestion and de-centralised systems for urban, peri-urban and rural areas.

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

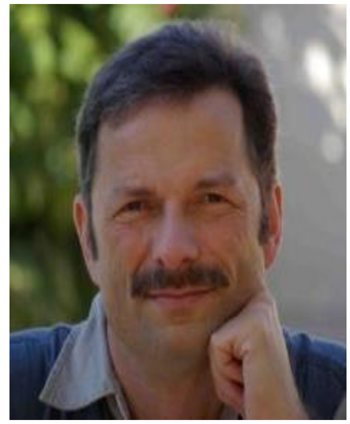
- None

Waste to Energy Colleagues

- None

Prof. Stefan Schmidt
HoD, Discipline of Microbiology

Discipline of Microbiology
Rabie Saunders Building
Life Sciences Campus
University of KwaZulu-Natal
Carbis Road
Scottsville
3209
Tel: +27 33 260 5523
Fax: +27 33 260 6127
E-mail: schmidts@ukzn.ac.za



Current Waste to Energy Research Themes

- **Biochemical Conversion Technologies**
  - *Process*: Anaerobic digestion
  - *Feedstock*: Organic biomass
  - *Product*: Biogas
  - *Other*: System upscaling

Overview of Current Waste to Energy Research

- Optimisation of systems to extract biohydrogen and biomethane from organic biomass and scaling up of these processes;
- Future plans include increasing understanding of the microbiology behind hydrogen and methane production in order to develop stable upscaled systems.

Recommendations on Future Waste to Energy Research Focal Areas in South Africa

- None

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

- None

Waste to Energy Colleagues

- Dr. Gueguim Kana (University of KwaZulu-Natal, kanag@ukzn.ac.za)

Dr. Terry Everson
Researcher, Biodiversity/Evolutionary Biology

School of Life Sciences
Biodiversity/Evolutionary Biology
Life Sciences Campus
University of KwaZulu-Natal
Carbis Road
Scottville
Pietermaritzburg
3201
Tel: +27 33 260 5509
Fax: +27 33 260 5105
E-mail: eversont@ukzn.ac.za

Current Waste to Energy Research Themes

- **Biochemical Conversion Technologies**
  - *Process*: Anaerobic digestion
  - *Feedstock*: Animal waste, Food waste, Wastewater
  - *Product*: Biogas
  - *Product application*: Upgrade biogas to natural gas grade for use as a natural gas substitute
  - *Other*: Environmental and socio-economic analysis

Overview of Current Waste to Energy Research

- Experimental on-farm trials to determine the effect of bioslurry on crop production
- Laboratory trials to determine the nutrient release pattern of bioslurry
- Experimental on-farm trials to determine the effect of bioslurry on soil moisture and soil nutrients.

- Economic cost-benefit analysis to determine the economic and financial viability of biogas generation in rural communities.

Recommendations on Future Waste to Energy Research Focal Areas in South Africa

- Develop an economic model to determine the viability of up-scaling biogas implementation from a homestead level to a green village level;
- Determine green options to increase streamflow and decrease soil erosion through improved fodder management through the use of bioslurry as an organic fertilizer.

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

- Determine sustainable green options for household energy supply that (i) reduce local environmental impact, (ii) reduce national/global environmental impact, (iii) have the potential to stimulate local economic development and job creation.

Waste to Energy Colleagues

- Renen Energy solutions
- Agama energy

Dr. Danie la Grange
Senior Lecturer, Department of Biochemistry, Microbiology and Biotechnology

Department of Biochemistry, Microbiology and Biotechnology
Turfloop Campus
University of Limpopo
University Road
Turfloop
Sovenga
0727
Tel: +27 15 268 3016
E-mail: danie.lagrange@ul.ac.za

Current Waste to Energy Research Themes

- **Biochemical Conversion Technologies**
  - *Process*: Fermentation
  - *Feedstock*: Agricultural waste, Crop residues, Organic MSW
  - *Product*: Bioethanol

Overview of Current Waste to Energy Research

- Microbial and enzymatic hydrolysis of plant material for fermentation to bioethanol;
- Searching for novel microorganisms to be applied to the biofuel industry;
- Enhanced evolutionary studies on novel microorganisms to improve their efficiency, especially during fermentation in the presence of inhibitors and high temperatures;
- Biotyping and proteomic studies on enzymes produced by microorganisms producing extracellular enzymes. These novel enzymes will assist during the saccharification process of lignocellulose material, such as agricultural waste material.

Recommendations on Future Waste to Energy Research Focal Areas for South Africa

- Paper sludge conversion to bioethanol.

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

- Recycling of municipal waste by all municipalities in South Africa.

Waste to Energy Colleagues

- Dr. Elbert. Jansen van Rensburg (University of Limpopo, elbert.jansenvanrensburg@ul.ac.za)
- Prof. I. Ncube (University of Limpopo, ncubei@ul.ac.za)

Prof. Diane Hildebrandt
Director, Material and Process Synthesis Research Unit (MaPS)

Material and Process Synthesis Research Unit
PhaPha Building
Science Campus
University of South Africa
Corner of Christiaan de Wet and Pioneer Avenue
Florida
1709
Tel: +27 11 670 9046
E-mail: hilded@unisa.ac.za

Current Waste to Energy Research Themes

- **Thermal Conversion Technologies**
  - *Process*: Thermal gasification
  - *Feedstock*: Municipal solid waste, Wood waste, Plastic waste, Refuse-derived fuel, Sewage sludge, Crop residues, Waste tyres, Agricultural waste
  - *Product*: Syngas
  - *Product application*: Syngas for heat production
    : Syngas for power production in gas engines, turbines or fuel cells
    : Syngas for further processing to liquid fuels or chemicals
    - Gasoline (Fischer-Tropsch process)
    - Diesel (Fischer-Tropsch process)
    - Synthetic natural gas
    - High value chemicals
  - *Other*: Life-cycle assessment
    : Economic, technical, environmental and socio-economic analysis
    : Gasifier design and construct

- *Process*: Plasma arc gasification
- *Feedstock*: Municipal solid waste, Biomedical waste, Waste tyres, Agricultural waste, Wood waste
- *Product*: Syngas
- *Product application*: Syngas for heat production

  : Syngas for power production in gas engines, turbines or fuel cells

  : Syngas for further processing to liquid fuels or chemicals

  - Gasoline (Fischer-Tropsch process)
  - Diesel (Fischer-Tropsch process)
  - Synthetic natural gas
  - High value chemicals
- *Other*: Life-cycle assessment

  : Economic, technical, environmental and socio-economic analysis

- *Process*: Pyrolysis
- *Feedstock*: Wood waste
- *Product*: Bio-oil, Biochar
- *Product application*: Bio-oil for heat production in industrial boilers
- *Other*: Technical analysis

- **Biochemical Conversion Technologies**
  - *Process*: Anaerobic Digestion
  - *Feedstock*: Municipal solid waste, Wastewater, Industrial waste, Food waste, Crop residues, Sewage sludge, Animal waste, Abattoir waste
  - *Product*: Biogas
  - *Product application*: Biogas converted to electricity and heat in cogeneration units (CHP)

    : Upgrade biogas to natural gas grade for use as a natural gas substitute

- *Other*: Life-cycle assessment
  : Economic and technical analysis
  : Reactor design and construct

- **Chemical Conversion Technologies**
  - *Process*: Transesterification
  - *Feedstock*: Waste cooking oil, Animal fat, Waste processing grease, Butter factory effluent
  - *Product*: Biodiesel
  - *Other*: Life-cycle assessment
    : Economic and technical analysis
    : Reactor design and construct

Overview of Current Waste to Energy Research

- Small scale containerised plants to produce fuel and electricity from waste materials;
- Plasma gasification of waste;
- Research into Fisher-Tropsch;
- Anaerobic digestion;
- Thermodynamic analysis of processes for chemical conversion and/or energy production: Adapting process synthesis methods to biological systems.

Recommendations on Future Waste to Energy Research Focal Areas for South Africa

- The uptake of new technologies is often limited by the acceptance of society. Thus the interaction between new technologies and society is very important. We need to understand what limits the uptake of new technologies. An example of this is the limited uptake of biogas production (a relatively old technology) by our communities.

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

- None

Waste to Energy Colleagues

- Prof. Glasser (glassd@unisa.ac.za)
- Dr. Matambo (matamts@unisa.ac.za)
- Dr. Ngubevana (ngubelb@unisa.ac.za)
- Dr. Liu (liux@unisa.ac.za)
- Dr. Peters (petermgd@unisa.ac.za)
- Dr. Sempuga (sempubc@unisa.ac.za)
- Dr. Fox (Foxj@unisa.ac.za)
- Dr. Yao (yaoy@unisa.ac.za)
- Dr. Lu (lux@unisa.ac.za)
- Dr. Zhu (zhux@unisa.ac.za)

Dr. Martin Myer
Senior Lecturer, Department of Life and Consumer Sciences

Department of Life and Consumer Sciences
University of South Africa
Corner of Christiaan De Wet and Pioneer Ave
Calabash Building
Florida
Johannesburg
1710
Tel: +27 11 471 2180
E-mail: myer.msm@gmail.com

Current Waste to Energy Research Themes

- **Biochemical Conversion Technologies**
  - *Process*: Anaerobic digestion
  - *Feedstock*: Dairy manure and in combination with selected kitchen waste
  - *Product*: Biogas

Overview of Current Waste to Energy Research

- Working in association with Bioforsk in Norway, according to a SANCOOP agreement, specifically with a view to engage with rural communities in SA to adopt biodigester technology in their day to day living routine;
- As part of the roll-out of the SANCOOP agreement, laboratory facilities at the Institute for Soil, Climate and Water (ISCW) Research will be aligned to support ongoing preparation of biodigestate as well as selected wet soil samples for bacterial profiling according to DNA extraction/sequencing protocols.

Recommendations on Future Waste to Energy Research Focus Areas for South Africa

- Not enough attention is being paid to applied R&D, specifically to microbiological aspects, with a view to having some kind of predictive value attached to when a given biodigester installation is struggling, or likely to fail.

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

- From a Tertiary Training viewpoint, there is not enough synergy between agricultural engineers and natural scientists. In the whole of SA, not one University has a Department of Bioengineering.

Waste to Energy Colleagues

- Mr. Petrus Britz (ARC, britzpj@arc.agric.za)
- Ms. Primrose Magama (ARC, magamap@arc.agric.za)
- Dr. Mokhele Moeletsi (ARC, moeletsim@arc.agric.za)
- Dr. Rasheed Adeleke (ARC, adeleker@arc.agric.za)
- Dr. Emmanuel Mwendera (ARC, mwanderae@arc.agric.za)
- Mr. Francois Cilliers (francois@biopowercorp.co.za)
- Dr. Hendrik Cronje (hennie@leadafrika.com)
- Ms. Alicia van der Merwe (aliciavanderm@gmail.com)
- Dr. Dirk Swanevelder (ARC, swanevelderd@arc.agric.za)
- Mr. Mark Tiepelt (mark@biogassa.co.za)

Prof. Christopher Enweremadu
Associate Professor, Department of Mechanical and Industrial Engineering

Department of Mechanical and Industrial Engineering
GJ Gerwel Building
Science Campus
University of South Africa
Florida
1709
Tel: +27 11 471 2057
Fax: +27 86 604 3753
E-mail: enwercc@unisa.ac.za

Current Waste to Energy Research Themes

- **Chemical Conversion Technologies**
  - *Process*: Transesterification
  - *Feedstock*: Waste cooking oil, Animal fat, Waste processing grease
  - *Product*: Biodiesel

- **Mechanical Conversion Technologies**
  - *Process*: Briquetting
  - *Feedstock*: Agricultural waste
  - *Product*: Solid fuel

Overview of Current Waste to Energy Research

- Biodiesel production from waste cooking oil;
- Develop a predictive model for the determination of some densification characteristics of corncob briquettes;

- Evaluate the effects of some processing parameters on physical and densification characteristics of briquettes produced from corncob.

Recommendations on Future Waste to Energy Research Focal Areas for South Africa

- Briquetting (densification) of waste material

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

- Briquetting (densification)

  Briquetting is the process of compacting residues into a product of higher density than the original raw materials. This process also known as densification is used as a substitute for coal and charcoal especially when produced from biomass materials such as agricultural waste (rice husk, bagasse, peanut shells, sawdust, etc). It can be used for cooking and heating in rural communities and prevents health hazards from burning firewood as cooking stoves that use briquettes are easily fabricated. It also does not contribute to desertification as the biomass materials are waste products.

  Briquettes can also be fired in boilers or co-fired with coal in small-scale industries to generate heat which converts water to steam for process or electricity generation purposes. Biomass briquettes emit less carbon dioxide even when co-fired with coal. This is an aspect which is hardly worked on in South Africa.

Waste to Energy Colleagues

- Mr. Shumani Ramuhaheli (University of South Africa, ramuhs@unisa.ac.za)
- Dr. Hilary Rutto (Vaal University of Technology, hilaryr@vut.ac.za)

Dr. David Tinarwo
Renewable Energy/Sustainable Technology Consultant
Lecturer, Department of Physics

Department of Physics
University of Venda
University Road
Thohoyandou
Limpopo Province
0950
Tel: +27 15 962 8918
E-mail: david.tinarwo@univen.ac.za

Current Waste to Energy Research Themes

- **Biochemical Conversion Technologies**
    - *Process*: Anaerobic digestion
    - *Feedstock*: Municipal solid waste, Wastewater, Industrial waste, Food waste, Crop residues, Sewage sludge, Animal waste, Plant wastes, Abattoir waste,
    - *Product*: Biogas
    - *Product application*: Upgrade biogas to natural gas grade for use in fuel cells
    - *Other*: Life-cycle assessment
      : Economic, technical, environmental and socio-economic analysis
      : Reactor design and construct

Overview of Current Waste to Energy Research

- Work currently done in the group ranges from researching on the developing strategies of popularising the biogas technology and co-digestion of different substrates commonly found in the province;

- Optimisation of biological processes: modelling and simulation of the biological process; research in management and control of microbiological decomposition processes;
- Optimisation of process control: development and optimisation of technical processes and of complete technical systems over the entire provision chain; technical optimisation examples using pilot plants;
- Optimisation of complete systems: technological optimisation of entire systems from biomass production to digestate disposal and gas use; evaluation and improvement of environmental impact, economic optimisation and of the overall efficiency;
- Substrate characteristics and substrate management: determination of substrate characteristics; epidemics and phyto-hygiene in the process chain; substrate logistics and storage;
- Assessment of the potential of the conversion of municipal waste to useful energy in the Province of Limpopo;
- Assessment of the biogas potential and economic viability at individual and selected farms in Limpopo;
- Feasibility studies and cost-benefit analysis for biogas plants;
- Evaluation of theoretical and technical biogas potentials for companies, regions, and countries in the SADC region;
- Laboratory analysis of biogas production (standardised batch and continuous tests), chemical and physical parameters of substrates.

Recommendations on Future Waste to Energy Research Focal Areas for South Africa

- Up scaling technologies application to generation off grid connected electricity;
- Increased research on most viable approaches and conversion technologies best suitable for the South African market conditions.

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

- Fuel cell technologies in the generation of electricity;
- Second and third generation biofuel production still needs to be researched to levels of wide commercialisation.

Waste to Energy Colleagues

- None

Prof. Vincent Gray
Associate Professor, School of Molecular and Cell Biology

School of Molecular and Cell Biology
University of Witwatersrand
1 Jan Smuts Avenue
Braamfontein
2000
Johannesburg
Tel: +27 11 717 6372
E-mail: vincent.gray@wits.ac.za

Current Waste to Energy Research Themes

- **Biochemical Conversion Technologies**
  - *Process*: Dark fermentation
  - *Feedstock*: Using sucrose as the synthetic wastewater organic material
  - *Product*: Biohydrogen
  - *Other*: Reactor design

Overview of Current Waste to Energy Research

- Investigate biohydrogen production by a consortium of mesophilic facultative anaerobic bacteria in a fluidized bed reactor consisting of carrier induced granular particles comprising *Clostridium species, Enterobacter cloacae* and *Citrobacter freundii*;
- Investigate anaerobic fluidised granular bed bioreactor system design and operation which could allow for high productivity and high hydrogen yield at the same time;
- Production of biohydrogen through dark fermentation of organic material (e.g. wheat-bran) by making use of anaerobic, thermophilic, cellulolytic hydrogen-producing bacteria originating from sewage sludge;

- Electricity generation *via* microbial fuel cells;
- Future plans involve applying genomics and bioinformatics to improve understanding of the molecular biology of metabolic processes responsible for the generation of high energy products that can be used as a biofuels.

Recommendations on Future Waste to Energy Research Focal Areas for South Africa

- Electricity generation couple to wastewater treatment using membraneless microbial fuel cells.

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

- None

Waste to Energy Colleagues

- None

Prof. Sunny Iyuke
Head, School of Chemical and Metallurgical Engineering

School of Chemical and Metallurgical Engineering
University of Witwatersrand
1 Jan Smuts Avenue
Braamfontein
2000
Johannesburg
Tel: +27 11 717 7546
Fax: +27 86 553 6435
E-mail: sunny.iyuke@wits.ac.za

Current Waste to Energy Research Themes

- **Biochemical Conversion Technologies**
  - *Process*: Anaerobic digestion
  - *Feedstock*: Municipal solid waste, Wastewater, Industrial waste
  - *Product*: Biogas, Biohydrogen
  - *Other*: Economic and technical analysis

  - *Process*: Fermentation
  - *Feedstock*: -
  - *Product*: Bioethanol
  - *Other*: Economic, technical, environmental and socio-economic analysis
    : Reactor design and construct

  - *Process*: Direct biophotolysis
  - *Feedstock*: -
  - *Product*: Biohydrogen
  - *Product application*: Biohydrogen purification and use in fuel cells

- *Other*: Reactor design and construct

- **Thermal Conversion Technologies**
    - *Process*: Thermal gasification
    - *Feedstock*: Wood waste, Waste tyres
    - *Product*: Syngas
    - *Product application*: Syngas for further processing to liquid fuels
      - Gasoline and diesel (Fischer-Tropsch process)
      - Hydrogen
    - *Other*: Economic and technical analysis

    - *Process*: Co-gasification
    - *Feedstock*: -
    - *Product*: Syngas
    - *Product application*: *Syngas* for further processing to liquid fuels
      - Gasoline and jet fuel (Fischer-Tropsch process)

    - *Process*: Plasma arc gasification
    - *Feedstock*: Municipal solid waste, Biomedical waste, Waste tyres
    - *Product*: Syngas
    - *Product application*: *Syngas* for further processing to liquid fuels
      - Gasoline and jet fuel (Fischer-Tropsch process)
    - *Other*: Economic, technical and environmental analysis

    - *Process*: Pyrolysis
    - *Feedstock*: Waste tyres, Industrial waste
    - *Product*: Bio-oil
    - *Product application*: Bio-oil used as a substitute for diesel fuel in stationary engines

: Bio-oil blends with standard diesel fuels or bio-diesel fuel

: Bio-oil as feedstock for synthesis gas production

- *Other*: Economic, technical and environmental analysis

- *Process*: Thermal depolymerisation
- *Feedstock*: Waste tyres
- *Product*: Light crude oil processed into diesel fuel and gasoline

  : Light crude oil used as a petrochemical feedstock

- **Chemical Conversion Technologies**
  - *Process*: Transesterification
  - *Feedstock*: Waste cooking oil, Animal fat
  - *Product*: Biodiesel
  - *Other*: Economic, technical, environmental and socio-economic analysis

    : Reactor design and construct

Overview of Current Waste to Energy Research

- Biofuel production from natural rubber and used tyres;
- Development of catalyst and testing for conversion of WtE;
- Biodiesel production from waste cooking oil and animal fats;
- Development of heterogeneous catalysts for biodiesel production from non-edible feedstock;
- Biohydrogen production from municipal waste;
- Development of membrane/catalytic membrane system for production of hydrogen from biodiesel waste.

Recommendations on Future Waste to Energy Research Focal Areas for South Africa

- Hydrogen production from renewable source for hydrogen fuel vehicles.

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

- Continuity in waste supply will be a problem;
- Consistency in particle sizes, moisture content and source will be a challenge;
- Divert sources and nature of wastes will affect yield.

Waste to Energy Colleagues

- Prof Joel Ogbonna (ogbonna.joel@ipsng.org)
- Dr. Daramola Michael (University of Witwatersrand, Michael.Daramola@wits.ac.za)
- Dr. Jean Mulopo (University of Witwatersrand, Jean.Mulopo2@wits.ac.za)

Other Research Institutes

Mr. Petrus Britz
Research Team Manager, ARC-Institute for Agricultural Engineering

ARC-Institute of Agricultural Engineering
Agricultural Research Council
141 Cresswell Road
Silverton
Tel: +27 12 842 4311
Fax: +27 12 842 4317
E-mail: britzpj@arc.agric.za

Current Waste to Energy Research Themes

- **Biochemical Conversion Technologies**
  - *Process*: Anaerobic digestion
  - *Feedstock*: Cattle manure
  - *Product*: Biogas, Organic fertilizer
  - *Product application*: Biogas converted to electricity and heat in cogeneration units (CHP)
    : Upgrade biogas to natural gas grade for use as a natural gas substitute
  - *Other*: Digester design and construct
    : Digester installation
    : Technical and socio-economic analysis

Overview of Current Waste to Energy Research

- Installed 9 biogas digesters in the Free State Province for small-scale farmers;

- Develop an improved biogas digester for rural communities, this includes an improved structure and improved microbiological activity (NRF-Norway SANCOOP project). It is intended to include a mechanical mixer to improve biogas production rates.

Recommendations on Future Waste to Energy Research Focal Areas for South Africa

- Extend research to other animal waste products;
- Develop a prefabricated biogas digester to improve installation efficiency and improve digester quality.

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

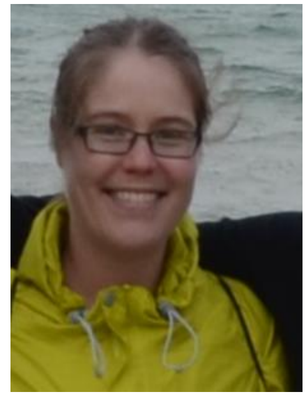
- Utilise solar heating principles to optimise biogas production rates.

Waste to Energy Colleagues

- Ms. Primrose Magama (ARC, MagamaP@arc.agric.za)
- Ms. Khuthadzo Mugodo (ARC, MugodoK@arc.agric.za)
- Dr. Dirk Swanevelder (ARC, SwanevelderD@arc.agric.za)

Ms. Debbie Jooste
Candidate researcher, CSIR Built Environment

Built Environment
Council for Scientific and Industrial Research
Meiring Naudé Road
Brummeria
Pretoria
0002
Tel: +27 12 841 3639
E-mail: djooste@csir.co.za



Current Waste to Energy Research Themes

- **Biochemical Conversion Technologies**
  - *Process*: Anaerobic digestion
  - *Feedstock*: Wastewater, Sewage sludge, Animal waste, Abattoir waste
    : Co-digestion (Abattoir waste, biological additives etc.)
  - *Product*: Biogas
  - *Product application*: Biogas converted to electricity and heat in cogeneration units
  - *Other*: Digester design and construct
    : Economic, technical, environmental and socio-economic analysis

Overview of Current Waste to Energy Research

- Applicability of anaerobic digestion technology in the South African market, both rural and municipal;
- Co-digestion: technical, legislative and logistical challenges.

Recommendations on Future Waste to Energy Research Focal Areas for South Africa

- None

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

- None

Waste to Energy Colleagues

- Dr. Wim Jonker Klunne (CSIR, wklunne@csir.co.za)
- Vusumzi Mema (CSIR, vmema@csir.co.za)

Mrs. Kubeshnie Bhugwandin
Strategy and Research Manager: Research, Testing and Demonstration

Eskom
Research, Testing and Development
Sustainability Division
Rosherville
Cleveland
2094
Tel: +27 11 629 5112
E-mail: kubeshnie.bhugwandin@eskom.co.za

Current Waste to Energy Research Themes

- **Thermal Conversion Technologies**
  - *Process*: Co-combustion
  - *Feedstock*: Coal/wood waste blends
  - *Product*: Electricity generation

Overview of Current Waste to Energy Research

- Fuel sourcing studies, Evaluation of co-firing options, Co-firing concept designs, Torrefaction technology evaluation, Torrefaction co-firing plant impact studies, Assessment of energy potential from different organic waste streams, WtE options for Eskom, Resource verification for renewable energy from municipal solid waste;
- Implementing of selected technology options at pilot scale application and further investigations into up-scaling of these options into commercial scale applications;
- Awareness of Clean Coal Technologies (CCT) by continually scanning and tracking emerging technologies;

- Introduction of CCT by evaluating their suitability for application within the Eskom or South African environment and conducting techno-economic assessments of CCT that have potential to be deployed in Eskom;
- Development of projects for pilot and demonstration execution through conceptualisation of viable CCT options;
- Future plans include to facilitate the development of a WtE plant, demonstrate large scale torrefied biomass co-firing, develop sustainability criteria for regulatory and policy frameworks to support biomass co-firing.

Recommendations on Future Waste to Energy Research Focal Areas for South Africa

- Evaluation of regional biomass logistic networks and alternative biomass sources.

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

- None

Waste to Energy Colleagues

- SANEDI, University of Witwatersrand, IEA Bio Energy, CSIR, VGB, North West University, EPPEI, Nelson Mandela Metropolitan University, Fort Hare University

ENVIROSERV WASTE MANAGEMENT

Waste Beneficiation Division
3 Brickfield Road
Meadowdale
Germiston
1401
Tel: +27 11 471 2180

Current Waste to Energy Research Themes

- **Biochemical Conversion Technologies**
  - *Process*: Anaerobic digestion
  - *Feedstock*: Abattoir waste, Slurry, Food waste
  - *Product*: Biogas

Overview of Current Waste to Energy Research

- EnviroServ have a $100m^3$ digester and 12, 40l digesters that are used to test the bio-methane potential of client feed stocks;
- All research is focused around delivering solutions to individual clients waste management problems. Test facilities enable monitoring for long term process stability and also to carry out assessments on the quality of the biogas and digestate products and how they can be optimised and utilised.

Recommendations on Future Waste to Energy Research Focal Areas for South Africa

- None

Recommendations on Potential Gaps Not Covered by Current Waste to Energy Research

- None

Waste to Energy Colleagues

- None

Summary of Current Waste to Energy Research and Implementation in South Africa

Waste to Energy Conversion Technologies

Up to now South Africa has mainly relied on landfilling for disposal of commercial, industrial and municipal waste. Although the recovery of commercial and industrial wastes has increased and some industries are involved in mass incineration or refuse derived fuel projects to destroy hazardous waste, these processes are not always linked to energy production. Furthermore, only a few municipalities in South Africa generate electricity from landfill gas processes with larger metropolitan municipalities including Johannesburg, Tshwane, eThekwini and Ekurhuleni being at different stages of planning, constructing and implementing these WtE projects (3). Biological WtE technologies are currently focused on methane gas extraction from landfills, agricultural waste and water treatment facilities. Furthermore, since 2011 a total of 38 biogas production operations have been registered by NERSA, most of them in rural areas in the Gauteng, Free State, KwaZulu-Natal, Limpopo and Western Cape provinces (13). Thermal technologies are still in the early stages of development where most of the projects are carried out by private companies (3). Moreover, several local authorities are at the pre-feasibility stage of investigating the potential for WtE projects through Public Private Partnership (5). WtE project implementation in South Africa is still limited due to lengthy EIA (environmental impact assessment), government approval processes, Municipal Finance Management Act (MFMA) constraints, time-consuming carbon financing registration processes as well as the ease and costs related to landfilling (3).

A range of WtE projects are being carried out in South Africa, and although interest in WtE technologies is increasing in the country, the fact remains that some of these initiatives are led by private sector waste companies collecting commercial and industrial wastes and operating their own landfills. Furthermore, although municipalities do have waste recovery initiatives like household recycling and Material Recovery Facilities (MRF's), WtE projects other than landfill gas capturing and combustion are presently lacking (3).

The table below gives an overview of the South African WtE technology landscape.

Table 1: WtE technology landscape in South Africa (modified from van Rooy *et al*. 2013)

Technology	Examples	Application in SA
Current technology landscape		
Cement Kiln Co-Combustion	Cement kilns using old tyres as an alternative fuel source.	Lafarge is one of the largest cement manufacturers globally and their Lichtenburg production facility is capable and licenced to accept hydrocarbon-sludge and waste tyre waste-derived-fuels for co-processing. Interwaste and Lafarge have an exclusive agreement for the provision of waste as a fuel into kilns in South Africa.
Fluidised bed Co-Combustion	Co-combustion of site specific process wastes.	▪ Mondi Business Paper, at Merebank in Durban, uses a multifuel boiler to convert residual process material generated at the mill into stream energy, which is then passed through a steam turbine to generate electricity. ▪ Sappi have several co-combustion projects currently in testing phase which will be announced later in 2014.
Landfill Gas Utilisation	Methane of gasses from landfills are captured and combusted to generate electricity	▪ Nelson Mandela Bay Metropolitan's Landfill Gas Project. ▪ Ekhurhuleni Landfill Gas Recovery Project: Landfill gas extraction and flaring systems at Simmer and Jack, Weltevreden, Rietfontien and Rooikraal landfill sites. The municipality is currently generating electricity from the produced gas. ▪ The EnviroServ Chloorkop Landfill Gas Recovery Project. ▪ The Durban Landfill Gas to Electricity Project: Marriannhill and La Mercy landfills, Bisasar Road landfill. ▪ Alton Landfill Gas to Electricity Project (Private landfill site). ▪ Johannesburg landfill gas to energy projects: Robinson Deep landfill, Marie Louise project. Landfill gas is extracted, combusted and flared to generate electricity. A total of 19MW of electricity will be generated from 5 landfill sites.
Bio-Digestion	Sewage sludge, small-scale farm wastes, digested to combustible gas.	Small-scale off grid applications used on farms as well demonstration plants.
Bio-Digestion	Wastewater digested to biogas	Alrode Brewery in Gauteng treats its wastewater through anaerobic digestion and uses the biogas as an alternative energy source in its boiler. Similar units at two other SAB breweries are going to be incorporated in the near future.
Bio-Digestion	Biogas to electrical energy from wastewater	Johannesburg Water implemented a biogas to Energy Project at its Northern Waste Water Treatment Works (WWTW). The WWTW biogas plant has 3 biogas generators installed that produce 1.2 MW of electricity.
Bagasse Boilers (sugar industry waste)	Bagasse cogeneration of steam and electricity.	Sugar mills in SA use the bagasse they produce as a fuel source to operate boilers. A number of sugar producers including Tongaat Hulett, TSB and Ilovo have bagasse energy recovery projects planned.

Technology	Examples	Application in SA
Near future implementation		
Bio-Digestion	Organic waste to electrical energy.	The Bronkhorstspruit Biogas Plant (BBP) built by Bio2Watt is expected to come on stream early in 2015. The plant with a targeted generation capacity of 4 MW will receive its fuel supplies from one of South Africa's largest feedlots, Beefcorp. BMW South Africa has signed a power purchasing agreement with Bio2Watt for electricity supply to its Rosslyn plant.
Bio-Digestion	Organic waste to electrical energy	Bio2Watt envisage initiating a commercial biogas project housed in the Cape Dairy Biogas Plant (CDP). The plant is expected to generate between 3 and 4 MW of electricity from slurry manure with a mix of other waste streams available in the surrounding area by late 2015.
Fluidised Bed Boilers	Refuse or processed municipal WtE via combustion.	Technology used by paper industries to treat on-site wastes. Other industries, such as agro-processing and cement sector are becoming increasingly aware of its benefits for on-site waste management.
Mass Burn Incinerators	Municipal WtE *via* combustion.	Feasibility studies done, interest shown by private investment companies and municipalities alike (Blue IQ undertook a feasibility study on mass burn in the Gauteng province).
Mass Burn Incinerator	Municipal WtE *via* combustion	The Drakenstein municipality aims to slow down the fast decreasing lifespan of its landfill. Through mass burning all non-recyclable waste will be converted to electricity.
Plasma-Gasification	Beautifuels, research done by the South African Nuclear Energy Corporation (NECSA).	Laboratory scale research for the project has been complete. The unit will have the capability of converting organic waste material into fuel and energy.
Pyrolysis	Pyrolysis of plant wastes from the Working for Water Programme.	Interest shown by various municipalities where high intensity deforestation of invasive species are or will be done e.g. the Western Cape and KZN.
Pyrolysis	Waste tyres to be converted to boiler fuel and carbon char.	Eastern Cape Department of Economic Development, Environmental Affairs and Tourism have issued a positive Record of Decision for the construction and operation of a waste tyre pyrolysis plant in Zone 6 of the Coega Industrial Development Zone.
Pyrolysis	Pilot plastics-to-oil plant	The City of Cape Town has signed an agreement with a Japanese consortium as well as the Japan International Cooperation Agency for the establishment of a pilot plastics-to-oil plant at the Kraaifontein integrated waste management facility.
Potentially applicable		
Thermal Waste Gasification	Municipal waste and bio-wastes gasification from various sources.	No commercial or demonstration plants have been constructed and bankability of the technology has not been demonstrated in SA.

Research currently carried out in WtE conversion technologies at South African universities, universities of technology and other research institutes is mainly focused on biochemical (42%) and thermochemical (40%) conversion (Fig. 1).

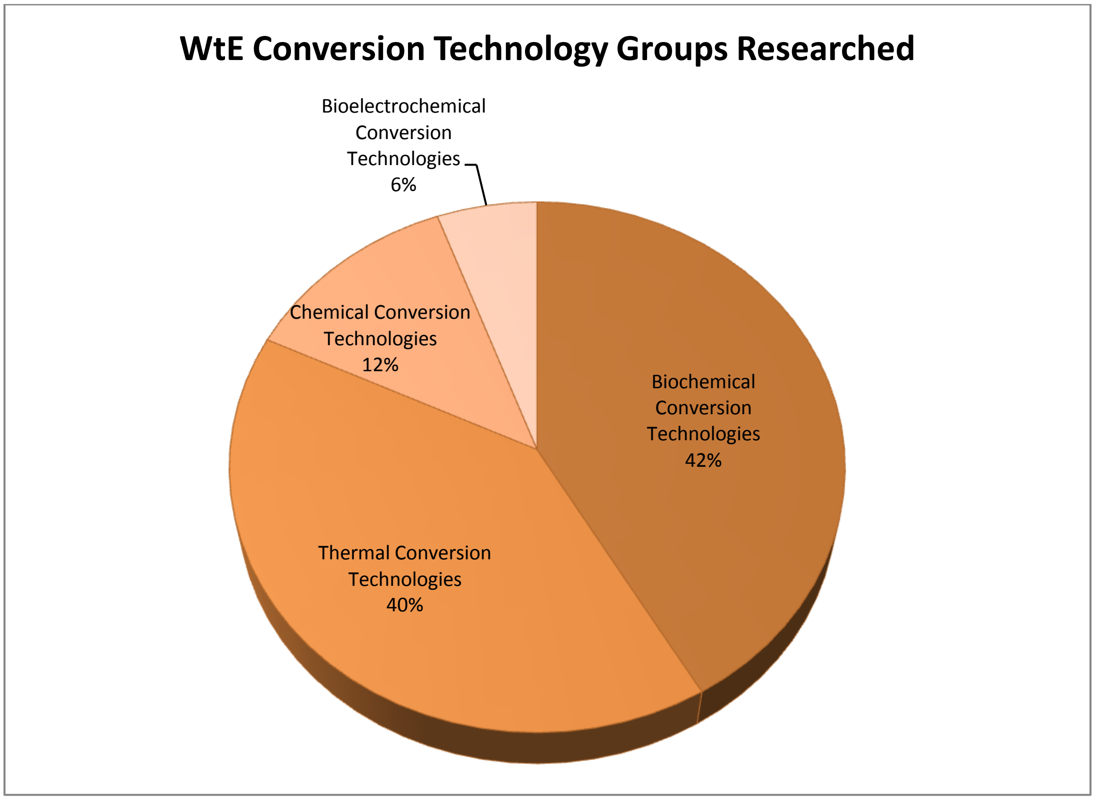


Figure 1: Current waste to energy conversion technology groups researched in South Africa.

When taking a closer look at the biochemical conversion technologies (Fig. 2), 54% of research is done on anaerobic digestion while pyrolysis (22%) and co-gasification (20%) form the dominant thermochemical technologies researched (Fig. 3). However, when taking all conversion technologies into consideration (Fig. 4), anaerobic digestion (22%), fermentation (9%), pyrolysis (9%), transesterification (8%), co-gasification (8%), gasification (7%) and microbial fuel cells (6%) are priority researched areas in South Africa at present.

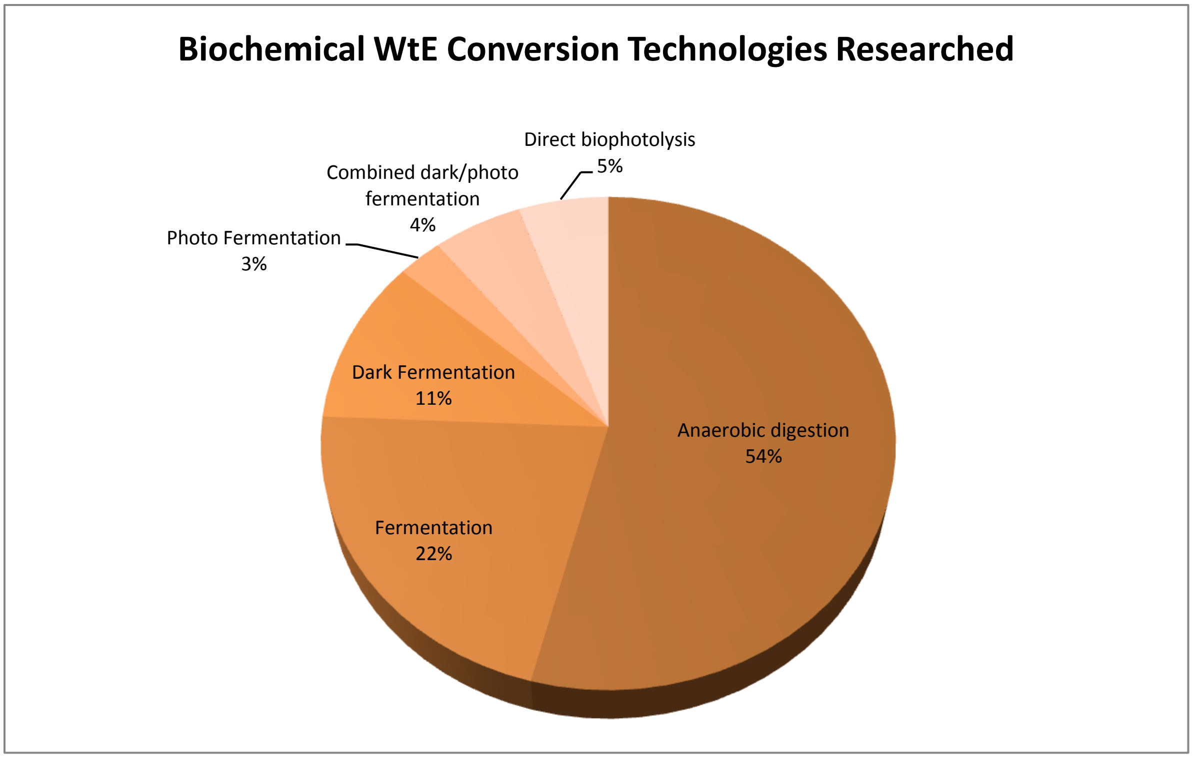


Figure 2: Current biochemical waste to energy conversion technologies researched in South Africa.

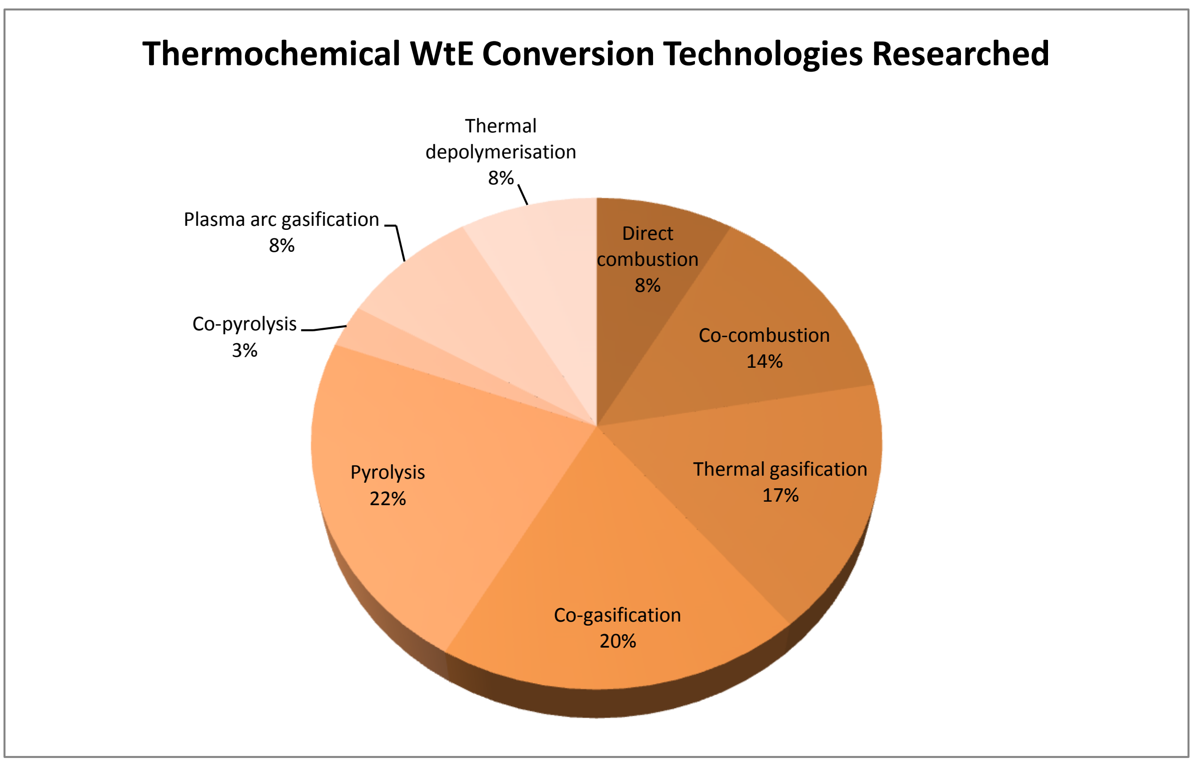


Figure 3: Current thermochemical waste to energy conversion technologies researched in South Africa.

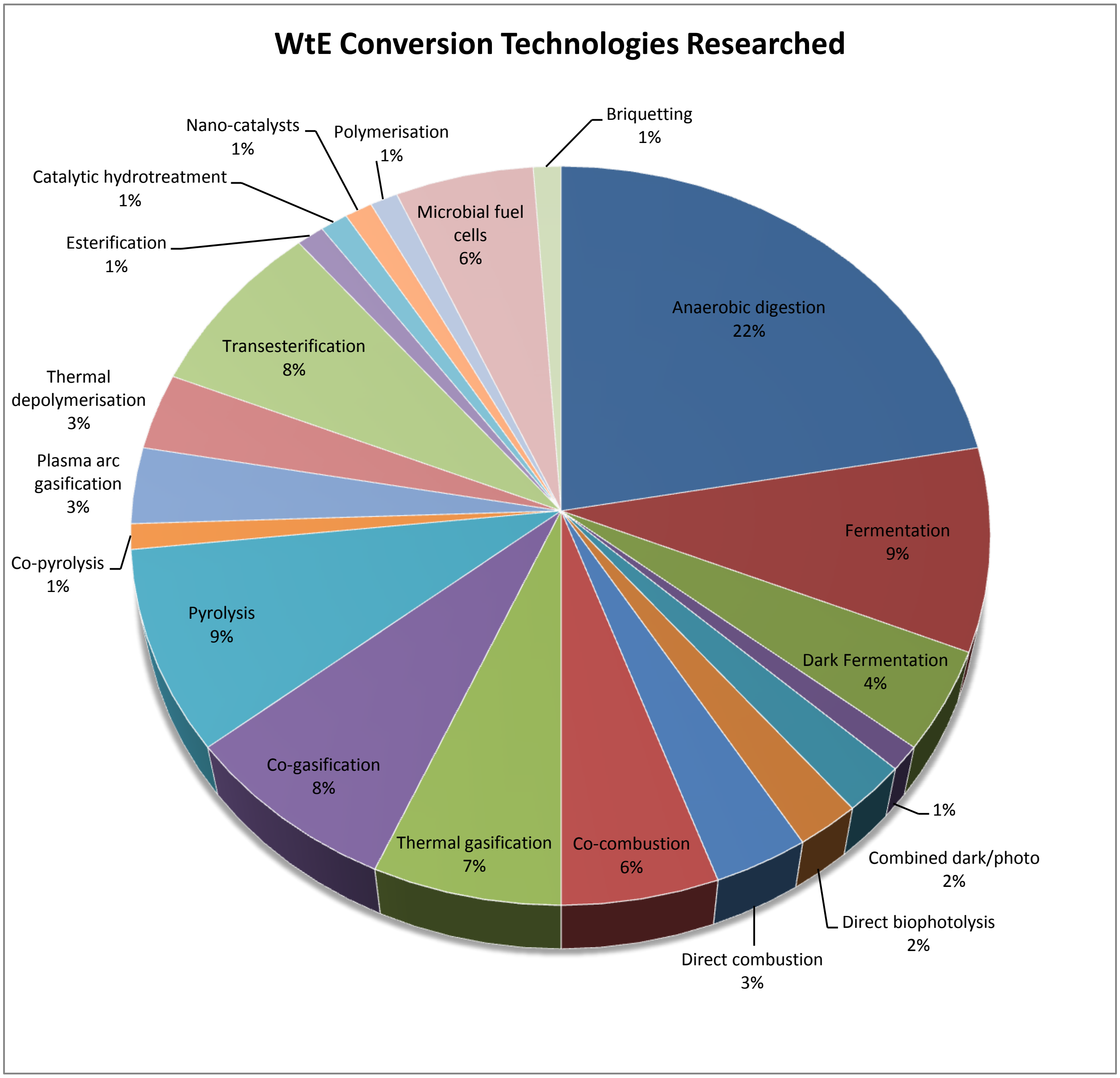


Figure 4: Current waste to energy conversion technologies researched in South Africa.

Waste to Energy Feedstock

The National Waste Management Strategy (6) has set targets to encourage (i) waste reduction, (ii) waste reuse and recycling, (iii) waste recovery through treatment or energy retrieval. For this strategy to be successfully implemented, the status quo of waste generation in the country needs to be recorded as accurately as possible. The South African Waste Information System (SAWIS) was developed by the Department of Environmental Affairs (DEA) to capture tonnages of waste generated, recycled and disposed on a routinely basis. The reporting of information into this system is however voluntary, resulting in low accuracy of waste generation data in South Africa. For this reason, a National Waste Information baseline study was carried out to more accurately model the prediction of waste generated, recycled, treated and landfilled in 2011 (4).

The modeled waste data showed that South Africa generated approximately 59 million tonnes of general waste during 2011 of which only 10% was recycled. Waste can be categorised into general/municipal, unclassified and hazardous waste streams. General waste, which makes up 55% (by weight) of total waste generated in South Africa (2011) comprises of non-recyclable municipal, organic, construction and demolition as well as recyclable waste. The non-recyclable municipal waste and organic waste which contributes 35% and 13% (by weight, excluding GW99) of the total general waste respectively may be suitable for recovery of energy (4). The table below illustrates selected wastes with energy conversion potential as well as amounts generated, recycled and landfilled for 2011.

Table 2: Selected wastes generated, recycled and landfilled in South Africa (adapted from DEA, 2012)

Waste Type, 2011		Generated (Tonnes/annum)	Recycled (Tonnes/annum)	Landfilled (Tonnes/annum)	Recycled (%)
GW01	Municipal waste (non-recyclable)	8 062 934	-	8 062 934	0
GW10	Commercial and industrial waste	4 233 040	3 259 441	973 599	77
GW20	Organic waste	3 023 600	1 058 260	1 965 340	35
HW20 GW21	Sewage sludge	673 360	130 160	500 508	19
GW50	Paper	1 734 411	988 614	745 797	57
GW51	Plastic	1 308 637	235 555	1 073 082	18
GW54	Tyres	246 631	9 865	236 766	4
GW99	Other*	36 171 127	-	36 171 127	0

*Mainly biomass waste from industrial sources

Current research in South Africa is done on a very diverse range of waste feedstock for conversion to energy products (Fig. 5). Although research was spread amongst all types of wastes, feedstock most researched included municipal solid waste (10%), agricultural waste (e.g. animal waste, crop residues) (9%), industrial waste (9%), wastewater (7%), wood waste (7%), food waste (6%) and waste tyres (6%), which in total makes up more than half of feedstock researched in the country.

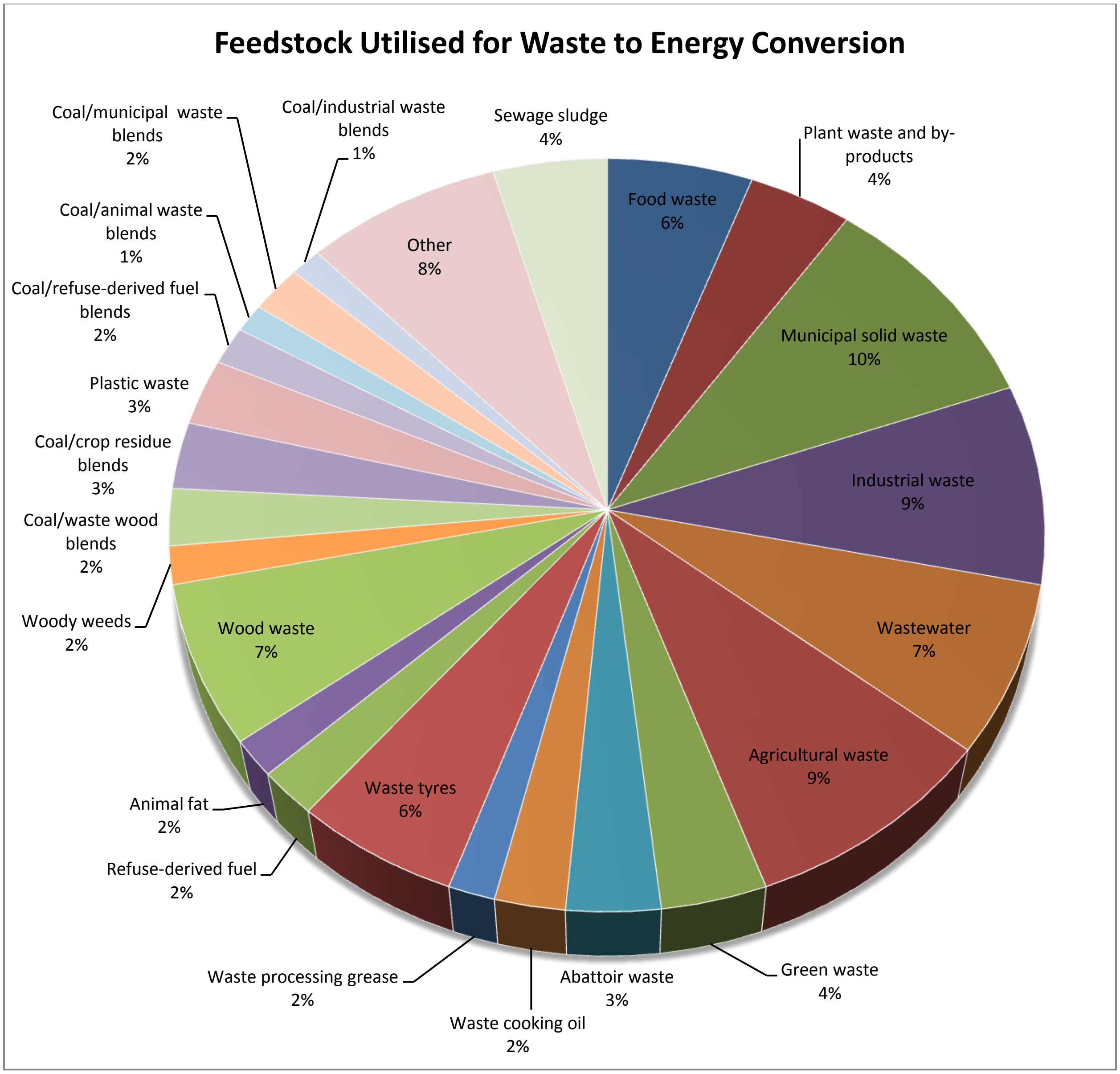


Figure 5: Current waste feedstock researched in South Africa.

Waste to Energy Products

From the above mentioned feedstock, through several conversion technologies, a wide array of energy products can be produced (Fig. 6). It is evident that biogas (29%) production dominates the research sector in South Africa however; syngas (16%), bio-oil (10%), biohydrogen (10%), bioethanol (8%) and biodiesel (8%) are also preferred energy products researched. Some energy products can be further processed to produce alternative products with various applications (Fig. 7).

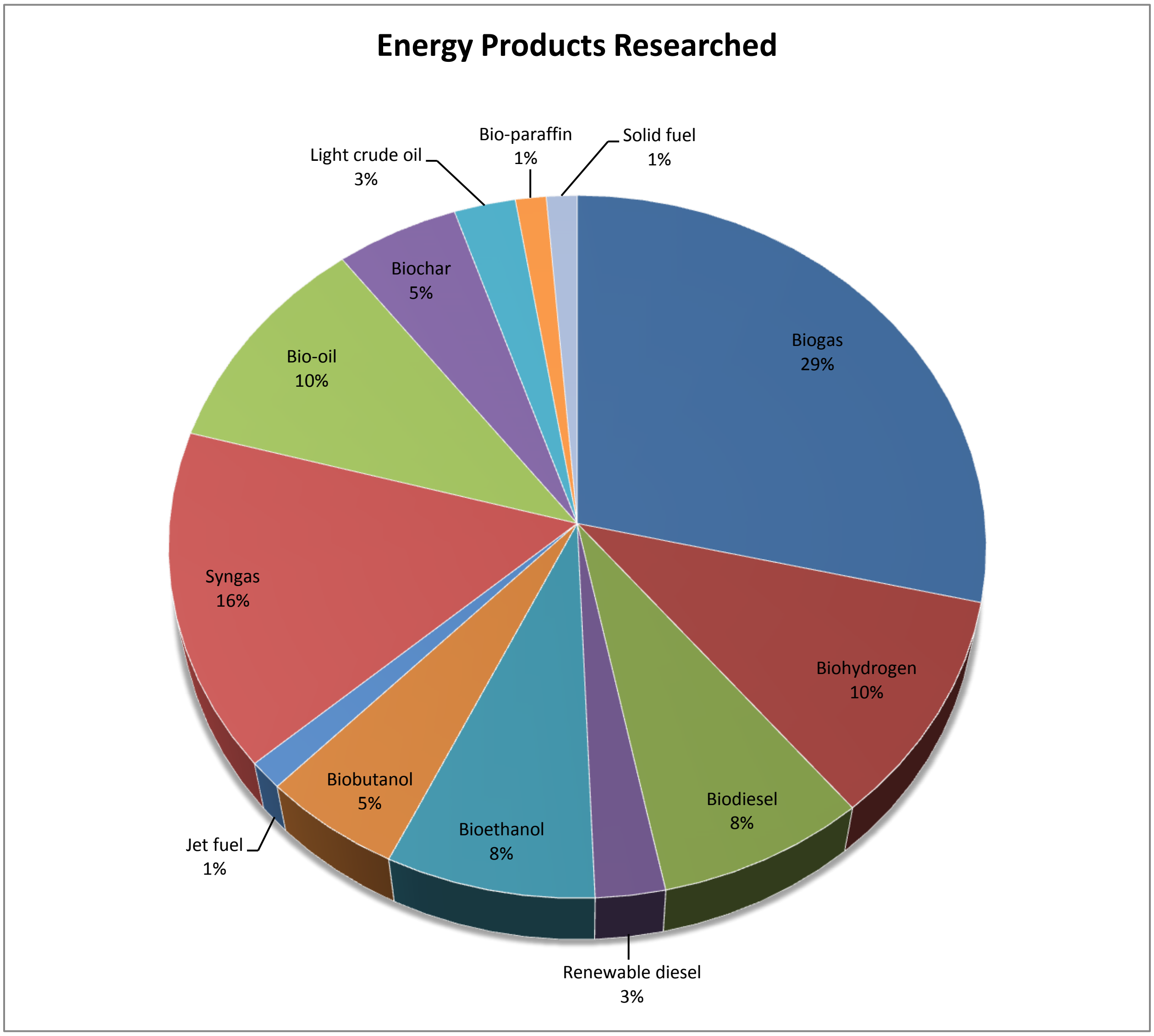


Figure 6: Current waste to energy products researched in South Africa.

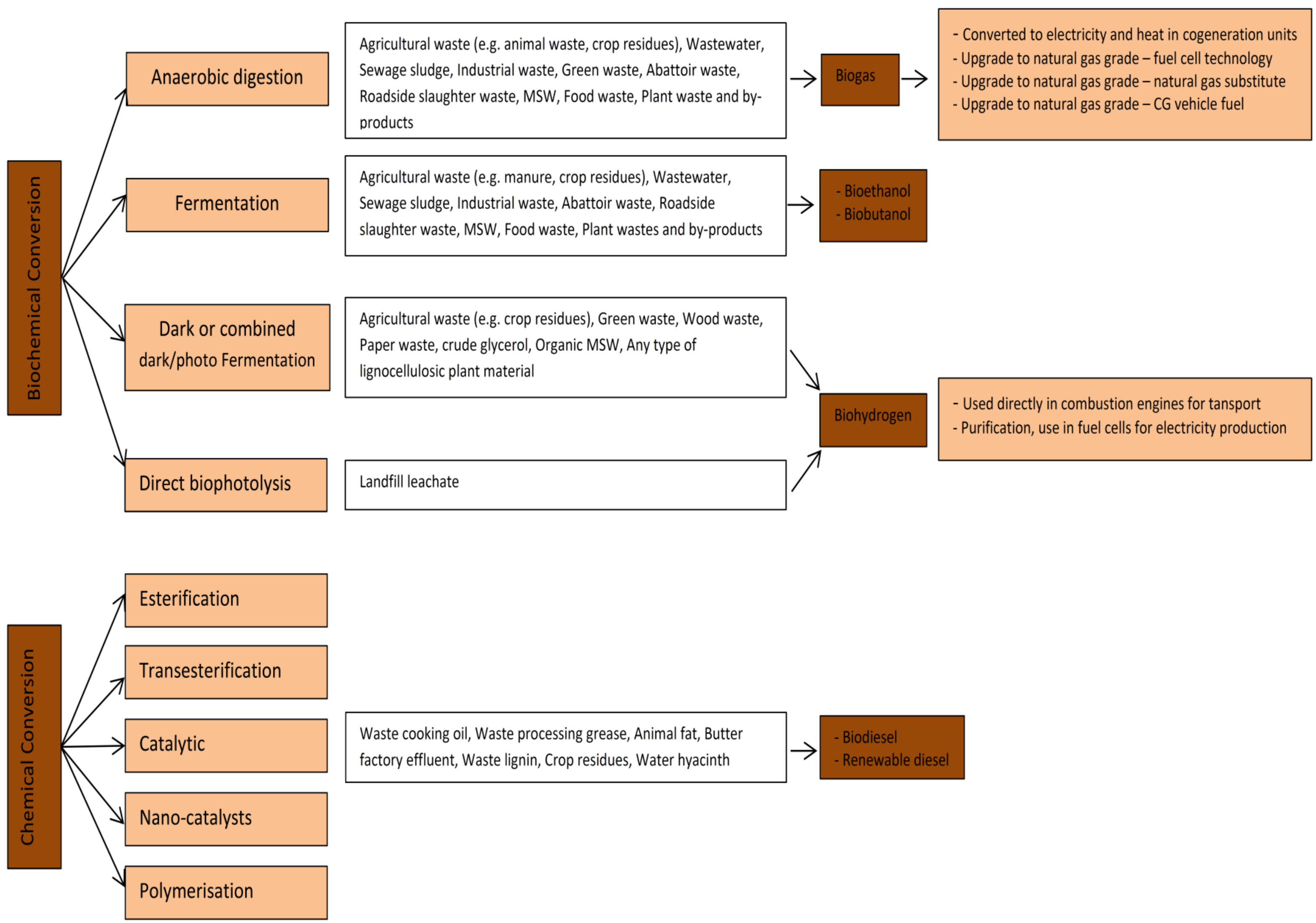


Figure 7: Summary of waste conversion technologies, feedstock, products and applications researched

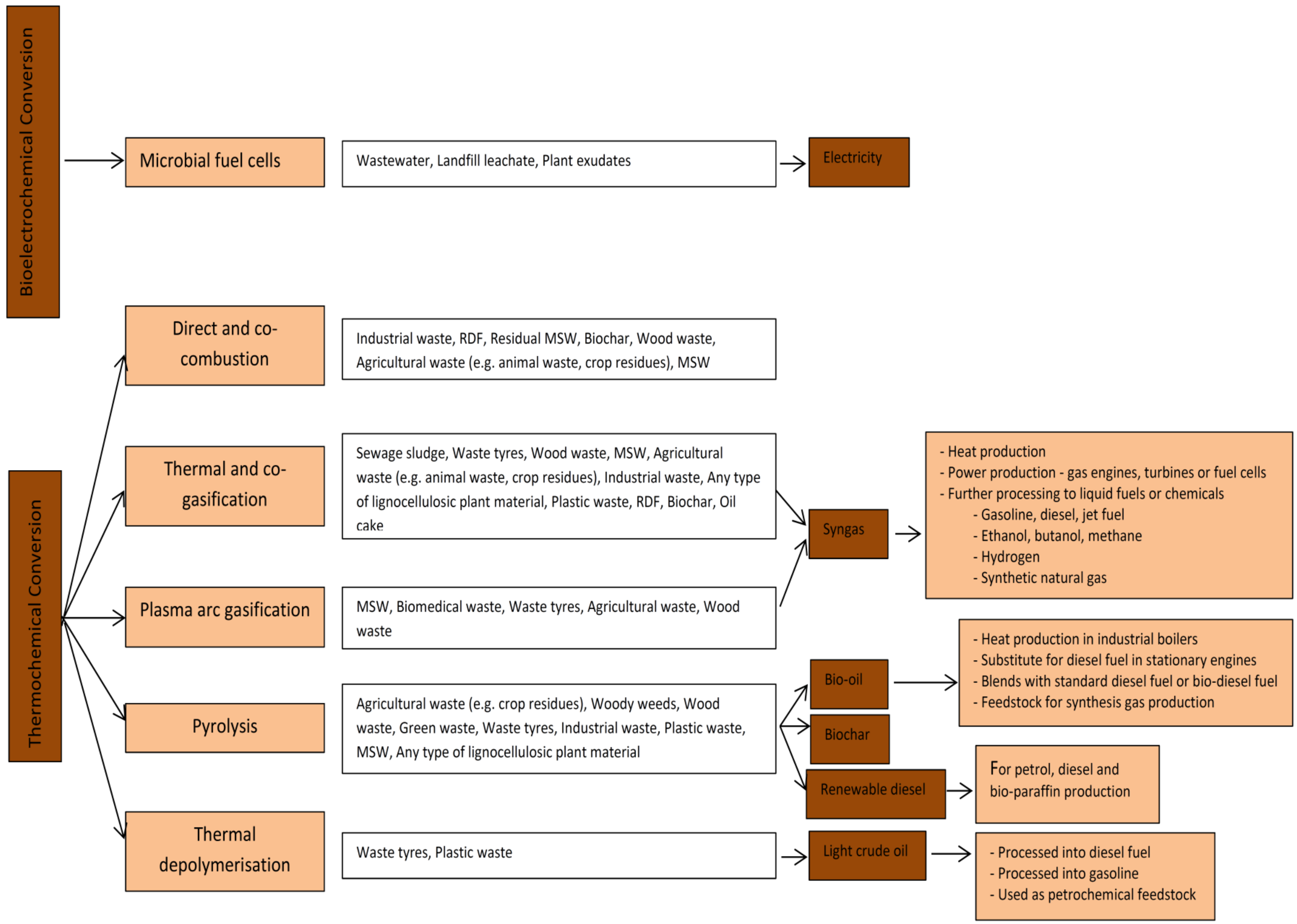


Figure 7: Summary of waste conversion technologies, feedstock, products and applications researched

Waste to energy research in South Africa focused primarily on generating biogas by anaerobic digestion. Due to the high level of research interest in this product and technology it was though prudent to present additional information on research conducted by each stakeholder (Table 3).

Table 3: Current waste to energy research conducted into anaerobic digestion

Research Institution	Researcher	Feedstock	Pre-treatment of Waste	Process Details	Reactor Type	Biogas Application	Other
CPUT	Dr. Vincent Okudoh	- Food waste - Plant waste and by-products - Municipal solid waste - Industrial waste	-	-	-	-	- Reactor design and construct - Reactor installation - Consultation and advice
DUT	Prof. Faizal Bux	- Waste water	-	-	-	-	-
MUT	Prof. Akash Anandraj	- Animal waste - Industrial waste - Plant waste and by-products - Wastewater	- Physical treatment - Chemical treatment - Biological treatment: Microbiological (multi-stage fermentation)	- Wet fermentation - One-phase digestion system	- Continuously stirred tank reactor	- Biogas converted to electricity and heat in cogeneration units (CHP) - Upgrade biogas to natural gas grade for use in fuel cell technology	- Economic, technical, and environmental analysis - Reactor design and construct
VUT	Prof. Ochieng Aoyi	- Abattoir waste - Food waste - Industrial waste - Sewage sludge - Wastewater	- Chemical treatment - Combined processes	- One-phase digestion system	- High-rate reactors: UASB, Fluidised bed, Anaerobic packed-bed	-	-
NWU	Prof. Sanette Marx	- Municipal solid waste - Industrial waste - Crop residues - Animal waste - Plant waste and by-products	-	-	-	-	-
NWU	Prof. Carlos Bezuidenhout	- Faecal sludge - Food waste - Green waste - Grease trap residue - Sewage sludge	- Physical treatment: Mechanical	- Wet fermentation - Mesophilic conditions - One-phase digestion system	- Continuously stirred tank reactor: Single –step system	- Biogas converted to electricity and heat in cogeneration units (CHP) - Upgrade biogas to natural gas grade	- Economic, technical and socio-economic analysis

Table 3: Current waste to energy research conducted into anaerobic digestion

Research Institution	Researcher	Feedstock	Pre-treatment of Waste	Process Details	Reactor Type	Biogas Application	Other
						for use as a natural gas substitute	
SU	Prof. Johann Görgens	- Food waste - Industrial waste - Plant waste and by-products	-	-	-	-	-
UCT	Prof. Sue Harrison	- Wastewater - Industrial waste - Food waste - Sewage sludge - Plant waste and by-products - Crop residues - Algal residues	- Physical treatment: Mechanical, Thermal - Biological treatment: Enzymatic Microbiological	- Wet fermentation system - Mesophilic conditions - One-phase digestion system - Multi-phase digestion system	- Continuously stirred tank reactor: Single-step system - High-rate reactor: UASB, Fluidised bed, Anaerobic packed-bed, Linear channel flow	-	- Life-cycle assessment - Economic, technical and Environmental analysis - Reactor design and construct
UCT	Dr. Amos Madhlopa	- Animal waste - Municipal solid waste - Wastewater	-	-	-	- Biogas converted to electricity and heat in cogeneration units (CHP)	-
UCT	Prof. Harro von Blottnitz	- Abattoir waste - Animal waste - Crop residues - Food waste - Industrial waste - Municipal solid waste - Plant waste and by-products - Roadside slaughter waste	- Biological treatment: Enzymatic - Combined processes: Steam explosion, Thermo-chemical	- One-phase digestion system	- Continuously stirred tank reactor: Single-step system	-	- Life-cycle assessment - Economic, technical, environmental and socio-economic analysis - Whole plant optimisation

Table 3: Current waste to energy research conducted into anaerobic digestion

Research Institution	Researcher	Feedstock	Pre-treatment of Waste	Process Details	Reactor Type	Biogas Application	Other
		- Wastewater					
UCT	Dr. Bothwell Batidzirai	- Municipal solid waste - Wastewater - Industrial waste - Food waste - Sewage sludge - Animal waste - Plant waste and by-products - Abattoir waste - Green waste	- Physical treatment: Mechanical - Chemical treatment Alkali	- Wet fermentation system - Mesophilic conditions - Thermophilic conditions	- Continuously stirred tank reactor: Single-step system	- Biogas converted to electricity and heat in cogeneration units (CHP) - Upgrade biogas to natural gas grade for use as a natural gas substitute	- Economic, technical, environmental and socio-economic analysis
UFH	Dr. Sampson Mamphweli	- Animal waste	- Physical treatment - Chemical treatment	- Wet fermentation system - Mesophilic conditions - Thermophilic conditions	- Continuous stirred tank reactor: Single-step system	- Biogas converted to electricity and heat in cogeneration units (CHP) - Upgrade biogas to natural gas grade for use as a natural gas substitute	- Technical analysis - Reactor design and construct
UJ	Prof. Edison Muzenda	- Abattoir waste - Animal waste - Crop residues - Food waste - Industrial waste - Municipal solid waste - Plant waste and by-products - Sewage sludge - Wastewater	- Physical treatment: Mechanical - Chemical treatment: Alkali	- Wet fermentation - Dry fermentation - Mesophilic conditions - Thermophilic conditions	- Dry batch reactor - Continuously stirred tank reactor: Single-step system	- Upgrade biogas to natural gas grade for use as CG vehicle fuel	- Economic, technical, environmental and socio-economic analysis - Reactor design and construct
UJ	Mr. Mansoor Mollagee	- Municipal solid waste - Wastewater	- Physical treatment: Mechanical, Thermal	- One-phase digestion system	- Dry batch reactor - Continuously	- Biogas converted to electricity and heat in cogeneration	- Life-cycle assessment - Economic, technical, environmental and socio-

Table 3: Current waste to energy research conducted into anaerobic digestion

Research Institution	Researcher	Feedstock	Pre-treatment of Waste	Process Details	Reactor Type	Biogas Application	Other
		- Industrial waste - Food waste - Crop residues - Sewage sludge - Animal waste - Plant waste and by-products - Abattoir waste			stirred tank reactor: Single-step system - Dry continuous reactor: Vertical, Horizontal	units (CHP) - Upgrade biogas to natural gas grade for use as a natural gas substitute - Upgrade biogas for use as CG vehicle fuel	economic analysis
UKZN	Prof. Cristina Trois	- Animal waste - Food waste	-	-	-	-	-
UKZN	Prof. Stefan Schmidt	- Organic biomass	-	-	-	-	-
UKZN	Dr. Terry Everson	- Animal waste - Food waste - Wastewater	- Physical treatment: Mechanical (hand mixing)	- Wet fermentation	- One-phase digestion system	- Upgrade biogas to natural gas grade for use as a natural gas substitute	- Environmental and socio-economic analysis
UNISA	Prof. Diane Hildebrandt	- Abattoir waste - Animal waste - Crop residues - Food waste - Industrial waste - Municipal solid waste - Sewage sludge - Wastewater	- Physical treatment: Mechanical	- Wet fermentation	- Dry batch reactors	- Biogas converted to electricity and heat in cogeneration units (CHP) - Upgrade biogas to natural gas grade for use as a natural gas substitute	- Life-cycle assessment - Economic and technical analysis - Reactor design and construct
UNISA	Dr. Martin Myer	- Animal waste - Food waste	-	-	-	-	-
UniVen	Dr. David Tinarwo	- Abattoir waste - Animal waste - Crop residues - Food waste - Industrial waste - Municipal solid waste	- Physical treatment: Mechanical - Chemical treatment: Alkali	- Wet fermentation - Mesophilic conditions	- Continuously stirred tank reactors - Dry continuous reactors: Vertical	- Upgrade biogas to natural gas grade for use in fuel cell technology	- Life-cycle analysis - Economic, technical, environmental and socio-economic analysis - Reactor design and construct

Table 3: Current waste to energy research conducted into anaerobic digestion

Research Institution	Researcher	Feedstock	Pre-treatment of Waste	Process Details	Reactor Type	Biogas Application	Other
		- Plant waste and by-products - Sewage sludge - Wastewater					
Wits	Prof. Sunny Iyuke	- Industrial waste - Municipal solid waste - Wastewater	- Physical treatment: Ultrasonic	- Wet fermentation - Mesophilic conditions - Thermophilic conditions	- Dry batch reactors - High-rate reactors: Anaerobic packed-bed		- Economic and technical analysis
ARC	Mr. Petrus Britz	- Animal waste	-	- Wet fermentation - Mesophilic conditions - Thermophilic conditions	- Continuously stirred tank reactors: Single-step system	- Biogas converted to electricity and heat in cogeneration units (CHP) - Upgrade biogas to natural gas grade for use as a natural gas substitute	- Technical and socio-economic analysis
CSIR	Ms. Debbie Jooste	- Abattoir waste - Animal waste - Sewage sludge - Wastewater	- Physical treatment: Thermal - Biological treatment: Enzymatic	- Wet fermentation system - Mesophilic conditions	- Continuously stirred tank reactor: Single- and two-step systems	- Converted to electricity and heat in cogeneration units (CHP)	- Economic, technical, environmental and socio-economic analysis - Reactor design and construct
EnviroServ	Ms. Sarah Edwards	- Abattoir waste - Slurry - Food waste	-	-	-	-	-

Conclusion and Recommendations

Conclusion

Although the South African WtE market is still in the early stages of development, anaerobic digestion from different waste and biomass sources is gradually becoming more established in the country. Furthermore, private sectors that generate appropriate volumes of waste currently dominate the thermal conversion segment in South Africa. As the country's mindset is shifted away from regarding waste as lacking in value towards a prospective resource for generating low carbon energy, the implementation of WtE becomes more secure.

Waste to energy research and implementation in South Africa is driven by social and economic factors as well as government directive. The vision of the South African government is to create a more environmentally sustainable economy by reducing greenhouse gas emissions and increasing the efficiency of energy use. Several incentives, policies and programmes have been put into place in order to promote WtE in the country. Below are a few examples that can stimulate current WtE research.

- The country has extensive environmental legislation that governs both waste management and air emission requirements.
- A proposed legislation, which will form part of a comprehensive waste management act, might be empowered by 2015 that bans organic waste disposal at landfills. This could contribute significantly towards the growth of the WtE sector.
- The DoE initiated the REIPPP programme that allocated 25 MW of electricity to be derived from landfill gas and 12.5 MW from each of biomass and biogas.
- The DEA through the Green fund promotes innovative green programmes and projects and under their Low Carbon Economy and Green Cities and Towns windows approved several (for due diligence) biofuel, biogas and WtE projects (2012-2013).
- The IDC (Industrial Development Corporation), under their Green Industries business unit, supports projects that fall under the Biofuels (bioethanol) and Fuel-based Clean Energy clusters (biomass, biogas, cogeneration/CHP and waste to energy). During 2014 the IDC participated in Round 3 of the REIPPP Programme, financed a 3 MW biogas energy project (Bio2Watt project) under AFD credit line, supported the established SA

Biogas Industry Association and implemented the Bon Accord Waste Recycling Project that created 406 jobs. A demonstration project indicated that the remaining waste from the Bon Accord Waste Recycling Project can be used for biogas generation. The IDC has increased funding for small-scale renewable energy and energy efficiency projects through the Green Energy Efficiency Fund (GEEF) and AFD credit lines with focus on industrial energy efficiency and biomass-to-energy.

- Eskom launched a rebate programme for small scale renewable energy generation under the company's Integrated Demand Management (IDM) Standard Offer Program (SOP). The incentive will at first only be available under the Standard Offer at a rate of R1.20 per kWh to be paid over a 3 year standard contract period. Here Eskom has included biomass waste/residue and municipal solid waste as part of their renewable energy definition. However, due to funding constraints Eskom has placed a hold on their demand-side management incentive programmes.
- The Manufacturing Competitiveness Enhancement Programme (MCEP) is an incentive by the DTI to support manufacturing enterprises with competitiveness improvement interventions. This would include grants for improvements made by utilising green technologies and the efficient use of resources. An example of such improvements would be the conversion of generated waste into energy.
- The DST has initiated a project that will be facilitated by the CSIR to develop a 10 year Waste Research, Development and Innovation Roadmap (2012-2022). The vision of this Roadmap is to encourage R&D, innovation, human capital development, enterprise development and job creation in the waste sector, therefore contributing to the governments drive towards a green economy.
- The Government, as part of its initiative to reduce, reduce and recycle has approved the REDISA plan (Recycling and economic development initiative of South Africa). The plan aims to remove waste tyres for the environment by adding a subsidy to its removal. REDISA is currently running successfully at depots site in KZN, the Western Cape and Gauteng, and is envisioned to be rolled out and fully operational in the rest of

the country in the next 5 years. Furthermore, plans are in place to generate boiler fuel, carbon char and steel from waste tyres, at a pyrolysis plant in the Eastern Cape.

- The national climate change response strategy (DEA) identified eight near-term priority flagship programmes, one of which includes The Waste Management Flagship Programme. This programme is to establish the potential of the waste management sector to mitigate GHG emissions. The investigation will also include WtE opportunities in the solid-, semi-solid- and liquid-waste management sectors particularly for methane generation, capture, conversion and use.
- It is recognised by Government in the White Paper on Renewable Energy (2003) that power generation from waste could form one of the key technologies to be implemented in remote rural areas. Furthermore, plant residues from agriculture/forestry as well as organic components in municipal and industrial wastes are seen as biomass sources which could be utilised to produce heat, liquid fuels, gas and electricity. Moreover, potential is seen in the conversion of manure and livestock litter by anaerobic fermentation to produce biogas or incineration for power production.
- The IDC, DBSA (Development Bank of Southern Africa) and TIPS (Trade and Industrial Policy Strategies) have compiled a document containing estimates of the direct employment potential of green technologies in the country. From this document it was estimated that the WtE segment has a total net direct employment potential (long-term) of over 55 000.

The alignment of WtE research in South Africa with government policies, current incentives and programmes is crucial to its successful implementation in the country. Although the current WtE research landscape in South Africa is very diverse, a specific preference has been shown towards anaerobic digestion for the production of biogas. Furthermore, other fields extensively researched included fermentation for the production of bioethanol, gasification for the production of syngas (which is further converted to several liquid fuels), pyrolysis for the production of bio-oil and transesterification for the production of biodiesel. Although research was spread amongst all types of wastes, feedstock most researched included municipal solid waste, agricultural waste (e.g. animal waste, crop residues), industrial waste, wastewater, wood waste, food waste and waste tyres, which in total makes up more than half of feedstock researched in the country.

The country's current drive towards the use of biomass waste/residues, municipal waste, industrial waste, waste tyres and small-scale renewable energy projects for the production of production of biogas, liquid fuels, heat and electricity is well complimented by research being conducted at South African research institutes.

The uptake of WtE technologies in the county shows promise however it is still hindered by several factors. To address some of these problems the following recommendation are presented.

Recommendations

- The South African government is aware of the contribution that the waste sector can have on the greening of the economy as well as its prospects for job creation, innovation and enterprise development. However, at present priorities for strategic direction, collaborative context and focused funding or incentives for waste is underdeveloped. Waste innovation can only be realised once a mind shift has been made from viewing waste as an unwanted product that requires treatment and disposal to a valuable renewable resource.
- When developing WtE technologies in South Africa factors like socio-economics and waste generation differences between urban and rural areas need to be taken in account. The installation of expensive and intricate designs that is not sustainable or requires particular skills to operate should be avoided. Rather, technologies that are adapted to the specific environment and community should be considered. The involvement of the community during development and implementation as well as making use of their knowledge and approaches will enhance the implementation as well as participation in these technologies.
- Public perception can be seen as an obstacle to waste innovation. For example the public opposition to mass-burn incineration on the basis of environmental and human health as well as cultural perceptions and norms. Another example is the lack in acceptance of methane gas produced from human/animal sewage for cooking on the grounds that it is seen as unsanitary. Therefore, the interaction between new technologies and society as well as an understanding of which factors limits their uptake is crucial.
- Most WtE facilities are becoming more technologically advanced. Therefore the appropriate private and public sector skills need to be developed in order to be able to manufacture, install, operate and maintain these technologies.
- Collaboration between different stakeholders, especially across disciplines. There is not enough synergy between agricultural, engineering and natural science departments. In this case the establishment of a Bioengineering degree could prove to be invaluable.

- Improved synchronisation of objective in Departments (e.g. DoE and DEA) can result in better support for waste to energy in DoE programmes.
- Electricity production from WtE conversion should be incorporated in the next draft of the Integrated Resource Plan (IRP) and Renewable Energy Independent Power Producer Procurement Programme (REIPPPP).
- Streamlining waste permits processes, carbon financing registration, environmental impact assessments, Municipal Finance Management Act's (MFMA's) etc.
- Alignment between the energy needs of the country and the research being conducted in this regard is crucial.
- Piloting and performance evaluation of the various WtE technologies at industrial scale in order to prove its viability.
- Most WtE facilities have a high capital cost and although the rise in the electricity price will increase the viability of renewable technologies, considerable support will still be required if these technologies are to be implemented on a commercial, large-scale basis.
- For WtE facilities to be as cost effective as possible strategic placement is necessary in order to avoid excessive inbound logistics cost and to exploit as many revenue streams as possible.
- Independent electricity producers should have ease of access to transmission networks thereby enabling them to sell their electricity to Eskom, municipalities and other end-users.
- Waste stream analysis of generated wastes in South Africa to determine the waste composition and quantities of specific fractions as well as evaluation of regional biomass logistic networks.
- Intergration of other renewable energy sources with WtE technologies thereby decreasing dependence on grid connected electricity.
- Alternative biomass resources need to be evaluated to supplement the current coal supply.

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Appendix

Table 4: Summary of current WtE research conducted in South Africa

Research Institution	Researcher	Conversion Technology	Energy Product	Feedstock	Pre-treatment of Waste	Process Details	Reactor/Fuel cell/Combustor/ Gasifier Type	Product Application	Other
CPUT	Dr. Okudoh	- Anaerobic digestion	- Biogas	- Food waste - Plant waste - Municipal solid waste - Industrial waste	-	-	-	-	- Digester design and construct - Digester installation - Consultation and advice
DUT	Prof. Bux	- Anaerobic digestion	- Biogas	- Wastewater	-	-	- High-rate reactors: UASB	-	- Evolutionary algorithm application
		- Dark fermentation	- Biohydrogen	- Crop residues	-	-	- Anaerobic baffled reactor	-	- Microbial community analysis
MUT	Prof. Anandraj	- Combined dark/photo fermentation - Photo fermentation	- Biogas - Biohydrogen	- Animal waste - Industrial waste - Plant waste and by-products - Wastewater	- Physical treatment - Chemical treatment - Biological treatment: Microbiological (multi-stage fermentation)	- Wet fermentation - One-phase digestion system	- Continuously stirred tank reactor	- Biogas converted to electricity and heat in cogeneration units (CHP) - Upgrade biogas to natural gas grade for use in fuel cell technology - Biohydrogen purification and use in fuel cells	- Economic, technical and environmental analysis - Reactor design and construct
		- Fermentation	- Biobutanol	- Agricultural waste - Organic MSW - Green waste	- Biological treatment	-	-	-	- Technical, environmental analysis - Reactor design and construct
		- Microbial fuel cells	- Direct electricity	- Wastewater - Landfill leachate	-	-	- Microbial electrolysis cell	-	-
		- Direct biophotolysis	- Biohydrogen	- Landfill leachate	-	-	-	- Biohydrogen purification and use in fuel cells	- Life-cycle assessment - Economic, technical, environmental and socio-economic analysis - Reactor design and construct
		- Direct combustion	-	- Industrial waste	-	-	-	-	-
VUT	Prof. Aoyi	- Integrated anaerobic digestion and photodegradation	-	- Abattoir waste - Food waste - Industrial waste - Sewage sludge - Wastewater	- Chemical treatment - Combined processes	- One-phase digestion system	- High-rate reactors: UASB, Fluidised bed, Anaerobic packed-bed	-	-
		- Direct combustion	-	- Industrial waste - Refuse-derived fuel	-	-	-	-	-
		- Pyrolysis	-	- Waste tyres	-	-	-	-	-

Table 4: Summary of current WtE research conducted in South Africa

Research Institution	Researcher	Conversion Technology	Energy Product	Feedstock	Pre-treatment of Waste	Process Details	Reactor/Fuel cell/Combustor/ Gasifier Type	Product Application	Other
		- Transesterification	- Biodiesel	- Waste cooking oil - Waste processing grease	-	- Alkali-catalysed - Acid-catalysed - Two-step methods: alkali-catalysed saponification-transesterification, Acid-catalysed esterification-transesterification, acid-catalysed esterification followed by alkali-catalysed transesterification	-	-	-
NWU	Prof. Marx	- Esterification - Transesterification - Catalytic hydrotreatment - Nano-catalysts - Polymerisation	- Biodiesel - Renewable diesel - Biobutanol	- Waste cooking oil - Waste processing grease - Animal fat - Butter factory effluent - Sweet sorghum bagasse - Water hyacinth - Waste lignin	-	- Alkali-catalysed - Acid-catalysed - Two-step: Alkali-catalysed saponification-transesterification, Acid-catalysed esterification-transesterification, Acid-catalysed esterification followed by alkali-catalysed transesterfication - Glycerol-free process - Hydrocracking	-	-	-
		- Microbial fuel cells	- Direct electricity	- Wastewater	-	-	- Mediator fuel cells - Mediator-free fuel cells	-	-
		- Fermentation	- Bioethanol - Biobutanol - Biomethanol	- Sweet sorghum bagasse - Amaranth stalks and stems - Crude glycerol	- Physical treatment: Mechanical comminution - Chemical treatment: Alkali, acid,	- Acid hydrolysis - Enzyme hydrolysis - Separate and simultaneous hydrolysis	-	-	-

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Research Institution	Researcher	Conversion Technology	Energy Product	Feedstock	Pre-treatment of Waste	Process Details	Reactor/Fuel cell/Combustor/ Gasifier Type	Product Application	Other
				- Wood waste - Paper waste	organosolvents - Physicochemical treatment: Microwave, ultrasound				
		- Anaerobic digestion	- Biogas	- Municipal solid waste - Industrial waste - Crop residues - Animal waste - Plant wastes and by-products - Water hyacinth	- Physical treatment: Mechanical, thermal, ultrasonic - Chemical treatment: Alkali - Biological treatment: Enzymatic - Combined: Thermo-chemical	- Wet fermentation - One-phase digestion system	-	-	-
		- Co-combustion	-	- Coal/biochar	-	- Direct co-combustion: combustion of primary and secondary fuels in single chamber	- Fixed bed	-	-
		- Co-gasification	- Syngas	- Coal/biochar (derived from liquefaction of waste)	-	-	- Fixed bed	- Syngas for further processing to liquid fuels or chemicals: Gasoline, diesel, jet fuel, synthetic natural gas	-
		- Liquefaction	- Biochar - Bio-oil - Biodiesel - Renewable diesel (for petrol, diesel and bio-paraffin production)	- Industrial waste - Woody weeds - Animal waste - Oil cake - Amaranth stalks - Sweet sorghum bagasse - Municipal effluent	-	-	- Batch - Continuous flow	- Bio-oil for heat production in industrial boilers - Bio-oil used as a substitute for diesel fuel in stationary engines - Bio-oil blends with standard diesel fuels or biodiesel fuel - Bio-oil as feedstock for synthesis gas production	- Biomass-coal kinetics - Heat transfer parameters

Table 4: Summary of current WtE research conducted in South Africa

Research Institution	Researcher	Conversion Technology	Energy Product	Feedstock	Pre-treatment of Waste	Process Details	Reactor/Fuel cell/Combustor/ Gasifier Type	Product Application	Other
NWU	Prof. Strydom	- Direct combustion	-	-	-	-	-	-	- Technical and environmental analysis
		- Thermal gasification	- Syngas	- Waste wood - Agricultural waste	-	-	- Fixed bed gasifier: Counter-current, co-current, cross draft - Fluidised bed gasifier: Bubbling, circulating, dual - Entrained flow gasifier - Underground coal gasifier	- Syngas for heat production - Syngas for power production in gas engines, turbines or fuel cells	- Technical analysis
		- Co-gasification	- Syngas	- Coal/wood waste - Coal/crop residues	-	-	- Fixed bed gasifier: Counter-current, co-current, cross draft - Fluidised bed gasifier: Bubbling, circulating, dual - Entrained flow gasifier	- Syngas for heat production - Syngas for power production in gas engines, turbines or fuel cells - Syngas for further processing to liquid fuels or chemicals	- Technical analysis
		- Pyrolysis	- Bio-oil	- Waste wood - Agricultural waste	-	- Slow pyrolysis - Fast pyrolysis	- Fluidised bed: circulating, bubbling	- Bio-oil as feedstock for synthesis gas production	- Technical analysis
NWU	Prof. Bunt	- Co-gasification	- Syngas	- Coal/waste tyres	-	-	- Fixed bed: Counter-current	- Syngas for heat production - Syngas for further processing to liquid fuels and chemicals	- Technical analysis
		- Pyrolysis	- Bio-oil - Char - Gas	- Waste tyres	-	- Slow pyrolysis	- Fixed bed	-	- Technical analysis
NWU	Prof. Bezuidenhout	- Anaerobic digestion	- Biogas	- Faecal sludge - Food waste - Green waste - Grease trap residue - Sewage sludge	- Physical treatment: Mechanical	- Wet fermentation - Mesophilic conditions - One-phase digestion system	- Continuously stirred tank reactor: Single –step system	- Biogas converted to electricity and heat in cogeneration units (CHP) - Upgrade biogas to natural gas grade for use as a natural gas substitute	- Economic, technical and socio-economic analysis
RU	Prof. Limson	- Microbial fuel cells	- Direct electricity	- Wastewater - Brewery	-	-	- Mediator fuel cells - Mediator-free fuel	-	-

Table 4: Summary of current WtE research conducted in South Africa

Research Institution	Researcher	Conversion Technology	Energy Product	Feedstock	Pre-treatment of Waste	Process Details	Reactor/Fuel cell/Combustor/ Gasifier Type	Product Application	Other
				wastewater			cells - Microbial electrolysis cells		
SU	Prof. Görgens	- Anaerobic digestion	- Biogas	- Food waste - Industrial waste - Plant waste and by-products	-	-	-	-	-
		- Fermentation	- Bioethanol - Biobutanol	- Agricultural waste - Crop residues - Organic MSW - Wood waste - Paper waste - Green waste	- Physical treatment - Chemical treatment: Acid, alkali, organosolvents, ionic liquids - Physicochemical treatment: Liquid hot water, ammonia fiber explosion, steam explosion	- Acid hydrolysis - Enzyme hydrolysis - Separate and simultaneous hydrolysis	-	-	- Life-cycle assessment - Economic, technical, environmental and socio-economic analysis - Reactor design and construct
		- Thermal gasification	- Syngas	- Waste wood - Refuse-derived fuel - Agricultural waste - Waste tyres	-	-	-	- Syngas for further processing to liquid fuels or chemicals: Gasoline, diesel, jetfuel, ethanol/butanol/methane (syngas fermentation)	- Life-cycle assessment - Economic, technical and environmental analysis
		- Co-gasification	-	- Coal/wood waste - Coal/crop residues	-	-	-	-	-
		- Pyrolysis	- Bio-oil	- Waste tyres - Industrial waste - Plastic waste - Green waste - Wood waste - Woody weeds - Agricultural waste - Municipal solid waste	-	- Slow pyrolysis - Fast pyrolysis - Vacuum pyrolysis	- Fluidised bed: bubbling - Vacuum	- Bio-oil for heat production in industrial boilers - Bio-oil used as a substitute for diesel fuel in stationary engines - Bio-oil blends with standard diesel fuels or biodiesel fuel - Bio-oil as feedstock for synthesis gas production	- Life-cycle assessment - Economic, technical, environmental and socio-economic analysis

Table 4: Summary of current WtE research conducted in South Africa

Research Institution	Researcher	Conversion Technology	Energy Product	Feedstock	Pre-treatment of Waste	Process Details	Reactor/Fuel cell/Combustor/ Gasifier Type	Product Application	Other
								- Chemicals recovery from oils	
		- Thermal depolymerisation	-	- Waste tyres - Plastic waste	-	-	-	-	-
SU	Prof. van Zyl	- Fermentation	- Bioethanol	- Agricultural waste - Crop residues - Wood waste - Green waste	- Chemical treatment: Acid	- Enzyme hydrolysis - Separate and simultaneous hydrolysis	-	-	-
UCT	Prof. Harrison	- Anaerobic digestion	-	- Wastewater - Industrial waste - Food waste - Crop residues - Sewage sludge - Plant wastes and by-products	- Physical treatment: Mechanical, thermal - Biological treatment: Enzymatic, microbiological (multi-stage fermentation)	- Wet fermentation - Mesophilic conditions - One-phase digestion system - Multi-phase digestion system	- Continuously stirred tank reactor: Single-step system - High-rate reactor: UASB, fluidised bed, anaerobic packed-bed - Linear channel flow reactor	-	- Life-cycle assessment - Economic, technical and environmental analysis - Reactor design and construct
		- Fermentation	- Bioethanol - Biobutanol	- Agricultural waste - Crop residues - Organic MSW - Process wastes	-	-	-	-	- Life-cycle assessment - Technical analysis
		- Transesterification	-	- Waste cooking oil	-	- Alkali-catalysed - Enzyme-catalysed	-	-	- Life-cycle assessment - Technical analysis
		- Microbial fuel cells	- Direct electricity	- Wastewater - Plant exudates	-	-	- Mediator fuel cells - Mediator-free fuel cells	-	-
UCT	Dr. Madhlopa	-	-	- Animal waste - Municipal solid waste - Wastewater	-	-	-	- Biogas converted to electricity and heat in cogeneration units (CHP)	-
UCT	Dr. Batidzirai	- Anaerobic digestion	- Biogas	- Municipal solid waste - Wastewater - Industrial waste - Food waste - Sewage sludge - Animal waste	- Physical treatment - Chemical treatment: alkali	- Wet fermentation - Mesophilic conditions - Thermophilic conditions	- Continuously stirred tank reactors: Single-step system	- Biogas converted to electricity and heat in cogeneration units - Upgrade biogas to natural gas grade for use as a natural	- Economic, technical, environmental and socio-economic analysis

Table 4: Summary of current WtE research conducted in South Africa

Research Institution	Researcher	Conversion Technology	Energy Product	Feedstock	Pre-treatment of Waste	Process Details	Reactor/Fuel cell/Combustor/ Gasifier Type	Product Application	Other
				- Plant wastes and by-products - Abattoir waste				gas substitute	
		- Fermentation	- Bioethanol - Biobutanol	- Agricultural waste - Wood waste - Green waste	- Physical treatment: Mechanical comminution - Chemical treatment: Acid, alkali	- Acid hydrolysis - Enzyme hydrolysis - Separate and simultaneous hydrolysis	-	-	- Economic, technical, environmental and socio-economic analysis
		- Direct combustion	-	- Residual municipal solid waste - Refuse-derived fuel	-	-	- Fixed-bed combustion: Underfeed strokers, grate firings - Fluidised-bed combustion: Bubbling, circulating - Entrained flow combustion	-	- Economic, technical, environmental and socio-economic analysis
		- Co-combustion	-	- Coal/wood waste - Coal/crop residues - Coal/municipal waste	-	- Direct co-combustion - Indirect co-combustion	- Pulverised fuel combustion - Fluidised bed combustion - Grate firing	-	- Economic, technical, environmental and socio-economic analysis
		- Thermal gasification	- Syngas	- Waste wood - Municipal solid waste - Agricultural waste - Industrial waste - Crop residues	-	-	- Fixed bed gasifier: counter-current, co-current, cross draft - Fluidised bed gasifier: Bubbling, circulating, dual - Entrained flow gasifier - Indirect gasifier (ECN Milena)	- Syngas for heat production - Syngas for power production in gas engines, turbines or fuel cells - Syngas for further processing to liquid fuels or chemicals: gasoline, diesel, jetfuel, synthetic natural gas	- Economic, technical, environmental and socio-economic analysis
		- Co-gasification	- Syngas	- Coal/refuse-derived fuel - Coal/crop residues - Coal/municipal waste	-	-	- Fixed bed gasifier: counter-current, co-current, cross draft - Fluidised bed gasifier: Bubbling, circulating, dual - Entrained flow gasifier	- Syngas for heat production - syngas for power production in gas engines, turbines or fuel cells - Syngas for further processing to liquid	- Economic, technical, environmental and socio-economic analysis

Table 4: Summary of current WtE research conducted in South Africa

Research Institution	Researcher	Conversion Technology	Energy Product	Feedstock	Pre-treatment of Waste	Process Details	Reactor/Fuel cell/Combustor/ Gasifier Type	Product Application	Other
							- Indirect gasifier (ECN Milena)	fuels or chemicals: gasoline, diesel, jetfuel, synthetic natural gas	
		- Pyrolysis	- Bio-oil	- Green waste - Waste wood - Woody weeds - Agricultural waste - Municipal solid waste	-	- Slow pyrolysis - Fast pyrolysis	- Fluidised bed: circulating, bubbling - Rotating cone	- Bio-oil for heat production in industrial boilers - Bio-oil used as a substitute for diesel fuel in stationary engines - Bio-oil blends with standard diesel fuels or biodiesel fuel - Bio-oil as feedstock for synthesis gas production	-
UCT	Prof. von Blottnitz	- Anaerobic digestion - Dark fermentation	- Biogas - Biohydrogen	- Abattoir waste - Animal waste - Crop residues - Food waste - Industrial waste - Municipal solid waste - Plant waste and by-products - Roadside slaughter waste - Wastewater	- Biological treatment: Enzymatic - Combined processes: Steam explosion, Thermo-chemical	- One-phase digestion system	- Continuously stirred tank reactor: Single-step system	- For cooking purposes	- Life-cycle assessment - Economic, technical, environmental and socio-economic analysis - Whole plant optimisation
		- Direct combustion	-	-	-	-	- Efficient stoves	-	- Life-cycle assessment - Economic, technical, environmental and socio-economic analysis
		- Plasma arc gasification	-	-	-	-	-	-	- Life-cycle assessment - Economic, technical, environmental and socio-economic analysis
		- Transesterification	-	-	-	-	-	-	- Life-cycle assessment - Economic, technical, environmental and socio-economic analysis

Table 4: Summary of current WtE research conducted in South Africa

Research Institution	Researcher	Conversion Technology	Energy Product	Feedstock	Pre-treatment of Waste	Process Details	Reactor/Fuel cell/Combustor/ Gasifier Type	Product Application	Other
UFH	Dr. Mamphweli	- Anaerobic digestion	- Biogas	- Animal waste	- Physical treatment - Chemical treatment	- Wet fermentation system - Mesophilic conditions - Thermophilic conditions	- Continuous stirred tank reactor: Single-step system	- Biogas converted to electricity and heat in cogeneration units (CHP) - Upgrade biogas to natural gas grade for use as a natural gas substitute	- Technical analysis - Reactor design and construct
		- Gasification - Co-gasification	- Syngas	- Wood waste - Agricultural waste	-	-	- Fixed bed gasifier: Co-current	- Syngas for heat production - Syngas for power production in gas engines, turbines or fuel cells	- Life-cycle assessment - Economic, technical and socio-economic analysis - Gasifier design and construct
UJ	Prof. Muzenda	- Anaerobic digestion	- Biogas	- Abattoir waste - Animal waste - Crop residues - Food waste - Industrial waste - Municipal solid waste - Plant waste and by-products - Sewage sludge - Wastewater	- Physical treatment: Mechanical - Chemical treatment: Alkali	- Wet fermentation - Dry fermentation - Mesophilic conditions - Thermophilic conditions	- Dry batch reactor - Continuously stirred tank reactor: Single-step system	- Upgrade biogas to natural gas grade for use as CG vehicle fuel	- Economic, technical, environmental and socio-economic analysis - Reactor design and construct
		- Co-combustion	-	- Coal/refuse-derived fuel - Coal/wood waste - Coal/crop residues - Coal/animal waste - Coal/municipal waste - Coal/industrial waste	-	-	-	-	-
		- Pyrolysis	- Bio-oil	- Waste tyres - Plastic waste	-	- Slow pyrolysis - Fast pyrolysis - Vacuum pyrolysis	- Fluidised bed reactor	- Bio-oil for heat production in industrial boilers - Bio-oil used as a substitute for diesel fuel in stationary	- Economic, technical, environmental and socio-economic analysis

Table 4: Summary of current WtE research conducted in South Africa

Research Institution	Researcher	Conversion Technology	Energy Product	Feedstock	Pre-treatment of Waste	Process Details	Reactor/Fuel cell/Combustor/ Gasifier Type	Product Application	Other
								fuel in stationary engines - Bio-oil blends with standard diesel fuels or biodiesel fuel	
		- Thermal depolymerisation	- Light crude oil processed into gasoline	- Plastic waste	-	-	-	-	-
UJ	Dr. Aboyade	- Anaerobic digestion	- Biogas - Biohydrogen	- Municipal solid waste - Wastewater - Industrial waste - Food waste - Crop residues - Sewage sludge - Animal waste - Plant wastes and by-products - Abattoir waste	- Physical treatment: Mechanical, thermal	- One-phase digestion system	- Dry batch reactors - Continuously stirred tank reactors: Single-step system - Dry continuous reactors: Vertical, horizontal	- Biogas converted to electricity and heat in cogeneration units - Upgrade biogas for use as a natural gas substitute - Upgrade biogas for use as CG vehicle fuel - Biohydrogen purification and use in fuel cells	- Life-cycle assessment - Economic, technical, environmental and socio-economic analysis
		- Co-combustion	-	- Coal/refuse-derived fuel - Coal/wood waste - Coal/crop residues - Coal/animal waste - Coal/municipal waste - Coal/industrial waste	-	- Direct co-combustion - Indirect co-combustion - Parallel co-combustion	- Pulverised fuel combustion - Fluidised bed combustion - Grate firing	-	- Life-cycle assessment - Economic, technical, environmental and socio-economic analysis
		- Thermal gasification	- Syngas	- Waste wood - Plastic waste - Aluminium waste - Municipal solid waste - Refuse-derived waste - Agricultural waste	-	-	- Fixed bed gasifier: counter-current, co-current, cross draft - Fluidised bed gasifier: bubbling, circulating, dual - Entrained flow gasifier	- Syngas for heat production - Syngas for power production in gas engines, turbines or fuel cells - Syngas for further processing to liquid fuels: Gasoline,	- Life-cycle assessment - Economic, technical, environmental and socio-economic analysis - Gasifier design and construct

Table 4: Summary of current WtE research conducted in South Africa

Research Institution	Researcher	Conversion Technology	Energy Product	Feedstock	Pre-treatment of Waste	Process Details	Reactor/Fuel cell/Combustor/ Gasifier Type	Product Application	Other
				- Sewage sludge - Crop residues - Waste tyres				ethanol/butanol/methane (syngas fermentation)	
		- Co-gasification	- Syngas	- Coal/refuse-derived fuel - Coal/wood waste - Coal/crop residues - Coal/animal waste - Coal/municipal waste - Coal/industrial waste	-	-	- Fixed bed gasifier: counter-current, co-current, cross draft - Fluidised bed gasifier: bubbling, circulating, dual - Entrained flow gasifier	- Syngas for power production in gas engines, turbines or fuel cells - Syngas for further processing to liquid fuels: Gasoline, diesel, jetfuel	- Life-cycle assessment - Economic, technical, environmental and socio-economic analysis - Gasifier design and construct
		- Pyrolysis	- Bio-oil	- Waste tyres - Industrial waste - Plastic waste - Green waste - Sewage sludge - Waste wood - Woody weeds - Agricultural waste - Animal waste - Municipal solid waste	-	- Slow pyrolysis - Fast pyrolysis - Vacuum pyrolysis	- Fluidised bed: circulating, bubbling - Ablative - Rotating cone - Vacuum	- Bio-oil for heat production in industrial boilers - Bio-oil used as a substitute for diesel fuel in stationary engines - Bio-oil blends with standard diesel fuels or biodiesel fuel - Bio-oil as feedstock for synthesis gas production	- Life-cycle assessment - Economic, technical, environmental and socio-economic analysis - Gasifier design and construct
UKZN	Prof. Trois	- Anaerobic digestion	- Biogas	- Animal waste - Food waste	-	-	-	-	-
UKZN	Prof. Schmidt	- Anaerobic digestion	- Biogas	- Organic biomass	-	-	-	-	- System upscaling
UKZN	Dr. Everson	- Anaerobic digestion	- Biogas	- Animal waste - Food waste - Wastewater	- Physical treatment: Mechanical (hand mixing)	- Wet fermentation	- One-phase digestion system	- Upgrade biogas to natural gas grade for use as a natural gas substitute	- Environmental and socio-economic analysis
UL	Dr. la Grange	- Fermentation	- Bioethanol	- Agricultural waste - Crop residues - Organic MSW	- Physical treatment: Mechanical comminution - Chemical treatment	- Enzyme hydrolysis - Separate and simultaneous hydrolysis	-	-	-
UNISA	Prof. Hildebrandt	- Anaerobic digestion	- Biogas	- Abattoir waste - Animal waste	- Physical treatment: Mechanical	- Wet fermentation	- Dry batch reactors	- Biogas converted to electricity and heat	- Life-cycle assessment - Economic and technical

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				- Crop residues - Food waste - Industrial waste - Municipal solid waste - Sewage sludge - Wastewater				in cogeneration units (CHP) - Upgrade biogas to natural gas grade for use as a natural gas substitute	analysis - Reactor design and construct
		- Thermal gasification	- Syngas	- Waste wood - Plastic waste - Municipal solid waste - Refuse-derived fuel - Agricultural waste - Sewage sludge - Crop residues - Waste tyres	-	-	- Fixed bed gasifier: Counter-current, co-current	- Syngas for heat production - Syngas for power production in gas engines, turbines or fuel cells - Syngas for further processing to liquid fuels or chemical: gasoline, diesel, synthetic natural gas, high value chemicals	- Life-cycle assessment - Economic, technical, environmental and socio-economic analysis - Gasifier design and construct
		- Plasma arc gasification	- Syngas	- Municipal solid waste - Biomedical waste - Waste tyres - Agricultural waste - Wood waste	-	-	-	- Syngas for heat production - Syngas for power production in gas engines, turbines or fuel cells - Syngas for further processing to liquid fuels or chemical: gasoline, diesel, synthetic natural gas, high value chemicals	- Life-cycle assessment - Economic, technical, environmental and socio-economic analysis
		- Pyrolysis	- Bio-oil - Biochar	- Waste wood	-	- Slow pyrolysis	-	- Bio-oil for heat production in industrial boilers	- Technical analysis
		- Transesterification	- Biodiesel	- Waste cooking oil - Animal fat - Waste processing grease - Butter factory	-	- Acid-catalysed	-	-	- Life-cycle assessment - Economic, technical analysis - Reactor design and construct

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				effluent					
UNISA	Dr. Myer	-	-	- Animal waste - Food waste	-	-	-	-	-
UNISA	Prof. Enweremadu	- Transesterification	- Biodiesel	- Waste cooking oil - Animal fat - Waste processing grease	-	- Alkali-catalysed - Acid-catalysed - Two-step method: acid-catalysed esterification-transesterification, Acid-catalysed esterification followed by alkali-catalysed transesterification	-	-	- Reactor design and construct - Engine performance and emission characteristics
		- Briquetting	- Solid fuel	- Agricultural waste	-	-	-	-	-
UniVen	Dr. Tinarwo	-	-	- Abattoir waste - Animal waste - Crop residues - Food waste - Industrial waste - Municipal solid waste - Plant waste and by-products - Sewage sludge - Wastewater	- Physical treatment: Mechanical - Chemical treatment: Alkali	- Wet fermentation - Mesophilic conditions	- Continuously stirred tank reactors - Dry continuous reactors: Vertical	- Upgrade biogas to natural gas grade for use in fuel cell technology	- Life-cycle analysis - Economic, technical, environmental and socio-economic analysis - Reactor design and construct
Wits	Prof. Gray	- Dark fermentation	- Biohydrogen	- Sucrose as synthetic wastewater organic material	-	-	-	-	- Reactor design
Wits	Prof. Iyuke	- Anaerobic digestion	- Biogas - Biohydrogen	- Industrial waste - Municipal solid waste - Wastewater	- Physical treatment: Ultrasonic	- Wet fermentation - Mesophilic conditions - Thermophilic conditions	- Dry batch reactors - High-rate reactors: Anaerobic packed-bed	-	- Economic and technical analysis
		- Fermentation	- Bioethanol	-	- Chemical treatment: ionic liquid	-	-	-	- Economic, technical, environmental, socio-economic analysis - Reactor design and construct

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		- Direct biophotolysis	- Biohydrogen	-	-	-	-	- Biohydrogen purification and use in fuel cells	- Reactor design and construct
		- Thermal gasification	- Syngas	- Waste wood - Waste tyres	-	-	- Fixed bed gasifier	- Syngas for further processing to liquid fuels or chemical: gasoline, diesel, hydrogen	- Economic and technical analysis
		- Plasma arc gasification	- Syngas	- Municipal solid waste - Biomedical waste - Waste tyres	-	-	-	- Syngas for further processing to liquid fuels or chemical: gasoline, diesel	- Economic, technical and environmental analysis
		- Pyrolysis	- Bio-oil	- Waste tyres - Industrial waste	-	- Slow pyrolysis - Fast pyrolysis	-	- Bio-oil used as a substitute for diesel fuel in stationary engines - Bio-oil blends with standard diesel fuels or biodiesel fuel - Bio-oil as feedstock for synthesis gas production	- Economic, technical and environmental analysis
		- Thermal depolymerisation	- Light crude oil processed into diesel fuel and gasoline	- Waste tyres	-	-	-	- Light crude oil processed into diesel fuel and gasoline - Light crude oil used as petrochemical feedstock	-
		- Transesterification	- Biodiesel	- Waste cooking oil - Animal fat	-	- Alkali-catalysed - Acid-catalysed - Two-step: Alkali-catalysed saponification-transesterification, Acid-catalysed esterification-transesterification, Acid-catalysed esterification followed by alkali-	-	-	- Economic, technical, environmental and socio-economic analysis - Reactor design and construct

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						followed by alkali-catalysed transesterfication			
ARC	Mr. Britz	- Anaerobic digestion	- Biogas	- Animal waste	-	- Wet fermentation system - Mesophilic conditions - Thermophilic conditions	- Continuously stirred tank reactors: Single-step system	- Biogas converted to electricity and heat in cogeneration units (CHP) - Upgrade biogas to natural gas grade for use as a natural gas substitute	- Technical and socio-economic analysis
CSIR	Ms. Jooste	- Anaerobic digestion	- Biogas	- Abattoir waste - Animal waste - Sewage sludge - Wastewater	- Physical treatment: Thermal - Biological treatment: Enzymatic	- Wet fermentation system - Mesophilic conditions	- Continuously stirred tank reactor: Single- and two-step system	- Converted to electricity and heat in cogeneration units (CHP)	- Economic, technical, environmental and socio-economic analysis - Reactor design and contruct
Eskom	Mrs. Bhugwandin	- Co-combustion	- Electricity	- Coal/wood waste	-	-	-	-	- Fuel sourcing studies - Evaluation of co-firing options - Co-firing concept designs - Torrefaction technology evaluation - Torrefaction co-firing plant impact studies - Assessment of energy potential from different organic waste streams - Resource verification for renewable energy from municipal solid waste
EnviroServ	Ms. Sarah Edwards	- Anaerobic digestion	- Biogas	- Abattoir waste - Slurry - Food waste	-	-	-	-	-