Technology Transfer and Absorptive Capacity: Case Study of the PEEPOWER Technology

A thesis submitted for the degree of Doctor of Philosophy

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Abstract:

A technology is more than the hardware or system used to deliver a service. In its broad sense, it also encompasses skills, knowledge and expertise on how the technology works and how to manufacture and operate it. Literature on technology transfer have emphasised the essential role of knowledge sharing and capacity building for technology transfer effectiveness. Although this is widely agreed upon and discussed across literature, there seems to be a gap in practice. In the case of international Technology Transfer, transfer agreements often focus on the successful procurement or installation of technology. The Technology Recipients must rely on Technology Providers for ongoing maintenance and repair. In the case of the PEEPOWER, as an innovative technology developed in the UK and transferred internationally for implementation, there are further challenges in ensuring the transfer process is effective, such as obtaining timely support from Technology Transfer Offices to ensure IP protection and legal coverage.

The current research aims to investigate enabling factors for the effective transfer of the PEEPOWER with a closer look at Absorptive Capacity. Conceptual frameworks are developed and used to inform empirical research. A chronological timeline showing the evolution of the concept of Absorptive Capacity is also presented. The case study of the PEEPOWER technology is used to consolidate theory with practice, using a qualitative approach to collect and analyse data. Empirical data obtained from interviews and participant observations are used to gain insight into the level of effectiveness of the PEEPOWER transfer to Kisoro, Nairobi and Durban and the extent of knowledge sharing. These empirical findings are illustrated in the proposed framework for assessing technology transfer effectiveness. The PEEPOWER technology is also presented on a novel '*techberg*' model, showing all technology elements beyond the hardware.

Key recommendations from empirical findings are implemented as part of the Action Research process: (1) Establishing a partnership with institutions at national and international levels for the development of user-friendly, educational MFC resources for schools; (2) Leading the design and development of an innovative MFC educational toy; (3) Leading strategic changes to enable independent maintenance and repair by the Technology Recipient and (4) Developing a Monitoring, Evaluation and Learning (MEAL) questionnaire for future projects.

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Acronyms and Abbreviation:

AC: Absorptive Capacity

BBiC: Bristol BioEnergy Centre

DETI: Digital Engineering Technology and Innovation

FDI: Foreign Direct Investment

MFC: Microbial Fuel Cell

MEAL: Monitoring, Learning and Evaluation

P&P: Prototype and Play

R&D: Research and Development

SME: Small and Medium Enterprise

SPV: Solar Photovoltaic

STEM: Science, Technology, Engineering and Mathematics

Tech: Technology

TR: Technology Recipient

TP: Technology Provider

TT: Technology Transfer

UKZN: University of Kwazulu Natal

UWE: University of the West of England

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Preamble:

I dedicate this thesis to my grandma, Mbopuwouo Mariama, the village of Foumban and the Thandanani community, whom I had the pleasure to meet in Durban. *Yii paa yengain.*

My thanks and gratitude go to my supervisory team –Dr Basil Omar for his coaching and mentoring, Prof Ioannis Ieropoulos for welcoming me fully into his research centre, Dr Lisa Brodie for her support during my most challenging PhD years, Prof Mohammed Saad for his guidance and advice and finally Dr Jonathan Winfield for helping me cross the finish line.

I thank my family and friends for their support and help while I had to juggle childcare, work and studies.

The completion of this PhD would not have been possible without the blessing of my Creator Almighty Allah, the Sustainer, the Helper, the One able to do all things. Praise and thanks be to Him.

« Et au-dessus de tout Homme détenant la science,
il y'a un savant plus docte que lui »
Al Mulk : 15

CHAPTER 1: INTRODUCTION

1.1 Research context, aim and objectives:

Nine hundred and forty million people have no access to electricity globally, two-thirds of whom live in sub-Saharan Africa (Ritchie & Roser, 2019). Rural areas are the most affected by the lack of energy access, whilst power supply in urban areas is erratic, with frequent and abrupt power cuts (Ritchie & Roser, 2019; Sanchez, 2010). Today more than ever, the need for efficient renewable energy technologies has become vital to addressing some of the global challenges in the energy sector. The PEEPOWER, developed by the Bristol Bioenergy Centre (BBiC), is a novel technology which uses microbial fuel cells (MFC) that feed on urine to generate a small amount of electricity (Santoro et al., 2020). So far, the primary application of microbial fuel cells (MFC) has been for wastewater treatment and bio-sensors (Singh & Yakhmi, 2014). The PEEPOWER is the first MFC system of its kind to have been trialled for in situ electricity generation in large-scale, real-world settings such as remote villages, urban settlements and festival sites (Ieropoulos et al., 2016; Seelam et al., 2018; Santoro et al., 2020). As an innovative technology developed in the UK and transferred internationally for implementation in Africa, there are associated challenges in ensuring the transfer process is effective.

Literature on technology transfer have emphasised the essential role of knowledge sharing and capacity building in technology transfer effectiveness. Although this is widely agreed upon and discussed across literature, there is seen to be a gap in practice. Especially, in the case of international Technology Transfer, with transfer agreements often focussing on the successful procurement or installation of technology. This results in Technology Recipients having to rely on Technology Providers for ongoing maintenance and repair. Such a challenge is amplified by the need for companies to protect their know-how and IP.

The current research thus seeks to answer the following question: *"How can adequate knowledge transfer be facilitated to ensure effective technology transfer?"* The aim is to investigate enabling factors for the effective transfer of the PEEPOWER with a closer look at Absorptive Capacity. The following research objectives will be thus addressed:

1) To define key theoretical concepts: Technology, Technology Transfer, Effective Technology Transfer and Absorptive Capacity.
2) To investigate Technology Transfer channels used for energy technologies in Africa and identify the main enabling factors required for effective transfer.
3) To investigate the role of capacity building as an enabler of technology transfer.
4) To propose recommendations for effective technology transfer and capacity building based on the case study of the PEEPOWER technology.
5) And finally, to implement key recommendations from the PEEPOWER case study and reflect on the outcome.

1.2 Terms and scope of the research:

The research begins with a baseline understanding of the main theoretical concepts surrounding the topic of technology transfer and knowledge sharing:

Technology: A comprehensive definition of the construct of "technology" is presented, going beyond the description of an artificially created product or process that solves a problem (Morris, 2014), to include associated skills, knowledge and expertise (Li-Hua, 2007).

Technology Transfer (TT): Cleveland and Morris (2014) build on the holistic understanding of the concept of technology and define Technology Transfer as the movement of goods, knowledge, techniques and capital amongst parties. There are typically three main actors in this process: The Technology Provider, the Technology Recipient and the Technology Transfer Offices (Lopez and Maurico, 2018). PEEPOWER is an innovative technology transferred from the UK for trials in South Africa, Kenya and Uganda, so the current research will focus on international technology transfer (particularly within the African context) whilst adding some discussions on the vertical transfer from R&D to market. The concept of ***diffusion of innovation*** is also briefly discussed in the current research.

Effective Technology Transfer: Bozeman's (2000) conceptual framework for defining effective technology transfer is used, which has been applied by researchers in various industries (Gunsel et al., 2019; Borge and Broring, 2017; Qiu et al., 2017, cited by Gunsel et. al; Hafeez et. al, 2020; Barros et al., 2020). The model is based on five dimensions: who is doing the transfer, how the transfer is done, what is being transferred, factors that influence the transfer and to whom the technology is transferred. The way these dimensions interact then determines how effective a Technology Transfer process is. According to Bozeman et al. (2016) this effectiveness can be gauged by seven criteria: (1) the reception of technology by the transferee, (2) the commercial impact of the technology transfer, (3) the impact on the broader regional or national economy, (4) the impact on scientific and human capital, (5) the effect of technology transfer on enhancing public values, (6) resulting political benefits, and (7) other opportunity costs resulting from the technology transfer activities. A lack of research assessing Technology Transfer effectiveness with a real focus on Scientific and Human Capital is highlighted by Bozeman et al. (2016). The current study adds value by focusing on knowledge sharing during Technology Transfer whilst also touching on public values and public engagement during Technology Transfer. It is beyond the scope of this work to propose metrics to measure the effectiveness of a Technology Transfer.

Absorptive Capacity (AC): Cohen and Levinthal (1990) define Absorptive Capacity as a firm's ability to value, assimilate and exploit external knowledge that is fundamental to its innovative capacities. At national level, Mowery and Oxley (1995) defined a country's absorptive capacity as relating to the broad range of skills required to exploit the tacit or implicit components of a transferred technology and the ability to modify imported technologies to fit the domestic context. This definition is further reinforced in other reports that highlight the importance of developing skilled human capital and investing in R&D at national level (Kim & Dahlman, 1992; Keller, 1996; Liu & White, 1997; Luo, 1997; Veuglers, 1997; Glass & Saggi, 1998; cited by Zahra & George, 2002; Kim, 1998). It thus helps to understand how acquisition and assimilation of knowledge are crucial for the success of technology transfer. The concepts of ***Knowledge transfer*** and ***capacity building*** are, therefore, other key terms explored in this research.

1.3 Research strategy:

The ***relativist*** ontology is adopted in the research, considering the subjective nature of reality according to different contexts and the variety of perspectives on what truth constitutes (Easterby-Smith et al., 2015). Defining reality in such a way affects what the researcher sees as grounds for knowledge and the assumptions made when attaining and validating knowledge. The epistemological best suited to the research was thus ***interpretivist*** or ***constructivist***. It considers the intricate, nuanced and complex nature of technology and knowledge transfer challenges. A purely ***qualitative*** methodology was chosen for the research to have: (1) a greater focus on meanings (beyond facts), (2) a better understanding of events happening (as opposed to stressing on causality and fundamental laws), and (3) the opportunity to explore small samples in-depth, instead of getting generalised views from large samples (O'Gorman and MacIntosh, 2015). The research uses the PEEPOWER technology as an illustrative case study to help validate theoretical findings and further explore challenges around international technology transfer. Beyond the investigation of challenges around the PEEPOWER technology transfer, the research also emphasises the implementation of key actions from theoretical and empirical findings. This research strategy is known as ***action case study***, ***action-based case study*** or ***action-research case study*** (Halecker, 2015; McManners, 2016; Ramly & Mohd, 2018). An overview of the methodological framework summarising the overall research design and the steps followed in the action-research is shown in figure 1.1. The framework is developed by adapting models developed by Eisenhardt (1989), Maimbo & Pervan (2005) and Ramly & Mohd (2018) for case study and action case study research designs. The case being studied consolidates lessons learnt from the PEEPOWER field trials over five years (2015-2020) in three different locations: Kisoro (Uganda), Nairobi (Kenya) and Durban (South Africa). A qualitative action research methodology involves semi-structured interviews of employees and participant observations through close collaboration with the technology developer for 15 months. Thematic analysis is carried out on collected data using Computer Assisted Qualitative Data Analysis (CADQAS).

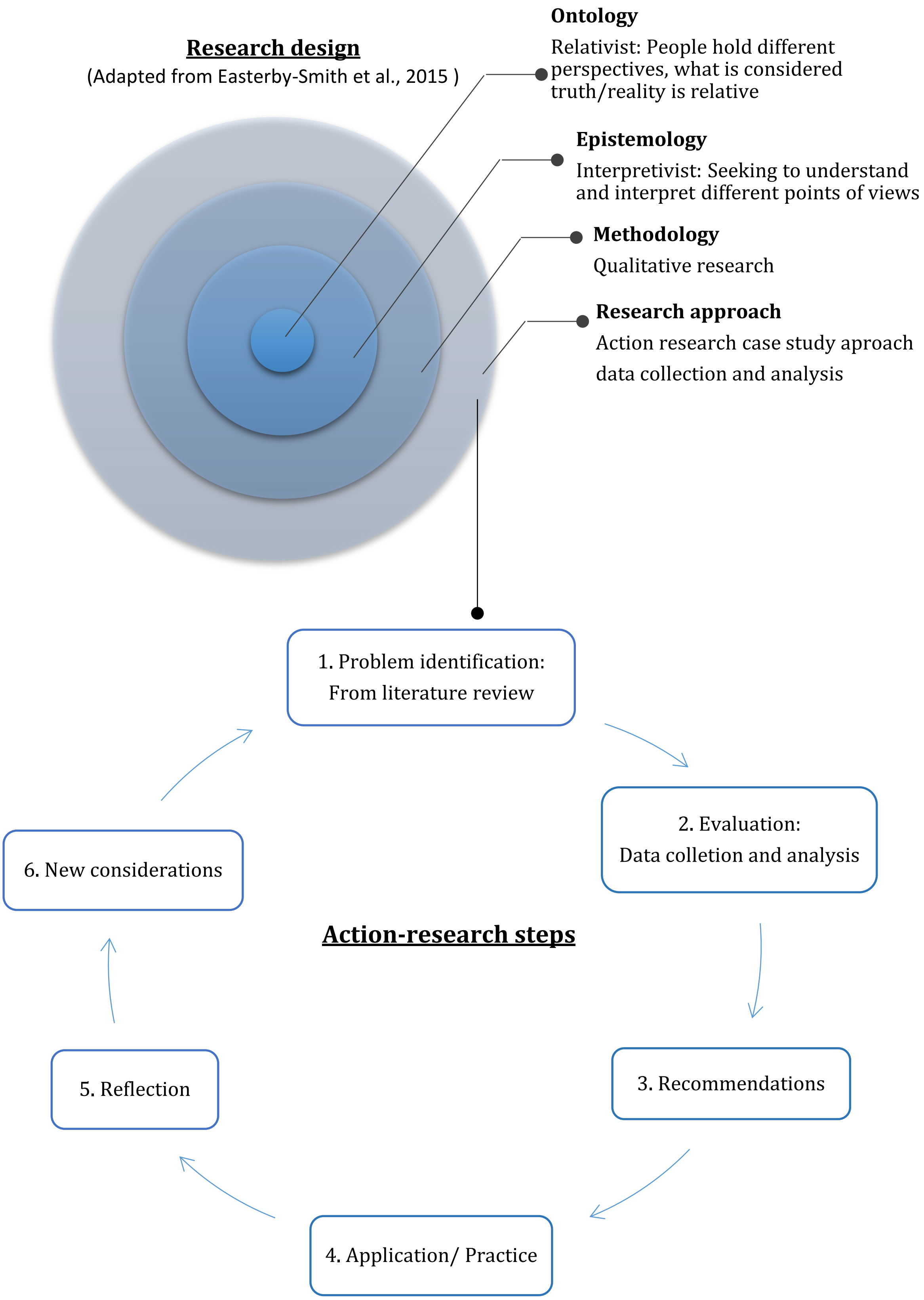


Figure 3.1: Methodological framework summarising the research

1.4 Research contributions and main findings:

The main findings and contributions of the research can be summarised as follows:

Development of conceptual/theoretical frameworks:

- '*Techberg*'
- Explanation of Technology Transfer mechanisms using examples of real applications in the context of energy technologies in Africa
- Absorptive Capacity timeline
- Conceptual map for effective Technology Transfer and Absorptive Capacity

Qualitative evaluation of field trials:

- Identifying the main enabling factors for effective transfer of the PEEPOWER
- Providing BBiC with an insight into their strengths, challenges to anticipate and key success factors for future trials
- Proposing a template evaluation questionnaire for Tech Transfer partners in similar contexts

Successful implementation of highly resourceful and challenging actions spanning multiple disciplines:

The most impactful contribution of this research has to be the successful implementation of key recommendations from the PEEPOWER case study.

Actions taken were transdisciplinary, requiring the researcher to develop strong management, negotiation and leadership skills.

Key actions taken were led and followed closely by the researcher till completion.

- Action 1: Establishing partnerships with institutions at national and international levels for the development of user-friendly, educational MFC resources for schools
    - DETI – School packs for teachers and STEM clubs
    - Siemens Stiftung –MFC website promoted in schools in Africa and Latin America
- Action 2: Leading the design and development of an innovative MFC educational toy
    - Design sprint facilitation (staff, masters students, intern)
    - Funding application
    - IP
- Action 3: Leading strategic changes to enable independent maintenance and repair by the Tech Recipient
    - Development of the PEEPOWER maintenance and repair manual
    - Establishing partnership with Renewable World to support the maintenance of the system in Nairobi
- Action 4: Developing a Monitoring, Evaluation and Learning (MEAL) questionnaire for future projects

Journal paper publication

Paper submitted in the International Journal of Technology Management and Sustainable Development" (See Appendix 10).

Wider impacts of actions taken

- Actions 1 and 2 have a direct impact on innovation diffusion, tech acceptance, nation's Absorptive Capacity by enhancing STEM teaching and MFC learning in schools
- PhD studentship
- Establishing partnerships between BBiC and external organisations such as Renewable World and Siemens Stiftung
- MFC toy ready for commercialisation

1.5 Thesis layout:

The thesis comprises five main chapters; **Chapter 1** and **Chapter 2**, the Introduction and Conclusion sections.

Chapter 2 (Literature Review) expands on the work of Bozeman (2016) on technology transfer effectiveness. It presents an in-depth definition of the construct of technology, with the notion of '*techberg'* being introduced. Drawing relevance on international Tech Transfer mechanisms within the energy sector in Africa, enabling factors for effective Tech Transfer are discussed. A timeline representation of the evolution of research on Absorptive Capacity is presented. The chapter is concluded with a theoretical framework for mapping effective Tech Transfer against Absorptive Capacity.

Chapter 3 (Research Methodology) outlines the overall approach of the current research, starting from the underpinning philosophical paradigm to the main data collection and analysis strategies used to address the research objective 4. A justification of each chosen method and a critical comparison with alternative options are provided.

Chapter 4 (Results and Discussion) presents a critical appraisal of empirical findings from the PEEPOWER case study, followed by the main actions implemented in the research. The chapter adds value to the body of knowledge by presenting the PEEPOWER technology on a '*techberg', w*hich eases the understanding of what to transfer in addition to the physical hardware. It also presents the main enabling and inhibiting factors for the effective transfer of the PEEPOWER. This provides the Tech Providing team (BBiC) with insights into their strengths and challenges to anticipate in future field trials. Conceptual frameworks are used to assess the effectiveness of the PEEPOWER's Tech Transfer, based on knowledge and skill transfer and levels of Absorptive Capacity. Finally, a template Monitoring, Evaluation & Learning questionnaire applicable to Tech Transfer projects is proposed.

CHAPTER 2: LITERATURE REVIEW

Links to research objectives:

This literature review expands on the work of Bozeman (2016) on technology transfer effectiveness; starting with an in depth definition of the construct of technology. It is then complemented by a thorough review of literatures on absorptive capacity.

This chapter addresses research **objectives 1, 2 and 3.**

Chapter highlights:

This chapter adds value to the body of knowledge by:

- Introducing the notion of '*techberg*' to illustrate the comprehensive nature of the construct of technology
- Drawing relevance from Tech Transfer mechanism used in the context of the energy sector in Africa, to discuss enabling factors for international Tech Transfer
- Developing a timeline representation of the evolution of research on the topic of Absorptive Capacity
- Developing a conceptual framework for mapping effective Tech Transfer against

2.1 Understanding Technology Transfer:

2.1.1 Conceptual definition of technology and Technology Transfer:

The term "technology" has been used to describe an artificially created product or process (Morris, 2014) that solves a problem. However, in the complete sense of the term, it goes beyond just the hardware to include associated skills, knowledge and expertise (Li-Hua, 2007). Saad (2000) refers to these main elements as 'software' or know-why, 'brainware' (or know-what and know-why) and 'support net' needed to use and manage the technology effectively. Earlier definitions of technology have described it more as a set of information: "*information of both technical and commercial character*" (Li-Hua, 2009), "*a bundle of information, right and services*" (Contractor and Sagafi-Nejad, 1981), "f*irm-specific information concerning (…) production processes and product design*" (Dean and LeMaster, 1995), or "*information necessary to achieve a certain production outcome*" (Maskus, 2004). Other literature has offered different perspectives on the definition of technology; an artificial, human-made product that uses scientific knowledge to solve a defined problem (Hawthorne, 1971, Pacey, 1983, Goulet, 1989; cited by Wahab et al., 2012). Karatsu (1990) refers to technology as "*human understanding of natural laws (…) to make things that perform certain functions*", and Miles (1995) defines it as "*a means by which we apply our understanding of the natural world to solutions of practical problems".* A broad definition of technology is provided by Burgelman et al. (2008) as the *"theoretical and practical knowledge, skills and artefacts used to develop products and services".* It presents the concept of technology as intricately linked with knowledge, and this is supported by several literature reports (Teece, 1976, Sahal 1981, 1982, Hawkins and Gladwin, 1981, Natarajan and Tan, 1992, Levin, 1996, cited by Wahab et al., 2012; Bozeman, 2000; Tihanyi and Roath, 2002; Maskus, 2004; Ajibo et al., 2019). As summarised by Li-Hua (2007), technology is "*the product itself, and the knowledge, technique and organisation by which it is produced*". As such, a Tech Transfer process is incomplete without the transfer of knowledge and skills relating to how the technology works, how to make it, and how to organise and manage its production, distribution or sale. Further work has gone into constructing taxonomies to help classify knowledge and skills associated with the concept of technology (Madeuf, 1984, Robock, 1990, Chudson, 1971, cited by Wahab et al., 2012; Mansfield, 1975; Hall and Johnson, 1970, cited by Reddy and Zhoa, 1990; Bell, 1984). First, there is technical knowledge that comes in material forms, such as manuals, blueprints and books, or as embedded R&D knowledge within the product itself (Bell, 1984; Inkpen and Dinue, 1998). Then there is tacit technical knowledge that comes as embodied within skilled personnel. Madeuf (1984) and Hall and Johnson (1970) referred to this tacit knowledge as 'human embodied' or 'person embodied' technology. Non-technical knowledge and soft skills needed for the use, production, and sale of the technology have also been included in the concept of technology (Saad, 2000; Li-Hua, 2007; Wahab et al., 2012). Figure 2.1 illustrates the concept of technology based on this review, where the product, system or artefact only constitutes the tip of the iceberg. Whilst underneath what can be called the *"techberg"* are associated knowledge and skills that form an even more important part of the technology.

Technology transfer refers to the movement of technology along its lifecycle stages or across geographical boundaries, sectors, or firms. Mansfield (1982) distinguishes the former as vertical Tech Transfer, which may go "*from basic research to applied research, then development and finally, production"*, or from market to R&D – frugal innovation (Weyrauch and Herstatt, 2017). The rest is then classified as horizontal technology transfer. Horizontal Tech Transfer takes place from one place, organisation or sector to another. This includes international Tech Transfer across national borders, regional Tech Transfer, inter-firm Tech Transfer, intra-firm Tech Transfer, cross-sector Tech Transfer or a combination of the above (Mansfield, 1982; Ramanathan, 2008; Ajibo et al., 2019). Cleveland and Morris (2014) build on the holistic understanding of the concept of technology and define technology transfer as the movement of goods, knowledge, techniques and capital amongst parties. The main actors in this process include the Technology Provider, the Technology Recipient, Technology Transfer Offices and the end users (Lopez and Maurico, 2018). Odekon (2015) also note that the Tech Transfer process has to encompass the transfer of capacity and knowledge associated with the technological product, which goes *"beyond the mere sale or lease of goods"* (UNCTAD, 2012).

Several systematic reviews of the literature have been carried out on the wider subject of Tech Transfer (Bozeman, 2000; Wahab et al., 2012; Lopez and Mauricio, 2018, Resiman, 2004) and the main areas explored include conceptual definitions, models and mechanisms of technology transfer and influencing factors. An overview of the main technology transfer categories or models found in the literature is presented in figure 2.2. The PEEPOWER technology being investigated in this study is a newly developed technology from the UK that has been transferred for trials in schools and settlements in South Africa, Kenya and Uganda. The subsequent section will therefore focus on international technology transfer and its mechanisms, particularly within the African context. Added challenges of dealing with an innovative technology being transferred from R&D to market, are also included in the discussion.

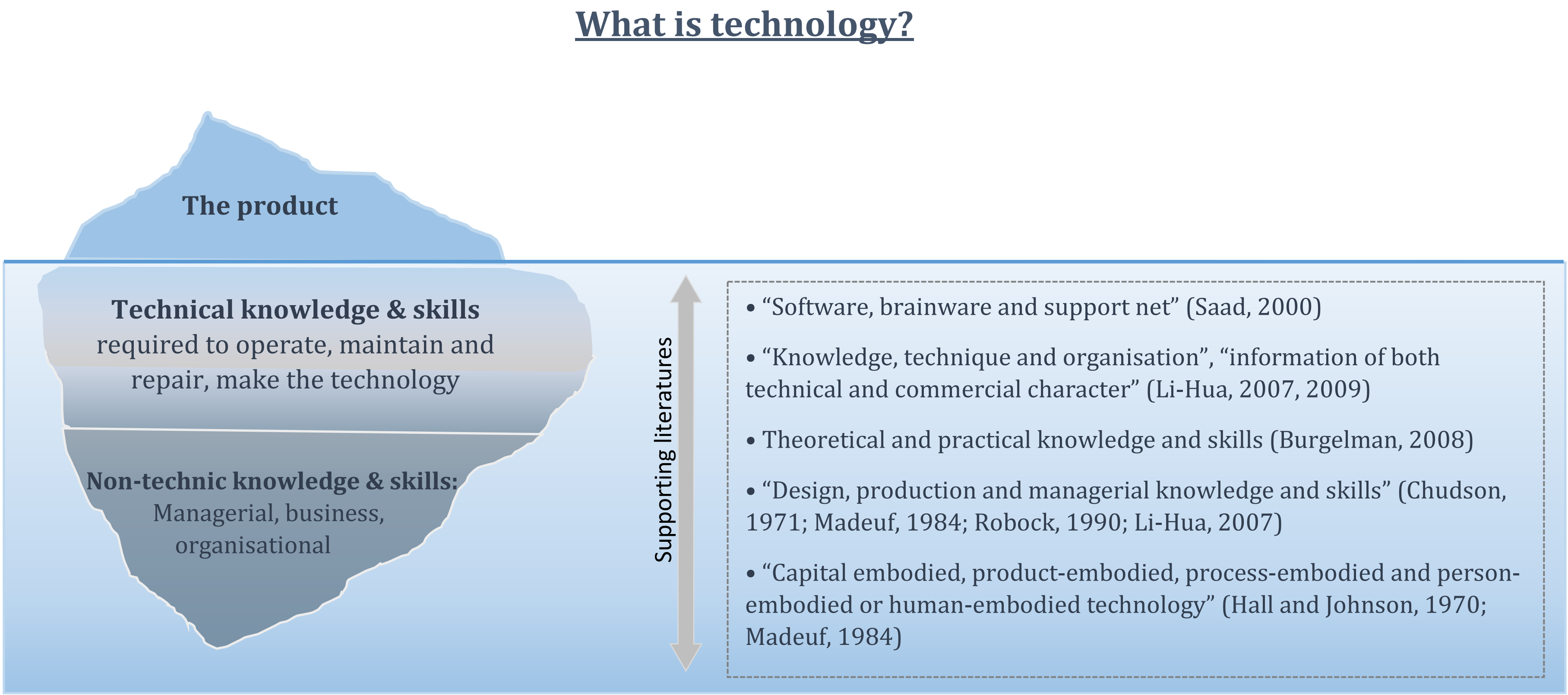


Figure 4.1: A *"techberg"* –Illustration of the concept of technology based on literature review. *Source: Author*

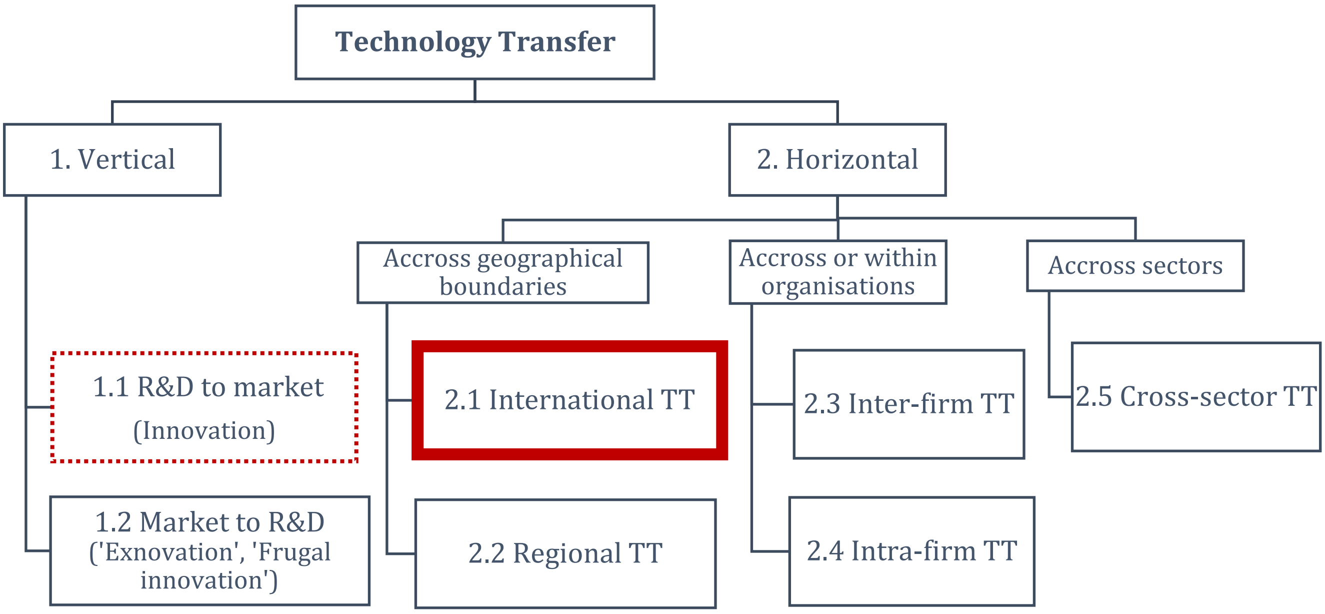


Figure 2.2: Overview of main Technology Transfer models, with highlighted boxes showing areas of focus of the current research. *Source: Author*

2.1.2 Critical review of international technology transfer mechanisms in the context of energy access in Africa:

This review is complemented with illustrative examples from various energy technologies transferred into Africa and a discussion of challenges faced.

a. Trade:

Trade is a common channel of transferring energy technologies. The energy technology market in Africa commonly comprises small-scale decentralised energy technologies imported from China, Europe and America and large-scale power plants. However, existing trade barriers in the continent raise the cost of technologies. The African Continental Free Trade Area (CFTA)[1] has reported on measures put in place to enable trade openness, such as reducing tariffs on products, liberalising services and tackling non-tariff barriers (The Economist, 2018). There is a level of embedded R&D that comes with traded capital goods. Such embodied R&D can contribute to the technological growth of an economy and its productivity (Coe, Helpman, and Hoffmaister, 1997). Studies have shown that economies that are more open to trade experience faster growth (Hardison, 2015). Hoekman *et al*. (2005) explain that openness to trade increases economic growth by facilitating technology adoption. However, whether trade openness automatically guarantees technology adoption remains an open question.

[1] Trade agreement signed on the 21st March 2018 between African countries, enabling individual countries to sell their energy produced locally and to neighbouring countries. (Luke, 2018)

Hoppe (2005) highlights two further important contributing factors; the absorptive capacity of a nation and the contextual differences in the environment of trading parties. Schiff et al. (2002) also see the level of absorptive capacity of the receiving country as an essential factor, as well as the country's ability to adapt to imported technologies.

However, the challenge with trade as a technology transfer mechanism is that it is, arguably first and foremost, a means of equipment acquisition. It mainly facilitates the transfer of the physical product (and embedded R&D), not the associated managerial and technical competencies. Nonetheless, energy technologies such as Pico Solar PV have had an uptake in the African market, particularly in Kenya (see figure 2.3). Orlandi *et al*. (2016) discuss some of the main strategies used to facilitate the transfer of pico solar PV in Kenya:

- The first one relates to market catalysts that helped raise awareness about the technology and build users' trust, such as consumer-education campaigns, business-to-business support services, product-quality assurance, marketing support, financial de-risking through loan guarantees, foreign-exchange and facilities.
- Then there needed to be transparent quality verification and service standards to avoid false advertisement claims and improve complaint-response times.
- And lastly, the protection of Intellectual Property rights had to be ensured through smart business strategies and government policies that prevent counterfeits and enable entrepreneurs to gain returns on investment.

These measures mostly work in the early stages of the technology transfer from R&D to market due to changing customer profiles as the market evolves. They are critical at that stage, as a negative first-hand experience of consumers can make it much harder to re-catalyse the market. However, they can take several years of effort and require heavy investments.

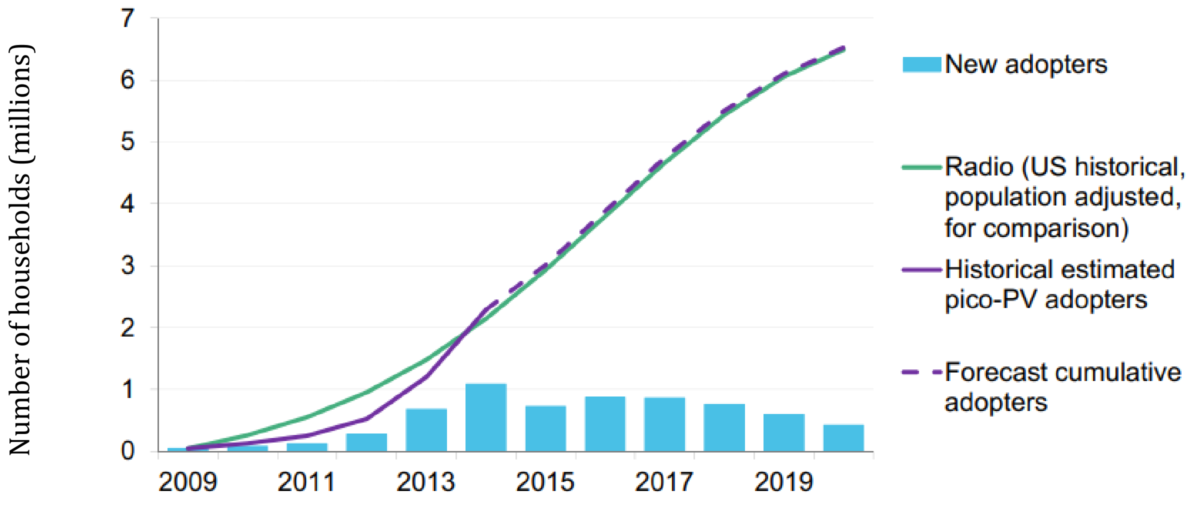


Figure 2.3: Off-grid solar adoption in Kenya by million households (Orlandi et. al, 2016)

b. License and franchise agreements:

Technologies protected by Intellectual Property (IP) must be licensed to be used in the receiving country. The TR uses the IP whilst paying an agreed fee or in exchange for an asset (WIPO, 2004). IP can come in the form of patents, copyright, know-how, trade secrets, trademarks or any other intangible asset owned by the technology developer or licensor. According to the World Intellectual Property Organisation (WIPO), a license agreement may be ratified for a specific IP right (i.e. pure IP license); for all IP rights necessary to complete reproduction and sale of the technology (i.e. product license); or all IP rights needed for a technology to meet specific technical standards (i.e. standard license). Obtaining a license agreement can be costly, often takes a long time and provides restricted scope for knowledge transfer (Saad, 2000).

Owners of technology IP often create a special purpose vehicle (SPV) to act as intermediaries that issue the IP portfolio to the receiving country, based on agreed assets. The SPV facilitates the delivery of large-scale projects without putting the technology developer at financial risk (PwC, 2011). That was the case with the construction of the 155 MW Nzema Solar Power Station in Ghana, reported to be the largest solar power station in the continent (Blue Energy, 2015). Mere Power Nzema Ltd acted as an SPV subsidiary of Blue Energy Plc from the UK to construct the plant. It received a generation and distribution license for the plant's operational life, with a guaranteed feed-in tariff.

Technologies can also be licensed by franchising to account for trademarks, business methods, marketing systems and distribution processes. In a franchise agreement, a strategic alliance is set between multiple parties who use the technology developer or franchisor's brand name, business systems and ongoing support in exchange for a royalty (Gappa, 2008). That often requires high capital investment and strong managerial and technical skills (Saad, 2000). Egg-energy is an example of a franchise group providing rent-to-own solar systems to off-grid households in Tanzania (Egg-energy, 2014). The company's scope includes installation and maintenance, consumer financing and sales and marketing, which are all shared in the franchise network.

c. Subcontracting:

It is common in energy projects to delegate production and subassemblies of specific technologies to sub-contracting companies. Sub-contracting takes various forms depending on the emphasis of the agreement between the sub-contractor and the principal. As such, outsourcing, offshoring, externalisation, delocalisation, and partnering are forms of sub-contracting agreements (Martini, 2015).

China, as a leading solar panel manufacturing country (EnergySage, 2018), is a primary technology supplier in both small-scale and large-scale solar energy projects in Africa. Examples include Chinese corporation group NARI, which sub-contracted in the energy project Akon Lighting Africa to supply solar power equipment across its 15 operating countries (Akon Lighting Africa, 2015), and Chinese company Yingli, manufacturing solar lights for SunnyMoney, a charity-owned social enterprise providing low-cost lighting in Southern Africa (SolarAid, 2017).

While the subcontracting partnerships facilitate the acquisition of ready-made technology, it limits the degree of transfer to just the equipment (and the embedded R&D). It can create dependency on the technology developer for supply, maintenance and repair.

d. Turnkey agreements and support contracts:

Large-scale energy projects are often delivered using turnkey agreements. A contractor is subcontracted for the technology's design, manufacturing, and installation in the receiving country. Then they pass on the control of operation, distribution and sale of the system to a local company. The advantage of this agreement is that it facilitates the acquisition of complex technologies in a ready-made form, usually within a prompt timeframe. A current example is the turnkey engineering, procurement and construction contract between the Danish firm Vestas and the power generation company Lekela[2] in Senegal (Lekela, 2018). That agreement involved the building and commissioning of the 158 MW Taiba N'Diaye Wind Power Project within two years. Another example is the four-year 50MW Reppie Waste to Energy Facility project[3] (ESI Africa, 2018).

The quick delivery and relatively short term of turnkey contracts constitute part of the risk associated with this type of agreement since the contractor only has a temporary presence in the country (Jonnard, 1998). In cases where local capacities are not strong enough, various maintenance issues are often faced in the long run, such as frequent equipment breakdowns due to incorrect usage, long lead times of spare parts and lack of repair facilities (Saad, 2000). And as such, the host country often becomes over-reliant on the technology supplier for maintenance, repair and operation. Turnkey agreements have only proven to be successful in countries with a high level of absorptive capacity. It has been seen in the case of Japan and many other eastern Asia countries after the 1940s (Inkpen and Dinur, 1998).

Nonetheless, there are alternative agreements that provide enhanced platforms for knowledge and skill transfer. Turnkey agreements can also be set to include training and skill transfer as part of the agreement. Support contracts such as "product-in-hand" often have additional aspects that can facilitate a more comprehensive technology transfer. These comprise the provision of training in necessary technical and managerial skills, the offer of guarantees for continued maintenance of the technology and the adaptation of the project concept to the local context. Similar agreements were signed between Kenya and China for developing the Standard Gauge Railway project, including

[2] Lekela Power is a 60:40 joint venture between Actis and Mainstream Renewable Power to install 860 MW of wind energy and solar power infrastructure in South Africa, Egypt and Ghana.

[3] The project used technology from DP Cleantech and was developed by Cambridge Industries Ltd (CIL) and China National Electrical Engineering Corporation (CNEEC) as a turnkey project for Ethiopian Electric Power (EEP), with Ramboll of Denmark as Owners Engineer

a $US 239m railway electrification contract between Kenya Electrification Transmission Company (Ketraco) and China Electric Power Equipment and Technology (CET). The agreements involved the development of a 609km railway line between East Africa's largest port, Mombassa, and Kenya's capital city, Nairobi, as well as the electrification of the railway (Ketraco, 2018). Skill transfer platforms included scholarship programs to train Kenyan railway staff and engineering students at Chinese universities (Wissenbach and Wang, 2017).

e. Foreign Direct Investment:

The World Bank estimates an annual investment of around USD 50 billion for meeting energy needs in sub-Saharan Africa (Rosnes and Vennemo, 2009, cited by Gualberti et al., 2013). The three largest trade partners investing in the continent are the EU, China and the U.S., through various initiatives (such as the UN's Sustainable Energy for All, China-Africa Development Fund and Power Africa). A Foreign direct investment (FDI) is defined as an "*investment made by one company into another located in another country*" (Chen, 2020). It can bring an inflow of knowledge about new technologies, their production methods and organisational management skills into a country (Bodman and Le, 2013). However, as Osano and Koine (2016) pointed out, FDI can only be an effective channel of technology transfer if the receiving country has appropriate national innovation systems (NIS) that support the development of local absorptive capacities and provide a regulatory framework for intellectual property. An example of an energy programme funded by FDI is Eneo Cameroon, a public-private partnership between UK Group Actis and the Cameroonian Government[4], responsible for generating and distributing electricity in the country (Actis, 2017).

FDI presents several benefits to transnational corporations (TNC), notably the creation of a new market, the removal of export barriers and access to lower labour costs, low corporate taxes and raw materials (Gualberti et al., 2013, Lu, 2007, Antras, 2005, cited by Saadi, 2011; Reis, 2006). This mutually beneficial aspect of FDI is further elaborated in the macro-economic theory of FDI by Kojima and Ozawa as follows:

> *"Countries gain (…) when technology is transferred via FDI or licensing from the home countries' comparatively disadvantaged industries[5] to the host countries' comparatively advantaged ones. This transfer will improve the efficiency of comparatively advantaged industries in the host countries and contract comparatively disadvantaged industries in the home countries."*(Kojima and Ozawa, 1985)

Conversely, a range of published reports bring up challenging arguments, suggesting that FDI can deteriorate the receiving country's terms of trade[6] and welfare (Bhagwati, 1973; Bhagwati et al., 1978; Brecher & Diaz-Alejandro, 1977; Cardoso and Dornbusch,

[4] A joint venture partnering 51% Actis, 44% Cameroon government and 4% Eneo employees.
[5] Comparative advantage: ability to produce goods and services at a lower opportunity cost, not necessarily at a greater volume or quality
[6] Terms of trade: ratio of the country's export prices index to its import prices index.

1989; Helleiner 1989; Young and Miyagiwa, 1986 and Reis,2001, 2006). That is manifested in cases where there is a return of income and profit to investors, expatriation of technical and managerial employees to operate TNCs, as opposed to training local workforces, and the financial threat presented to local businesses (Saadi, 2011). Reis (2006) refers to this as a creative destruction that redistributes national assets to investors. Whilst FDI partners increasingly strive to involve and train local labour, some countries still impose limits on FDI for strategic reasons. Such as the case of Nigeria, putting in place policies to develop domestic capacity for producing goods and delivering services that would usually be imported; but also restricts FDI in their oil and gas sector (SDOIA, 2016), using turnkey agreements instead.

f. Foreign Aid:

The question of the actual benefit and cost of foreign aid has long been a subject of debate amongst economists and policy-makers. Benarroch and Gaisford (2001) group foreign aid into three main categories in the context of technology transfer: aid given in the form of transfer of funds, aid that directly targets technology transfer and foreign aid that indirectly promotes technology transfer.

With monetary aid donated to lower-income countries, Benarroch and Gaisford (2001), in their analysis of the effect of foreign aid on technology transfer, innovation and learning, note an improvement in the recipient country's terms of trade in the short-run[7]. However, in the long run, they point out potential adverse effects to donor and recipient countries through the reduction in rates of innovation in high-income countries and an impediment in technology transfer and learning in low-income countries. This argument is based on the view that technological innovation mostly comes from high-income countries. It is also based on the logic that when foreign aid has detrimental effects on the recipient country's economy, it lowers the demand for goods from high-income countries. So with lower demand for new products comes lower rate of innovation. These assumptions are arguable; moreover, the dynamic between innovation, income level and demand may not be as linear as Benarroch and Gaisford (2001) describe.

Foreign aid that targets technology transfer and knowledge transfer enhances local capacity building and raises the recipient country's labour productivity and national income (Liu et al., 2021). Nevertheless, disadvantages such as the creation of dependency on donor countries, uncompetitive use of local resources and risk of political pressure on recipient countries have been cited in various reports (Tumwebaze, 2009, Gaille, 2018).

[7] When there is a home-bias in consumption

2.1.3 Defining ‘effective’ Technology Transfer?

The technology transfer process is multifaceted in practice, as seen from the above review. It often requires collaborations between individuals from different structural, cultural or organisational backgrounds (Gibson and Smilor, 1991; Sung and Gibson, 2005), making it a somewhat complex process. Furthermore, researchers, developers and users may hold different understandings of what a technology constitutes and what should be transferred (Wahab et al., 2012). Gibson and Smilor (1991) describe technology transfer as “*an interactive process, with a great deal of back-and-forth exchange among individuals over an extended period”.* This associated level of complexity has been widely acknowledged in the literature (Zaltman et al., 1973; Kidder, 1981; Smith and Alexander, 1988; Agmon and von Glinow, 1981; cited by Wahab et al., 2012). It then becomes challenging to agree on what constitutes an effective technology transfer. Is it gauged by the extent to which all elements of a technology have been transferred –i.e. the product as well as technical and non-technical knowledge and skills? Or, in the case of international technology transfer, is it gauged by the outcome, i.e. whether a technology ends up being adopted and used widely? Bozeman (2000) developed a conceptual framework for defining effective technology transfer based on five dimensions: who is doing the transfer, how the transfer is done, what is being transferred, factors that influence the transfer and to whom the technology is transferred. The way these dimensions interact then determines the effectiveness of a technology transfer process, which according to Bozeman et al. (2016), is gauged by seven criteria: (1) the reception of technology by the transferee, (2) the commercial impact of the technology transfer, (3) the impact on the wider regional or national economy, (4) the impact on scientific and human capital, (5) the effect of technology transfer on enhancing public values, (6) resulting political benefits and (7) other opportunity costs resulting from the technology transfer activities. Bozeman’s model (see figure 2.4) has been applied by researchers in various industries (Gunsel et al., 2019; Borge and Broring, 2017; Qiu et al., 2017, cited by Gunsel et. al; Hafeez et. al, 2020; Barros et al., 2020). The current research builds on this comprehensive model and presents an in-depth study of the Scientific and Human Capital criterion for effective Tech Transfer. The role of Tech Transfer actors in the process and the object of transfer will be the main dimensions used to assess this effectiveness (see figure 2.4). Bozeman et al. (2016) highlight the lack of Tech Transfer research focusing on Scientific & Human Capital and Public Value as effectiveness factors. The current study will thus be complementary contributions in those areas.

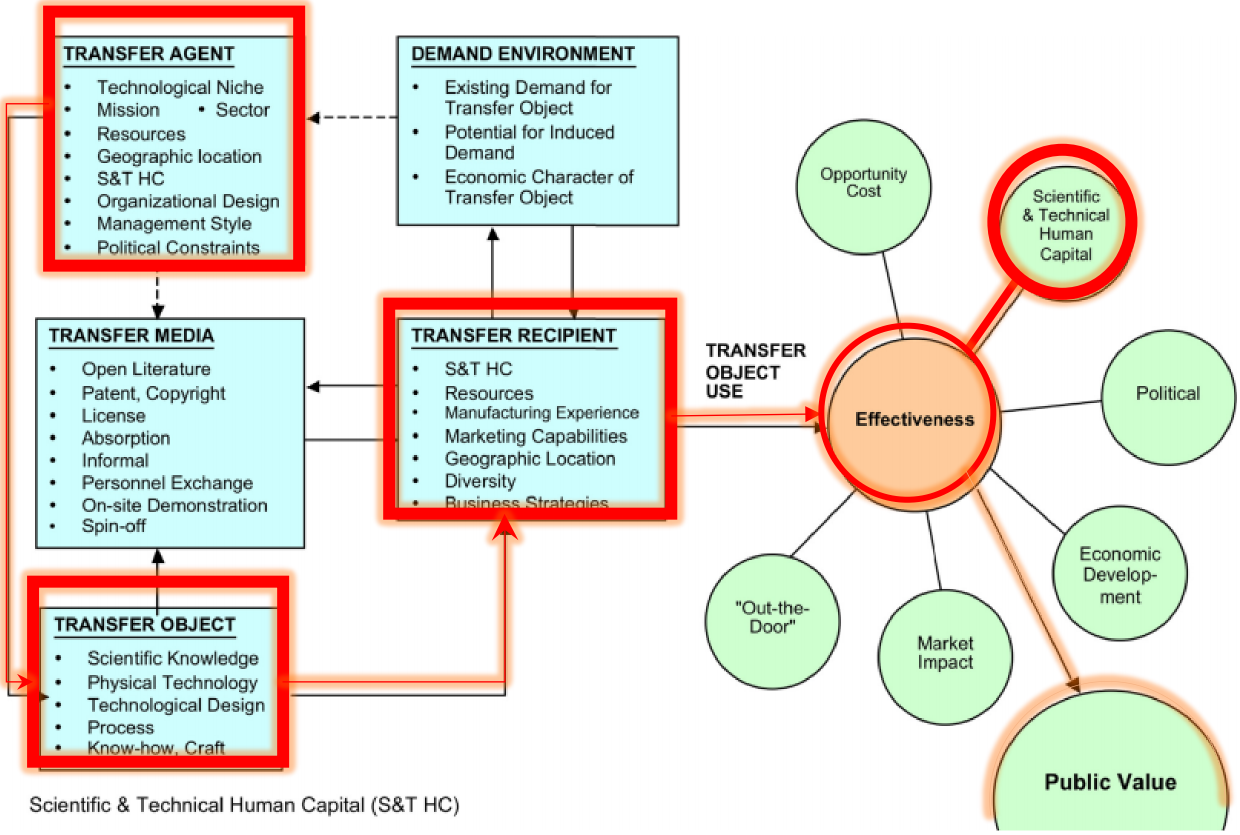


Figure 2.4: The revised model of Bozeman's contingent effectiveness model of Tech Transfer with research focus highlighted in red (Bozeman et al., 2016)

2.2 Absorptive Capacity as an enabler of effective Technology Transfer:

The review of technology transfer literature showed that effective technology transfer goes beyond the transfer of hardware or product. It also integrates the transfer of knowledge and skills relating to how the technology works, how to make it, and how to organise and manage its production, distribution or sale. However, for a technology recipient to absorb such an inflow of knowledge and skills, a prior R&D level is required. This section thus seeks to explore measures that can be used to increase a technology recipient's absorptive capacity. Before that, a clear understanding of the concept of Absorptive Capacity is required.

2.2.1 Definition of Absorptive Capacity: timeline representation:

The concept was initially developed in the early 1990s to provide a perspective on the acquisition of knowledge from external sources, learning and innovation within firms. Cohen and Levinthal (1990) showed that a firm's ability to value, assimilate and exploit external knowledge is fundamental to its innovative capacities; this ability strongly depends on the level of related prior knowledge within the firm; and is defined as its absorptive capacity. Several researchers built on that definition, extending it to other areas of organisational learning, notably for the understanding of managerial IT use (Boynton et al., 1994), technology transfer (Mowery & Oxley, 1995; Keller, 1996), transfer of best practices (Szulanski, 1996), research productivity within a firm (Cockburn & Henderson, 1998, cited by Zahra & George, 2002) and open innovation (Zobel, 2017). Cohen & Levinthal (1990) also note the effect of increased absorptive capacity on the diffusion of innovation[8].

The evolution of the absorptive capacity construct then expanded over the years with numerous propositions for reconceptualisation. Building on Cohen and Levinthal's definition, Van den Bosch et al. (1999) adds that a firm's absorptive capacity should not only be gauged by its level of prior related knowledge. Instead, its organisation form (i.e. hierarchical structure) and combinative capabilities (i.e. ability to systematise, socialise and coordinate knowledge) should also be considered. An extensive review of literature on absorptive capacity carried out by Zahra & George (2002) led to another reconceptualisation. The conceptual model proposed is accentuated on the ability to acquire (which goes beyond valuing), assimilate, transform and then apply or exploit new knowledge. They also distinguished between the realised absorptive capacity of a firm and the potential absorptive capacity. Combining this new conceptual model with the original construct, Tsai et al. (2012) came to propose what was called the 3R's model, which distinguished the Responsive absorptive capacity (sensing and acquisition), Reconfigured Absorptive Capacity (socialisation and transformation) and Realised absorptive capacity (assimilation and combination).

Nonetheless, Cohen and Levinthal's definition has remained the main paradigm. Figure 2.5 shows a timeline of the evolution of the construct since Cohen and Levinthal's original definition. Efforts have now shifted towards measuring or expanding on the different dimensions of absorptive capacities and linking them to other constructs (Zobel, 2017; Aghion & Jaravel, 2015; Chinho et al., 2002). Saad et al. (2017) further expand on the importance of awareness as an antecedent dimension of absorptive capacity. In an empirical study of 43 manufacturing SMEs, the authors show how awareness based on taking the first step to generate interest and motivation to value external knowledge significantly impacts its acquisition, assimilation, transformation and exploitation.

The work of Mowery and Oxley (1995) was amongst the earliest examples to apply the notion of absorptive capacity at a national level; to examine the role of national innovation systems on inward technology transfer. They defined a country's absorptive capacity as relating to the broad range of skills required to exploit the tacit components of a transferred technology and the ability to modify imported technologies to fit the domestic context. This definition was further reinforced in various other reports, elaborating on the importance of developing skilled human capital and investing in R&D at national level (Kim & Dahlman, 1992; Keller, 1996; Liu & White, 1997; Luo, 1997;

[8] There are five decision stages in the process of innovation diffusion: knowledge, persuasion, decision, implementation, confirmation. Increasing absorptive capacity (and thus knowledge) help with the diffusion of innovation (Cohen & Levinthal, 1990).

Veuglers, 1997; Glass & Saggi, 1998; cited by Zahra & George, 2002; Kim, 1998). It thus helps to understand how knowledge acquisition and assimilation are critical conditions for technology transfer success. Keller (1996) argued that while technology transfer mechanisms such as trade liberalisation were beneficial for the domestic economy, sustained growth, in the long run, required rapid upskilling of the labour force. Liu & White (1997) demonstrated through a five-year study of 145 Chinese firms from 29 manufacturing industries that national innovation level is driven by a synergy between investment in foreign technology transfer and investment in developing skilled R&D personnel. Kim (1998) also pointed out the necessity for firms in Newly Industrialising Countries to go beyond the assimilation of external knowledge for imitation to developing problem-solving skills that lead to innovation. It shows that good assimilation and adaptation of external knowledge should enable organisations and nations to re-innovate (Rothwell, 1992) or adapt that knowledge to the needs of a dynamic environment.

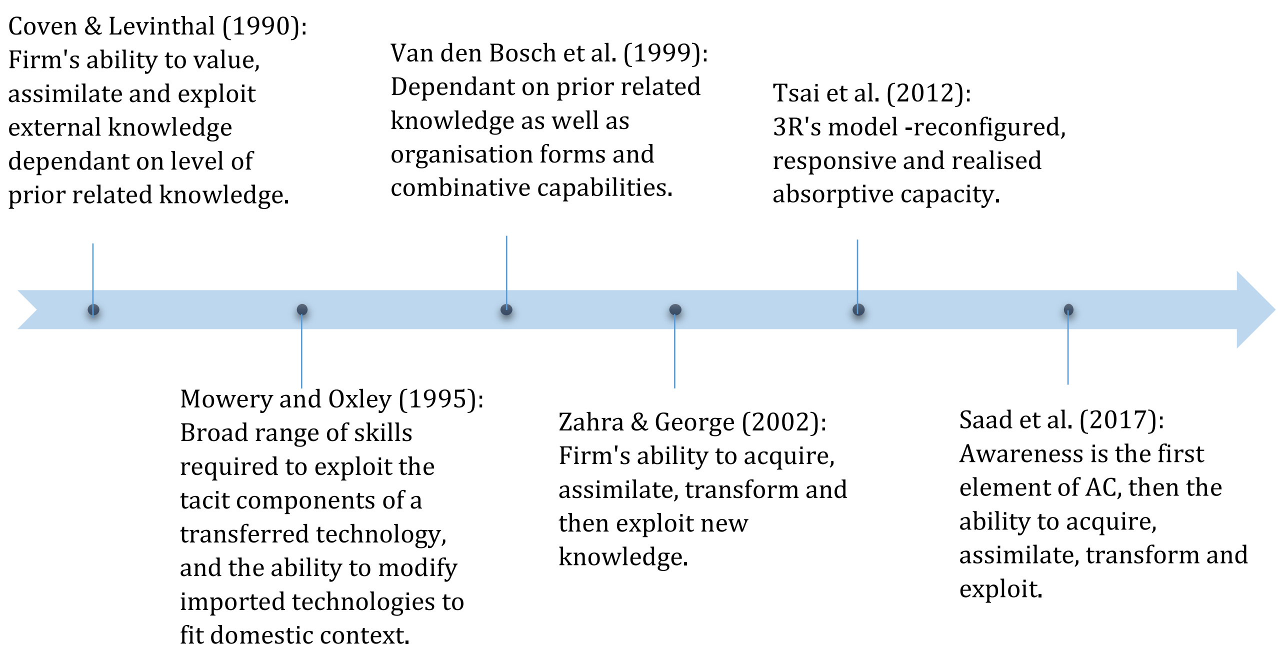


Figure 2.5: Timeline showing the evolution of the concept of absorptive capacity.

2.2.2 Ways to increase absorptive capacity at micro and macro levels:

a. Increasing firm's absorptive capacity –micro level:

The main factors to be considered for increasing a firm's absorptive capacity, as cited by Chinho *et al*. (2002) and Saad *et al*. (2017), are corporate culture within the firm, awareness of external knowledge, strategies used within the firm for knowledge management, and the firm's connections with outside organisations. These factors certainly require sufficient financial capability from the firm, which is a challenge for many in the context of low-income countries. Corporate cultures that support organisational changes and encourage learning are needed to increase absorptive capacity (Chinho *et al*., 2002); however, it takes time and effort to nurture such an environment within a firm. Saad *et al*. (2017) define awareness as being cognisant of external knowledge's benefits and potential. It creates motivation and interest in learning and innovation that firms need before they can even value or acquire external knowledge. With regards to knowledge management and sharing in a firm, this is fostered by continuous training of employees, strong teamwork ethics, opportunities for informal and social interactions amongst employees, good management of databases and then clearly communicated organisational procedures (Bonora and Revang, 1991; Hedlund, 1994; Nevis et al., 1996; cited by Chinho et al., 2002). Finally, it has been shown that firms in industrialising countries that establish linkages with MNCs, universities and research centres enhance their capabilities significantly (Szogs et al., 2008).

Considering the abovementioned factors, Zou *et al*. (2016) argue that a technology's lifecycle stages should dynamically drive a firm’s strategies to increase absorptive capacity. The authors explain that market demand varies with the technology lifecycle stages of initiation, growth, maturity and then decline. Zou *et al*. (2016) thus recommend that firms increase their absorptive capacity while technology is still at its growth stage and local market demand is ascending (as shown in figure 2.6). Furthermore, a given technology could be at different stages of its lifecycle in various countries. Criscuolo and Narula (2008) argue that when there is a technology gap between countries, those in the catching-up phase should accumulate external knowledge through absorption of trade, inward FDI and R&D spillovers and other forms of collaboration with countries in the pre-frontier and frontier phases. That has been the case with solar PV technologies, where there is a clear gap in adoption between African countries and China, where an exponential uptake and development of the same technology is seen (Masson and Brunisholz, 2015) and illustrated in figure 2.7. A few African countries, however, have managed to cross this technology adoption chasm. However, Kenya has been an exception, particularly with the pico-PV market. Estimates from the World Bank suggest it is well into the rapid growth stage in Kenya. Over 30% of the off-grid population in Kenya is said to have at least first-hand experience with solar lighting. That is greatly facilitated by awareness campaigns carried out during the early stages of the technology (Orlandi et al., 2016).

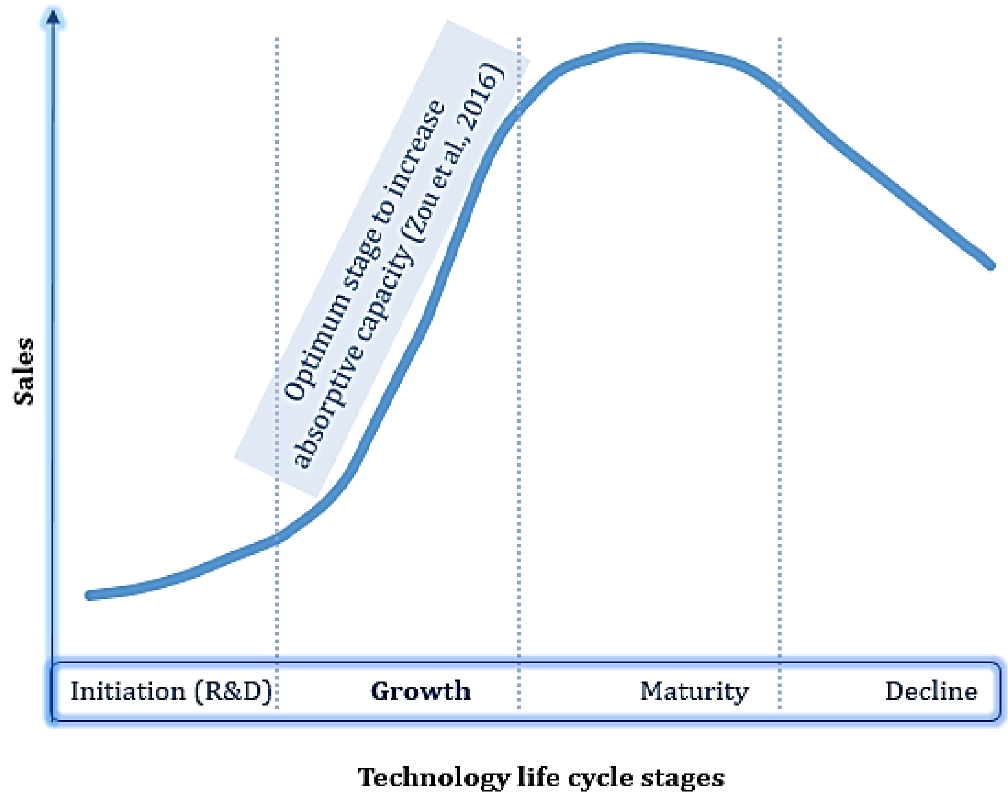


Figure 2.6: Optimum stage for increasing firms' absorptive capacity in a technology life cycle. *Source: Author*

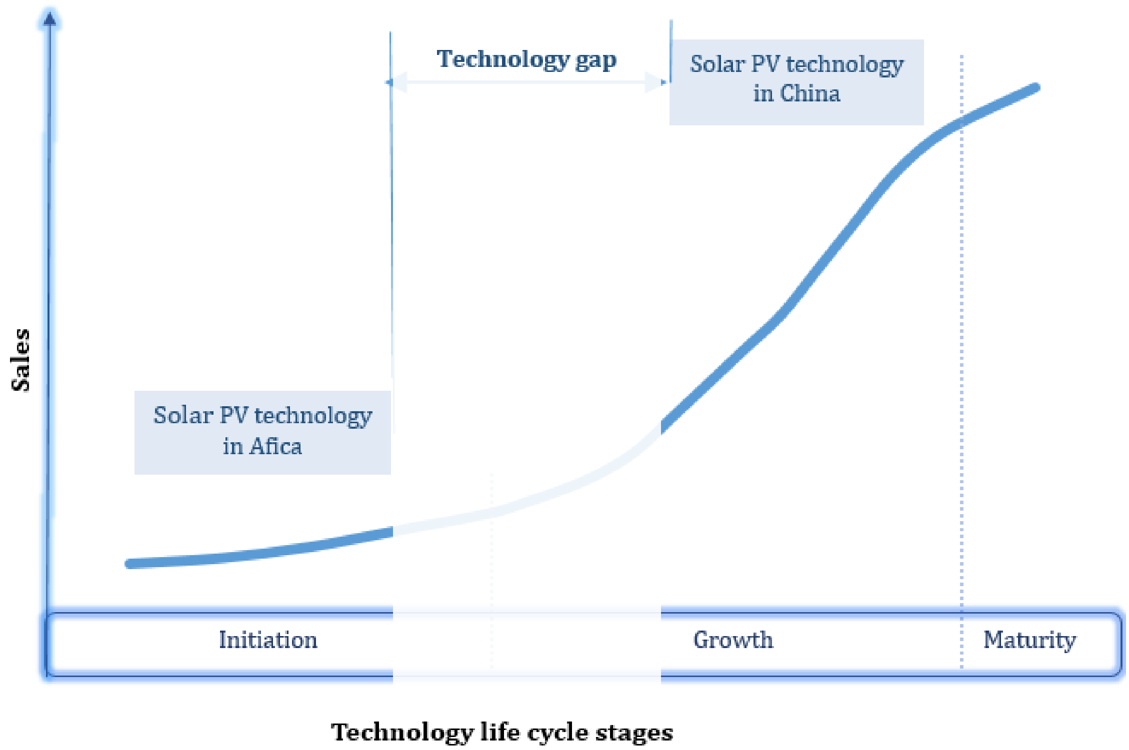


Figure 2.7: Technology gap in solar PV adoption between sub-Saharan African countries and China, based on IEA's 2015 snapshot of the global photovoltaics market.

b. Increasing absorptive capacity at a macro level:

The absorptive capacity of a nation is more than the cumulative sum of its firms' absorptive capacity (Narula, 2004; Eltamimi et al., 2010). Therefore, whilst individual firms in a country may have strong absorptive capacities, additional factors are required for this to translate into high absorptive capacity at a macro level, such as adequate educational infrastructure and systems, R&D institutions and government policies that facilitate knowledge and technology spillovers (Keller, 1996; Liu & White, 1997; Narula, 2004, Saadi, 2011; Saad, Guermat and Brodie, 2015; Fuentes & Mies, 2017; Elmawazini et al., 2008).

Eltamini et al. (2010), whilst acknowledging the complex, multilevel and dynamic nature of national absorptive capacity, define the two main driving elements for a country's absorptive capacity to be: (1) its National Capital Stock (NCS) which includes monetary assets, physical assets and level of institutional development; and (2) its National Innovation System (NIS) defined by the network of interactions between industries, government and educational and research institutions that drives technological innovation (Saad et al., 2015).

Authors have noted that there is no one-cap-fits-all approach to developing national absorptive capacities; countries are to adopt sector-specific, context-sensitive policies that enhance to drive their technological development (Narula, 2004; Egbetokun, 2016).

2.2.3 Knowledge transfer and capacity building during technology transfer – Strategies for knowledge:

There are three different types of knowledge needed for technological capacities (Bell, 1984): (1) explicit technical knowledge that comes in books, manuals and other material forms; (2) tacit technical knowledge embodied in skilled personnel; and then (3) knowledge relating to management, marketing and sale of the technology. Tacit knowledge is non-verbalised, intuitive and unarticulated knowledge that is not yet abstracted from practice (Polanyi, 1962; Spender, 1996; cited by Inkpen and Dinur, 1998). Winter (1997; cited by Inkpen and Dinur, 1998) proposes a similar distinction where knowledge is teachable versus non-teachable, simple or complex. Whilst authors distinguish between explicit and tacit knowledge, such distinction is not binary but sits more within a spectrum.

Learning can occur through various mechanisms during a technology transfer process, from passive learning when exposed to a technology to more proactive learning during training. Saad (2003) refers to these as 'learning by using' and 'learning by allocation of external resources'[9]. There is embedded R&D knowledge that gets transferred with the technological product or hardware (Inkpen and Dinur, 1998). Through close interaction with the technology, workers can understand how it works and how to repair it. As

[9] Saad (2003) also refers to 'learning by doing', which is more specific to manufacturing firms. It is less involved than 'learning by using' and occurs passively as workers carry out production task in a firm. It can take several years for workers to acquire descent understanding of the transferred technology.

such, in the long term, 'learning by using' may lead to the ability of crude copying, adaptation of imported technology and frugal innovation (Teubal, 1984; Dahlman et al., 1987; Rosenberg, 1982; cited by Saad, 2003; Bhatti, 2012).

Allocating resources to provide learning is seen as a more effective way of knowledge and skill transfer (Saad, 2013; Wissenbach and Wang, 2017). It can be done through in-house training, hiring external experts or conducting research in joint partnerships (Saad, 2013). For more tacit, non-teachable knowledge, Inkpen and Dinur (1998) propose two strategies that can be used in the Tech Transfer process: the use of site visits, tours and similar platforms for experiential learning and the exchange of personnel between organisations to learn about corporate norms and other subtle ways of doing that are not necessarily available in textbooks and manuals. However, the level of complexity and the quantity of knowledge to be acquired often slows down the Tech Transfer and knowledge transfer process (Cohen and Levinthal, 1990). For African countries, a key challenge remains the heavy financial investment required. Most technology transfer processes have a fixed-term agreement and limited budget. Therefore, due to such time and financial constraints, priority is often placed on getting the provider to simply install the technology.

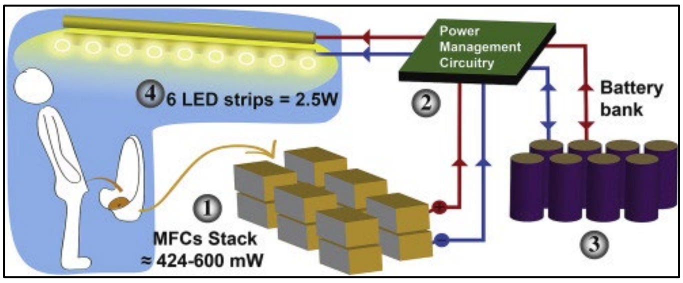
2.3 Relevance to the PEEPOWER technology transfer and discussion of key learnings from literature review:

2.3.1 Overview of the PEEPOWER:

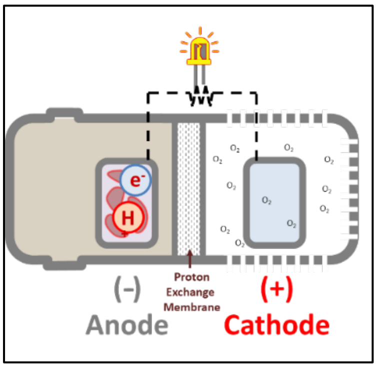
The PEEPOWER (shown in figure 2.8a) is a novel microbial fuel cells technology that generates electricity from undiluted urine and other forms of wastewater (University of the West of England, 2016). Microbial fuel cells are biological energy transducers (see figure 2.8b) that produce electricity through bio-electro-oxidation of organic compounds (Ieropoulos et al., 2016). The concept of using micro-organisms to generate voltage was first tested in 1911, then picked up in 1993 with Allen and Bennetto demonstrating higher efficiency of electron transfer and reaction rates in their fuel cells (Noll, 2006). Research and Development in this field have intensified over the last three decades. Today, MFCs still produce relatively low levels of power in comparison to other forms of renewable energy. Nonetheless, the potential of MFC technologies such as the PEEPOWER lies in their ability to also treat wastewater and produce fertilisers and disinfectants by-products (Walter et al., 2018). The PEEPOWER uses low-cost ceramic, self-stratifying MFCs assembled in stacks (see figure 2.8c), to reach useful power levels, whilst minimising cost and complexity.

A full representation of the PEEPOWER on the *techberg* will be developed in the later part of the research. Data collected and analysed will be used to outline technical and non-technical skills underpinning the PEEPOWER technology.

2.8a Illustration of the PEEPOWER energy system



2.8b Diagram of an energy transducer –a microbial fuel cell



2.8c A single ceramic MFC and a 12-stack assembly

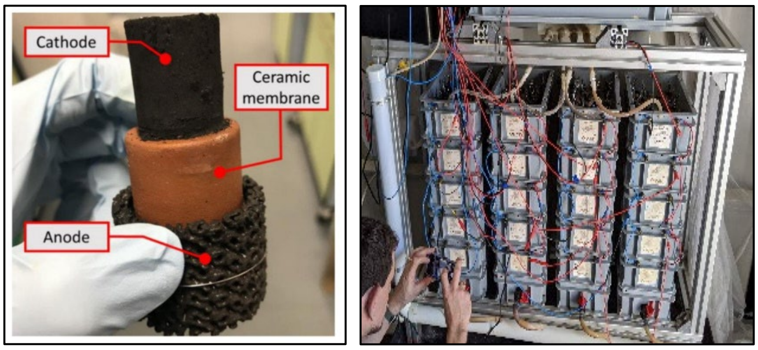


Figure 2.8: Photos and illustrations of the PEEPOWER system and microbial fuel cells units. Photo credit: Bristol Bioenergy Centre BBiC.

2.3.2 Key learnings from literature review:

Critical learnings were drawn from the review of mechanisms used in international technology transfer:

- *Knowledge transfer is essential for effective Tech Transfer.*

Technology encompasses hardware, related technical and non-technical knowledge and skills in its most comprehensive sense. During a Tech Transfer process, the focus should go beyond the mere transfer of hardware. For Tech Transfer to be effective, there should also be an inflow of knowledge and skills required to install, maintain and manage the technology (Keller, 2004).

- *The extent of knowledge and skills transfer depends on the Tech Transfer channel used.*

Technology transfer mechanisms such as trade, licensing, subcontracting and some turnkey agreements accentuate the acquisition of the hardware. Knowledge transfer here is limited to that of embedded R&D within a product. Integrated support contracts and franchising agreements provide a better scope for transferring technical and non-technical knowledge and skills. FDI and foreign aid can also provide platforms for knowledge and skills that enhance local capabilities. However, they are primarily based on a capital model and may have other financial and political implications. Table 2.1 summarises reviewed means of technology transfer, their advantages and the associated risks discussed in the previous section.

- *Knowledge and skills transfer is more effective when technology recipients already have high absorptive capacity.*

Technology recipients need to have prior R&D knowledge relating to the technology (OECD, 2012), skilled personnel and adequate infrastructures to be able to assimilate and exploit external knowledge acquired, which requires consistent financial investment and remains a challenge in many African countries (African Development Bank, 2014).

- *The effectiveness of the Tech Transfer process is not only defined by the level of knowledge and skills transferred to the technology recipient.*

It was discussed that Tech Transfer is said to be effective if it encompasses the transfer of the technological product and associated knowledge and skills. However, although essential, ensuring the transfer of all elements of a technology during a Tech Transfer process is not the only way to assess its effectiveness. Bozeman (2016) identifies other key criteria to be accounted for when discussing the efficacy of a Tech Transfer process. These include the reception of technology by the transferee, the commercial impact of the technology transfer, resulting political benefits, the effect of technology transfer on enhancing public values and other opportunity costs resulting from the technology transfer activities.

As the research aim is to investigate enabling factors for the effective transfer of the PEEPOWER with a closer look at Absorptive Capacity, the above learning points will be further discussed and compared with empirical findings.

Table 2.1: Mechanisms of transfer of energy technologies in Africa, their advantages and disadvantages

Models of Technology Transfer	Mechanisms of Technology Transfer	Advantages	Disadvantages/risks
Focus on the transfer of hardware	Trade	Faster economic growth (Coe, Helpman, and Hoffmaister, 1997; Hardison, 2015; Hoekman *et al.* , 2005)	No transfer of non-technical and technical competencies
	Licensing	Transfer of Intellectual Property rights (WIPO, 2004)	High cost, limited knowledge transfer, can be restrictive, may take a long time (Saad, 2000)
	Subcontracting	Acquisition of ready-made technology (Martini, 2015)	Strong dependence upon technology providers for supply, maintenance and repair
	Turnkey contract	Quick delivery of large-scale energy projects, with some degree of knowledge transfer	Over-reliant on the technology supplier for maintenance, repair and even operation (Saad, 2000)
	Foreign aid (via transfer of funds)	Short-term improvement in the country's terms of trade (Benarroch and Gaisford, 2001)	No knowledge and skills transfer, creation of dependency on donor country and risk of political pressure on recipient countries
With knowledge and skills transfer	Franchising	Use of trademark, business methods, marketing systems and distribution processes of an established business	High capital investment and strong managerial and technical skills required
	Support contract	Delivery of large-scale energy projects with an enhanced platform for knowledge and skills transfer, guarantees for continued maintenance of the technology and adaptation of project concept to the local context (Lekela, 2018; ESI Africa, 2018)	Relatively high cost
	Foreign Aid (via technology and knowledge transfer)	Enhanced local capacity building, increased labour productivity and recipient's country's national income (Liu et al., 2021)	Creation of dependency on donor country and risk of political pressure on recipient countries (Tumwebaze, 2009, Gaille, 2018)
With knowledge and skills transfer (capital model)	Foreign Direct Investment	The inflow of knowledge about new technologies, their materials, production methods and often organisational management skills	Risk of deterioration of recipient country's terms of trade and welfare and return of income and profit to investors
	Foreign Aid (via financial incentives)	Enhanced local capacity building, increased labour productivity and welfare of both donor and recipient countries (Liu et al., 2021)	Creation of dependency on donor country, uncompetitive use of local resources and risk of political pressure on recipient countries (Tumwebaze, 2009, Gaille, 2018)

2.3.3 Mapping Technology Transfer effectiveness against Absorptive Capacity – Conceptual framework

The conceptual framework presented in this section summarises the major learning points from the literature review. Firstly, the concept of technology, as illustrated in figure 2.1, has been described in its most comprehensive sense as going beyond the technological product (or the hardware) to include: the necessary knowledge and skills required to operate, maintain, repair or manufacture the technology; as well as managerial and business knowledge and skills needed to sale, distribute or produce the technology.

It then followed that technology transfer mechanisms that do not incorporate the transfer of knowledge and skills raise issues such as the lack of ability to maintain the technology and overreliance on the Technology Provider. It was also found that tech recipients do have a part to play in preparing an enabling environment for effective technology transfer. It consists in investing in initiatives that increase their absorptive capacity at both firm's level and national level. Table 2.2 and figure 2.5 show how technology transfer is more effective when the transfer of the product or system is coupled with the transfer of knowledge and skills; and when Technology Recipients have high levels of Absorptive Capacity. It is worth reiterating that the notion of effective technology transfer can be quite broad, with several defining criteria (see figure 2.4).

Nonetheless, Bozeman et al. (2016) highlighted a need for more focused research that explores tech transfer effectiveness exclusively from the angle of Scientific and Human Capital (i.e. knowledge and skill levels). The proposed framework is not a tool for measuring the effectiveness of a tech transfer. It will be used to gauge and visualise how effective the transfer of the PEEPOWER in relation to Scientific and Human Capital and then identify what is needed in order to facilitate knowledge sharing.

Table 2.2: Mapping effective Technology Transfer (TT) and Absorptive Capacity (AC) –a conceptual framework. *Source: Author*

Ineffective TT	**Object of transfer from Technology Provider**					Effective TT
	The Product		with technical knowledge & skills required to operate, maintain, repair and manufacture the technology		and non-technical knowledge & skills (managerial, business, organisational)	
	Absorptive Capacity of Technology Recipient					
	AC	**Level 1** Awareness and value of external knowledge	**Level 2** Assimilation of external knowledge	**Level 3** Transformation of external knowledge	**Level 4** Exploitation of external knowledge	
	Effect on TT	Creates need to acquire external knowledge	Facilitates ability to maintain and repair transferred technology	Facilitates ability to modify and adapt technology	Creates ability to innovative technology	

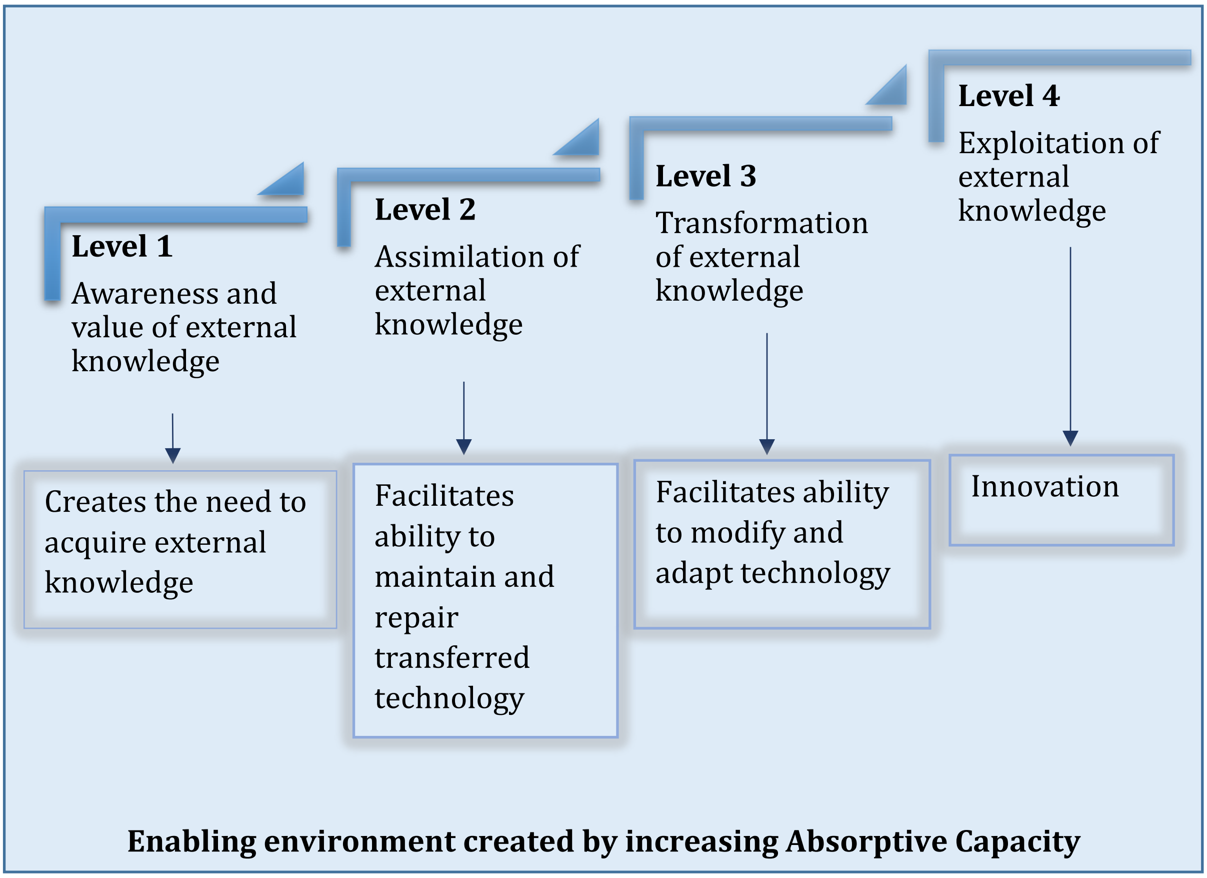


Figure 2.5: Absorptive Capacity as an enabler of effective technology transfer.

CHAPTER 3: RESEARCH METHODOLOGY

Links to research objectives:

This chapter clearly outlines the overall research approach, starting from the underpinning philosophical paradigm to the main data collection and analysis strategies used to address the research **objective 4**. A justification of each chosen method is provided along with a critical comparison with alternative options.

Chapter highlights:

This chapter presents:

- A justification for the approach and methods used to carry out the research
- A critical appraisal of limitations in the methodological approach and measures taken to ensure validity and robustness of research findings
- The overall methodological framework used collect and analyse research data

3.1 Philosophical paradigm:

Easterby-Smith et al. (2015) explain how the way the researcher views the world or defines the nature of reality (ontology) affects the assumptions they make when attaining and validating knowledge (epistemology). It thus influences their choice of techniques for investigating a research question (methodology). The relativist ontology, which takes into consideration the variety of perspectives on an issue and the nature of reality according to various contexts, is adopted in this research, as opposed to a realist ontology, where findings are based on facts and the belief in a single truth (Easterby-Smith et al.,2015). A constructionist or interpretivist epistemology is used, which takes into account the nuances in lived experiences and realities. It also allows for a deeper understanding of underlying meanings of activities and events. With this philosophy, the main research question of *"How can adequate knowledge transfer be facilitated to ensure effective technology transfer?"* could be addressed by keeping in mind the relative nature of what constitutes 'adequate knowledge' and 'effective technology transfer'. Clearly defining the philosophical paradigm of the research sets the foundation for choosing the best-suited approach, techniques and procedures for the research. This is well captured in Saunders et al.'s research onion, shown in figure 3.1. The main limitation of this relativist, interpretivist paradigm is its subjective nature, which can compromise generalisation, reliability and validity of findings. Leitch et al., 2010 propose a way to demonstrate quality and robustness of findings for interpretivist research, which will be further elaborated in a later section.

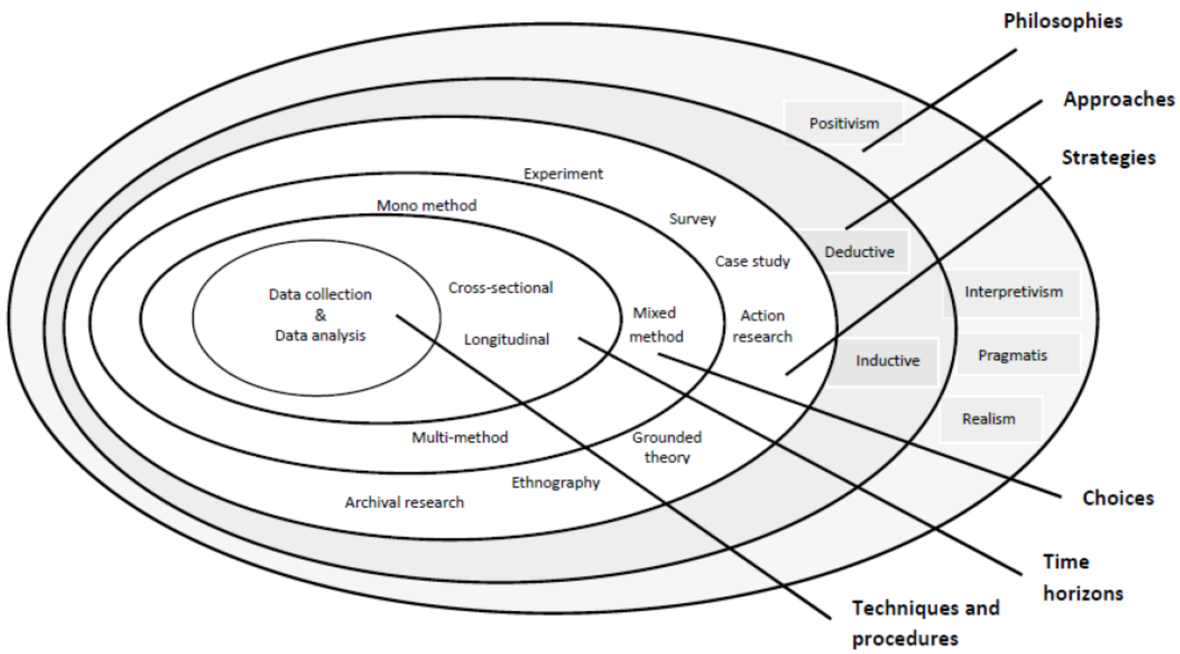


Figure 3.1: Research onion (Saunders et al., 2009, p.108)

3.2 Methodology:

As it follows from the above-defined research paradigm, a qualitative methodology is used in order to get: (1) a greater focus on meanings (as compared to facts), (2) a better understanding of what is happening (as opposed to stressing on causality and fundamental laws) by exploring small data samples in depth and in detail (O'Gorman and MacIntosh, 2015). The research uses a hybrid of action research and case study strategy. The PEEPOWER technology is used as an illustrative case study, and action-research steps are followed to implement theoretical insights from literature reviews into the chosen case study. It will then help to understand to what extent knowledge sharing was incorporated during the PEEPOWER transfer in Kisoro, Nairobi and Durban (thus addressing research objective 4).

3.2.1 Research strategy: Action research case study

Figure 3.1 shows different strategies that can be used to undertake research. The current thesis adopted a combination of action research and case study research. An exploratory case study research strategy allows the researcher to understand complex social phenomena while investigating real-life events, is used (Yin, 2003). On the other hand, action research is a type of applied social research that involves collaboration with participants through a series of interventions (or actions) that bring about changes and improvement in a situation (Jupp, 2006). This blended approach, where the case study highlights areas of improvement and the action research implements and tests recommended changes, is more common in sustainability and education research (Keahey, 2021).

A common criticism of such an approach focussing on specific cases is the ability to provide scientific generalisation; however, the purpose here is often not statistical generalisation. Rather, analytical generalisation, where theoretical issues are illuminated via the case study through the analysis of collected data (Yin, 2003; Harley, 2004; cited by Kohlbacher, 2006). An overview of the action research case study is shown in figure 1.1 of chapter 1.

3.2.2 Data Collection:

a. Case study location:

The PEEPOWER was tested for the first time outside a controlled laboratory environment in 2015 at the Glastonbury music festival (United Kingdom). The system has since been transferred for trial decentralised power supply in remote villages and slum areas in Uganda, Kenya and South Africa. During field trials, the PEEPOWER is connected to a toilet block and feeds from its urine waste. The aim is to generate enough electricity to power a light bulb in the toilet in a real-world setting. In 2016, the PEEPOWER was installed in a boarding school in the village of Kisoro in Uganda (see figure 3.2a), with the support of the local diocese, for a trial period of 18 months. In 2018, through a partnership with the charity organisation ACEF, the system was installed in a school in Mathare slum in Nairobi (Kenya), see figure 3.2b. In 2019, another trial was launched in the Thandanani settlement in Durban, South Africa (see figure 3.2c). The system was integrated into a Community Ablution Block CAB to supply light from urine treatment. This trial lasted for 9months benefitting from a partnership with the WASH centre of the University of Kwazulu Natal and the Khanyisa Project – a local organisation with experience in designing and implementing water and sanitation solutions for municipalities (You, 2020; University of the West of England, 2016; University of the West of England, 2018; University of Kwazulu-Natal, 2020).

The advantage of choosing these three locations for the case study is that, it allows for comparison of technology transfer between rural and urban settings and between two urban settings with different levels of technical supports.

3.2a PEEPOWER lighting a boarding school toilet at night in Kisoro, Uganda.

3.2b PEEPOWER maintenance at the Mathare school in Nairobi, Kenya.

3.2c PEEPOWER connected to a community ablution block in Durban.

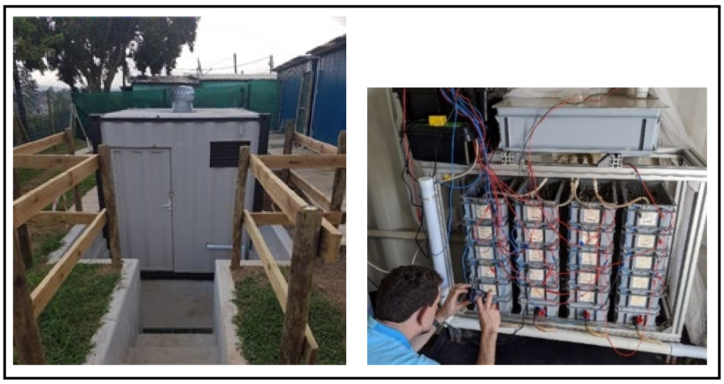


Figure 3.2: PEEPOWER transfer in Kisoro, Nairobi and Durban. Photo credit: BBiC and UKZN

b. Data collection methods:

The main methods used for collection of primary data were through semi-structure interviews, participant observation and the use of a research diary. Semi-structured interviews with staff members who took part in the PEEPOWER field trials in Kisoro, Nairobi and Durban allowed for a close insights into challenges faced, success factors for effective technology transfer and levels of absorptive capacity in those different locations. Participant observations was carried out as a working team member of the Bristol Bioenergy Centre for over 18 months, with field visits to the installation site in Durban. This allowed the researcher to see where and how the PEEPOWER technology was installed and understand the local context. It was also a means to validate responses collected during interviews, acquire further understanding of the technology and extent of knowledge transfer. By working closely with the BBiC team, the researcher also led the implementation of recommendations drawn from findings, as part of the Action Research process. Access to technical reports, minutes and presentations as secondary data allowed for further validation of findings. The research diary was used, as reflective practice, to record personal assumptions, thoughts and experiences, and to carry out critical discussion of research findings. A summary of data collection methods and sources used in the research, along with their purpose, is presented in table 3.1.

The sample units below were used for the interviews, as they provided varied perspectives about challenges and success factors of technology transfer:

- Sample unit 1 –Technology provider

Main personnel involved in developing and deploying the MFC system (seven UK-based participants).

- Sample unit 2 –Technology recipient

Local personnel involved in implementing the MFC system in the community (three participants based in Uganda, two participants based in Kenya, and five participants based in South Africa).

A total of 17 people were interviewed (face to face and via video conference), which constituted most of all team members involved in the PEEPOWER transfer (80% of all employees). It included Project Managers, Researchers, Community Liaison Officers, Technicians and Engineers from the Bristol Bioenergy Centre in the UK and the WASH R&D Centre at UKZN (South Africa). Ethical considerations were taken to get informed consent from participants whilst ensuring anonymity.

The approach used to select case study locations, sample units and research participants was a combination of convenience sampling for ease access and availability of participants and purposive sampling, to address set research aim and objectives.

An interview guide was created informed by the literature review (see table 3.2). The interview followed the structured questions with some room for unstructured exploration. The first part of the interview included more open-ended questions with the aim of uncovering challenges faced and success factors for effective technology transfer. The second part of the interview was informed by the literature on technology and absorptive capacity. Efforts were made to build an initial rapport with participants, and a relaxed conversational style was used to allow participants to express their ideas freely. The advantage of semi-structured interviews is that it allows the researcher to explore existing themes with participants by asking probing questions, while also allowing participants to raise new issues (Wilson, 2014). One disadvantage of this method is the volumes of transcript materials generated from the interview and the highly time-consuming tasks of proofreading and analysing the data generated.

Table 3.1: Summary of data sources.

Data sources	Amount	Collection method	Purpose
Face-to-face and video interviews	17 (total: 450min)	Primary data Semi-structured interviews	Understand challenges faced, success factors for effective technology transfer and level of absorptive capacity.
Field visit to Durban (South Africa)	3 days	Primary data Participant observation	To see where and how the PEEPOWER technology was installed and to understand the local context.
Team meetings with the technology developer (BBiC)	32 (total: 1920min)	Primary data Participant observation	Validate responses collected during interviews and acquire further understanding of the technology and extent of knowledge transfer
Meetings with BBiC's external partners	15 (total: 800min)	Primary data Participant observation	Implement/test recommendations drawn from findings
Emails	Over 200	Secondary data	Validate responses collected during interviews and acquire further understanding of the technology
Presentations, reports and posters	10	Secondary data	Validate responses collected during interviews and acquire further understanding of the technology
Press releases	Twitter posts in 2020/21	Secondary data	Acquire further understanding of the technology, challenges and opportunities
Research diary		Primary data	For reflective practice, used to record personal assumptions, thoughts, subjectivities and experiences. Also useful for critical discussion of research findings.

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Interview questions:

Research title: Technology Transfer and Absorptive Capacity: Case Study of the PEEPOWER Technology
Researcher: Maryam Lamere **Participant:** PEEPOWER Team

Part 1: Self-evaluation and reflection

Open-ended questions with the aim of uncovering challenges faced and success factors for effective technology transfer.

1. **Kisoro/Nairobi project:**

a. What went well in the project?
b. What could have been done differently by the team?
c. What external obstacles did the team face? (social, cultural, political, economic)
d. What recommendations would you give to someone willing to run a similar field-trial in Kisoro?

2. **Durban Project:**

a. How was the Durban trial run differently to the Kisoro/Nairobi trial?
b. What are the obstacles faced?

Part 2: Local Capacity building

Gauging absorptive capacity and extent of knowledge transfer.

	Kisoro	Nairobi	Durban
Yes			
How?			
No			
Why?			

1. Can local labour maintain and repair the MFC system?

	Kisoro	Nairobi	Durban
Yes			
How?			
No			
Why?			

2. What do you think about the ability of local technicians to modify, adapt or improve the MFC system?

	Kisoro	Nairobi	Durban
Yes			
No			

3. What do you think about the ability of local technicians to innovate similar technologies to MFC systems?

	Kisoro	Nairobi	Durban
Yes			
No			

Figure 3.2: Guide used for the semi-structured interviews.

Participant observation used as data collection method allowed the researcher to understand what takes place in addition to what is said. Gill and Johnson (2002) categorise four main types of participant observations dependant on the role of the researcher: (1) complete participant, (2) complete observer, (3) observer as participant and (4) participant as observer (see figure 3.2).

In the current thesis, the researcher adopted the role of participant as observer. From the onset of the data collection, the researcher's identity and role were made clear to team members at the Bristol Bioenergy Centre (BBiC) and the WASH Centre at the University of Kwazulu Natale. In addition, the researcher was actively involved in the other PEEPOWER projects, by liaising with internal and external partners for the promotion of Microbial Fuel Cell education, having field visits to Durban (South Africa) for closer observation of the PEEPOWER project implementation, working closely with the team by attending weekly meetings, assisting in bidding and maintaining the social media platform. This close working relationship allowed the researcher to develop a deeper understanding of the technology, its success factors, its challenges and its potential. Having such close access to an organisation is often a challenge for researchers. However, this was facilitated with the advantage of BBiC being part of the Engineering Department, where the research is supervised. The disadvantage of this approach is that it is highly demanding and time-consuming. Furthermore, the issue of observer bias can remain a dilemma, which was mitigated through various measures, as explained in the later section.

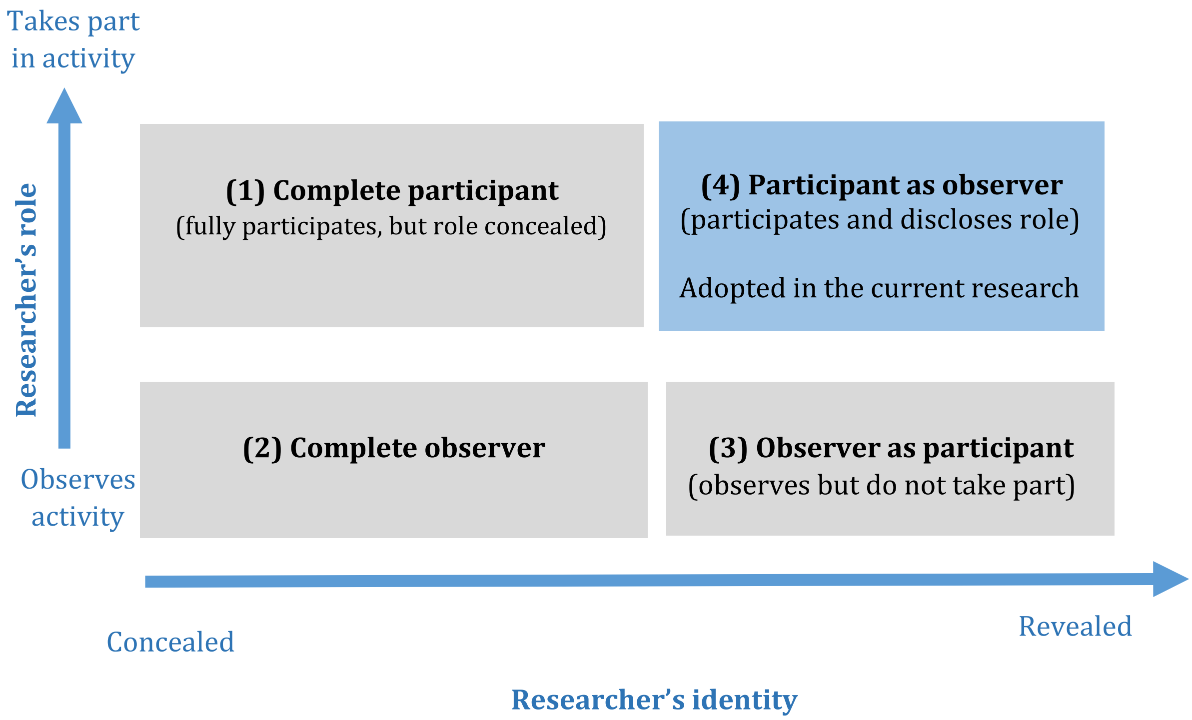

Figure 3.3: Four types of participant observation, according to researcher's role (Gill and Johnson, 2002)

A research diary was also used (see figure 3.4) to record personal assumptions, thoughts, subjectivities and experiences (Mruck & Breuer, 2003, p. 3 as cited by Ortlipp, 2008). An excerpt of the research diary is shown in figure 3.3 (see full diary in appendix 5), which helped with reflexivity in the research process, defined as the act of:

> *"...reflecting on the way in which research is carried out and understanding how the process of doing research shapes its outcomes"* (Hardy *et al.*, 2001, cited by Nadin & Cassel, 2006)

There are increased calls for reflexivity for management research (Nadin & Cassel, 2006), though little information is available on how to undertake the activity in practice. Reflexivity was carried out in the current research mainly by drawing on personal experience and observations growing up in a rural area in sub-Saharan Africa. This falls in line with the interpretive epistemological standpoint chosen for the research. It is an acknowledged research practice in constructionist research that will serve to bring further transparency, rigour and integrity to the research process (Ortlipp, 2008, Nadin and Cassel, 2006).

A. Proposed educational kit:
1. MFC Educational Kit/Ecobot:
Showcases UWE research and innovation; real world application of STEM (inclusivity factor); sustainable, years of outreach experience in schools; autonomous battery powered robot; sets of boxes already available (PeePower kits and some ecobots) and more can be made by the BBiC team if required.
2. Planete Sciences education box: https://www.planete-sciences.org/robot/boiteabots/fiches/
Versatile educational box with activities relating to Electrical Engineering, Robotics, Mechanical engineering and more; detailed instructions available; tailored made for schools; can be altered to meet P&P Lab's needs; Resources produced by an external organisation
Note: boxes needs to be made from scratch (materials to be purchased, staff to be allocated for making the boxes), instruction manuals are to be translated from French to English.
3. Way forward: Integrate MFC kit with Planete Sciences educational box for an engaging educational kit.
B. Note about the commercialisation of the MFC educational kit:
This is being carried out independently of the P&P Lab.
Link between P&P Lab and Maryam's PhD on Technology Transfer: Putting my research findings into action (Action Research). Research data pointed to public interest in the MFC science and in understanding how it works.
C. Questions raised:
-Training/briefing required for Students Ambassadors to prepare them for P&P Lab session. How long will it take? Will it be before each session?
-Do we need all the activities in the Planete Sciences learning journey? Bearing in mind the structure of our Prototype and Play Lab session.

Next action:
-Get confirmation from Laura about:
Session duration
Targeted age group

Figure 3.4: Excerpt of research diary.

c. Access and ethical considerations:

Integrity, quality and transparency had to be ensured when choosing an organisation for a case study. The Bristol Bio-energy Centre is part of the University of the West of England, and access to the research centre was negotiated through the intermediary of the Head of the department. Interview participants were employees of the Bristol Bio-energy Centre and the UKZN's WASH R&D Centre, who have taken part in developing the PEEPOWER technology. Consent was obtained from the director of the Research Centres before approaching employees for participation. This was initially done via email and then through face-to-face interaction. The participants were made aware that their responses would be anonymous. They were also given a choice to withdraw at any point in the interview process or afterwards. This was clearly outlined in the consent form given to participants beforehand (see appendix 1).
Access to partner organisations (Siemens Stiftung and Renewable World) and design sprint participants in the implementation phase of the Action Research also required given careful negotiation whilst maintaining integrity and transparency. As an incentive for participation, they were informed of the purpose of the research and its wider benefits. A Memorandum of Understanding (MoU)/NDA was produced and signed by all parties. Fundamental principles of research ethics such as protection of research participants, protection of integrity of the research community, transparency in research communication and avoidance of conflicts of interests and misleading reporting of research findings (Bell and Bryman, 2007, adapted by Easterby-smith *et al.*, 2015) were covered in the agreement document.

It is to be noted that the Director of the Bristol Bio-energy Centre was assigned to be part of the PhD supervisory team towards the end of the research. In order to manage the potential conflict of interest that may arise from working on a technology case study developed by a member of the supervisory team, specific due diligence measures were taken: (1) only sharing interview records and transcripts with other supervisors, not liaised with the PEEPOWER technology; (2) only sharing anonymised and analysed results with the Director of the centre All participants, answers were made anonymous. This arrangement was welcomed by the research centre's Director in order to maintain integrity and transparency of the research. Biases are said to be an inherent part of the participant observation research method. These biases can arise during observation by the researcher, during analysis of collected data and from participants who may consciously modify their way of working to align it with the research objectives. In the case of the current research, one way this was mitigated was to carry out interviews without joining the centre for participant observation; the researcher was able to collect detailed answers addressing challenging and lessons learnt from the technology transfer process. The research did notice a shift in the Centre's strategies focusing on prioritising knowledge transfer about the MFC technology. This was a positive implementation of research recommendations from the interview analysis, as opposed to a participant bias where a way of working is changed to align with the research.

3.2.3 Data analysis:

Data analysis is defined as the process of:

> *"...examining, categorising, tabulating, testing, or otherwise recombining both quantitative and qualitative evidence to address the initial propositions of a study."* (Yin, 2003, p.109)

In brief, it is the art of searching patterns in data (Neuman, 1997, p.426, cited by Kohlbacher). There are three main steps to qualitative data analysis, following Miles and Huberman's framework (Miles & Huberman, 1994; cited by Hair *et al.*, 2007 and Sekaran & Bougie, 2016). The first consists of data reduction, which involves simplifying large amounts of data collected and developing themes and patterns according to the research question, through coding and categorising data. The data collected is coded by labelling words or phrases with coding units. These coding units are then categorised by organising and classifying according to themes addressed in the literature review. This is known as deductive analysis. In the current research, this was followed by an inductive analysis of the data to identify significant themes that emerged from interviews but were not anticipated from the literature review. The second step is *data display*, where reduced data are then displayed in a condensed and organised manner through charts, matrices, diagrams or graphs, for instance. This helps to develop linkages and discover patterns. The last step is *drawing conclusions* by deciding on the meanings of identified themes and patterns; making contrast and comparisons. It is then essential to verify conclusions drawn by assessing their reliability and validity. These steps are not to be taken as a linear process from start to finish but rather as an iterative and continuous process. Throughout the process, consistency must be maintained in data coding and categorisation. The research outcome from case studies needs to be assessed against the researcher's prediction based on the literature review. This will ensure *reliability and validity* of analysis (Hair *et al*., 2007, p. 297).

Numerous analytical techniques are available for the categorisation and interpretation of qualitative data: constant comparison analysis, classical content analysis, pattern matching, explanation building, time-series analysis, logic models, cross-case analysis, qualitative comparative analysis, componential analysis, taxonomy analysis, domain analysis, observe-think-test-revise, classical content analysis (Baskarada, 2014). It is important to keep focus on the planned research objectives and allow it to lead to the choice of suitable analytical techniques so as not to get submerged in the multitudes of available tools. The method used in the current research was content analysis, which involved reading and re-reading the text to highlight meaningful passages.

The interview transcripts were first analysed using a deductive thematic approach, a top-down approach where a predetermined set of codes is used, and then excerpts found from the analysed text to fit those codes. Interviewees' answers were thus grouped into identified patterns or main themes predefined from the interview questions, such as 'what went well in during the trials?', 'what could have been done differently?' and 'what are the key recommendations for best practices in future field trials?' However, as other themes unexpected themes were seen to emerge from participants' answers, an induction coding approach was then used to complement the analysis. This was a bottom-up approach which involved exploring the interview transcripts and noting important themes brought up by the participants yet not directly related to the interview questions. About one-third of transcripts were initially coded manually (data from the Nairobi field trial). Although time-consuming, it allowed the researcher to proofread, get familiar with the text, and then analyse it with rigour and reflection. The transcripts were then re-analysed with the data computer-assisted qualitative data analysis software NVivo, along with the remaining data from the Kisoro and Durban field trials.

Other primary data from participant observation during team meetings and field visits were recorded in the form research diary and meeting minutes. These data gave the researcher a good understanding of the technology, and how it works, it also gave an insight into the challenges faced and key success factors in some of the projects. The main themes obtained from the interview analysis were further complemented and validated during the 18-month participant observation period. These themes were mapped out with the theoretical framework developed in the literature review.

A deductive thematic approach was carried out first, grouping interviewees' answers into main themes; then, an inductive analysis revealed other important themes that were not directly related to the interview questions. An overview of the data analysis process is given in the sub-sections below.

a. Interview transcription:

The recorded interviews were first transcribed using an automated transcription tool. A vast amount of text was generated from this (over 40,000 words of transcripts). These transcripts were then proofread line by line whilst listening to the audio recording in order to check for accuracy, remove injunctions and repetitions in speech and anonymised the text by replacing people's names with codes (reducing the text to be analysed to about 10,000 words).

b. Thematic analysis: Manual coding

A third of the transcribed documents were coded manually by re-reading the text and highlighting passages that answered the interview questions. There were patterns identified within the participants' answers. These patterns were then grouped into categories or codes (deductive analysis). Passages with insightful information not directly related to the questions in the interview guide were also highlighted (inductive analysis). The list of codes generated manually is shown appendix 2a.

c. Thematic analysis: Computer-assisted coding

These coding units are then categorised by organising and classifying according to themes addressed in the literature review. This is known as inductive analysis. In the current research, this was followed by a deductive analysis which consisted of reading the data to identify important themes that emerged from the interviews but were not anticipated from the literature review.

The themes or codes generated from the manual deductive and inductive analyses above were used to initiate computational coding. All the interview transcripts were uploaded to NVivo (the Computer-Assisted Qualitative Data Analysis CAQDA of choice). The list of codes generated manually was also uploaded to NVivo. All the transcripts were re-read line by line, and each passage was assigned a code or node (as referred to in NVivo) from the list in appendix 2a. Additional patterns were identified whilst re-reading the transcripts and added as nodes (or codes) in NVivo. A total of 146 nodes were created (see appendix 2b). These nodes could be grouped by field trial location (see Kisoro themes mapping diagram in appendix 3), and for each theme generated, a table of citations linked to that theme could be obtained (see appendix 4). These were later grouped into nine main themes according to their similarities (see figure 4.1). The transcripts were divided into two main samples: sample unit 1 (transcripts from Technology Provider) and sample unit 2 (transcripts from Technology Recipient). Passages from interview participants within these two samples were also categorised according to whether they were addressing technology transfer in Kisoro, Nairobi or Durban.

3.2.4 Validity and robustness

Triangulation of data by using multiple data collection methods and sources enhances the robustness and comprehensiveness of the research (Holtzhausen, 2001). In a purely qualitative research using case study approach, it was important to ensure validity and robustness of data and findings. This was done through the adoption of triangulation throughout the research: (1) the critical review of different key concepts in the literature review used for the development of the theoretical framework, (2) the use of different qualitative methods (collection of secondary and primary data) such as interview and participant observation, and (3) the adoption of inductive and deductive approaches in the analysis of interview data (see table 4).

Table 3.2: Triangulation of data and methods for research validity and robustness.

Theoretical framework based critical review of key concepts	Use of different qualitative methods	Use of different approaches in the analysis of interview data
• Definition of the concept of technology • Bozeman's model for effective Tech Transfer • Understanding absorptive capacity	• Primary data: transcripts of semi-structured interviews, minutes from participants' observation used to validate interview data • Secondary data: Meeting minutes, emails, presentation, reports and posters, press release	• Deductive analysis • Inductive analysis • Manual coding • Computer-aided coding using and data visualisation using NVivo

3.2.5 Methodological framework and Action Research plan:

The methodological framework summarising the Action Research steps and the research design is presented in Figure 3.5. Links to the research aim and objectives are also made.

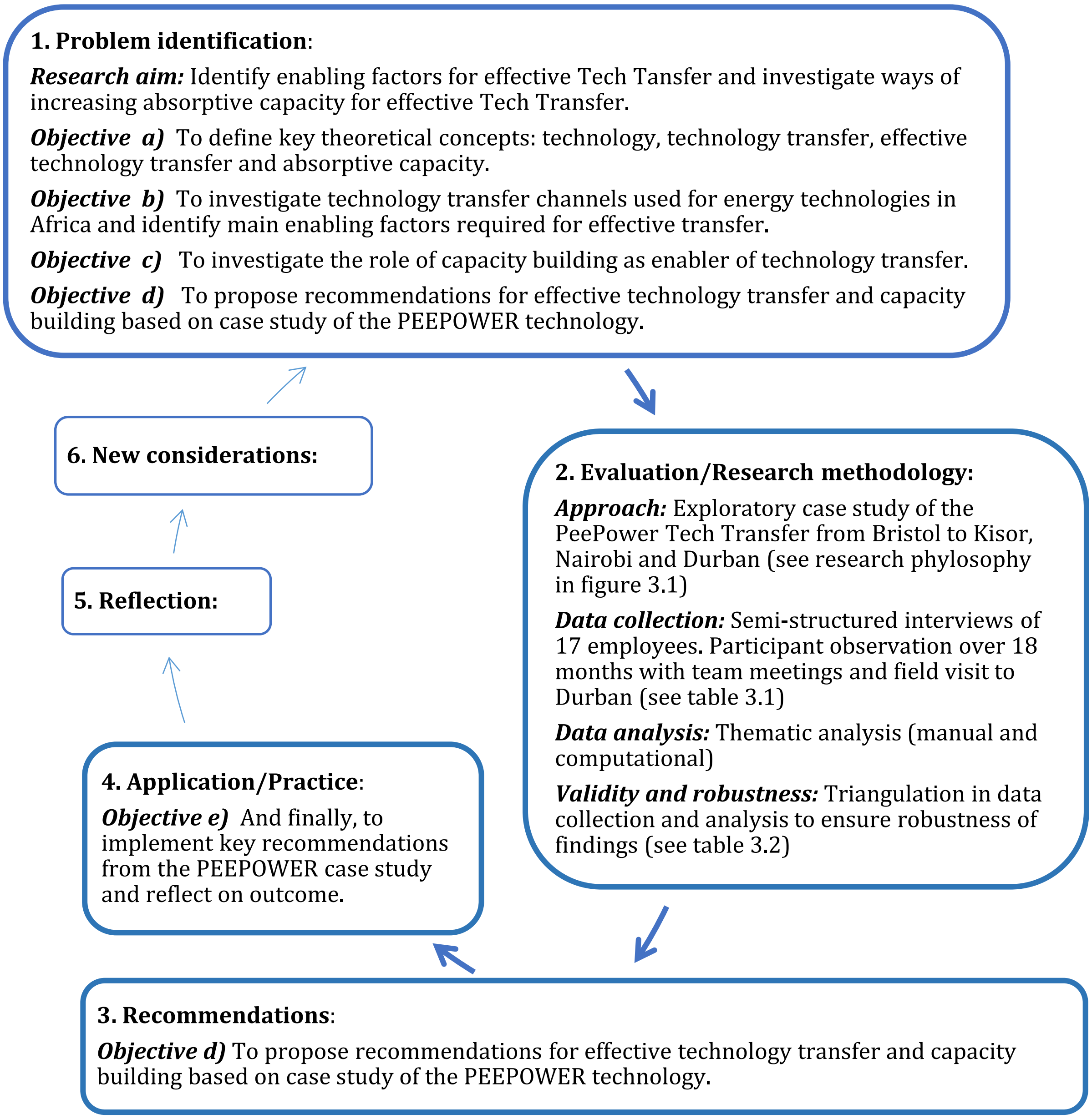

Figure 3.5: Methodological framework with Action Research steps.

CHAPTER 4: RESULTS AND DISCUSSION

Links to research objectives:

This chapter presents answers to research **objectives 4 and 5**:

- To what extend was knowledge sharing incorporated during The PEEPOWER transfer in Kisoro, Nairobi and Durban?
- What recommendations can be drawn from the PEEPOWER Technology Transfer?

Chapter highlights:

This chapter adds value to the body of knowledge by:

- Presenting the PEEPOWER technology on a '*techberg'* for ease of understanding of what needs to be transferred apart from the physical system;
- Presenting the main enabling and inhibiting factors for effective transfer of the PEEPOWER;
- Providing the Tech Providing team (BBiC) with insights on their strengths and challenges to anticipate future field trials;
- Using the conceptual framework developed to assess effectiveness of the PEEPOWER's Tech Transfer, based on knowledge and skill transfer and levels of Absorptive Capacity;
- Proposing a template Monitoring, Evaluation & Learning questionnaire applicable to Tech Transfer projects and
- Implementing key Action Research recommendations:
  1. The development of educational resources on Microbial Fuel Cells technology
  2. The development of a user manual for the PEEPOWER
  3. The design of a Microbial Fuel Cell toy
  4. And actions taken to make strategic changes within the PEEPOWER Research Centre

4.1 Findings from field trials evaluation in Kisoro, Nairobi and Durban:

80% of employees from the Tech Provider and Tech Recipient teams in Kisoro, Nairobi and Durban were interviewed using the interview guide presented in figure 3.2. The semi-structured interviews were conducted to uncover challenges faced during the transfer of the PEEPOWER in Kisoro, Nairobi and Durban, as well as success factors for effective technology transfer. The second objective of the interview, informed by models developed in the literature review, was to understand levels of absorptive capacity between the Tech Provider's and the Tech Recipient's teams and gather recommendations for future projects. Interview transcripts were analysed anonymously, manually and computationally using the thematic approach described in the previous chapter.

A summary of findings from the interview transcripts analysis is presented in table 4.1 below. These findings are further discussed in section 4.2 with the main recommendations presented in section 4.2.1.

Table 4.1 Summary of findings from end of trial evaluation interviews on the PEEPOWER transfer in Durban, Nairobi and Kisoro.

WHAT WENT WELL?	
Community acceptance and social benefits	In Kisoro: • The public was very enthusiastic about the technology. • The community requested more PEEPOWER installations. • The system provided lighting at night. Students were gathering near the toilet light to study when there was power cut in the village.
Overall project achievements	• The team was able to restore the system back to working order during maintenance visits (Durban, Kisoro, Nairobi). • Maintenance work and system decommissioning were carried out in a timely manner with the help of local partners. • The team was able to observe how the system performs in a real environment, learn from obstacles faced and identify type of maintenance work required. Improvements were made to the system based on lessons learnt from each trial.
Working with local partnership	• Access was gained by integrating an existing local project in Kisoro and Nairobi. • There was an excellent working relationship between the Durban and the Bristol team. • In Durban, having local contacts to help with community liaison, transport, logistics, installation, maintenance and decommissioning was helpful. • Durban's maintenance engineer was proactive and worked efficiently during maintenance and decommissioning. • School teachers in Kisoro and Nairobi kindly agreed to give regular updates about the system. • Communication between the Bristol team and Durban was timely and effective.
Interest in Microbial Fuel Cell science	• Staff members, visitors and users of the PEEPOWER system were fascinated by the process of getting electricity from urine, with many asking if *"it was magic".* • As a result, outreach activities were later organised in schools in Kisoro and Durban to demonstrate how the PEEPOWER Microbial Fuel Cell technology works.
Knowledge transfer	• Outreach activities, workshops and posters were used by local communities to learn about the technology during installation of the system in Kisoro and Durban. • Regular support was provided to the maintenance engineer during the Durban field trial. • Further training was provided post-decommissioning to ensure assimilation of knowledge gained by the maintenance engineer in Durban. Urine-tricity's main engineer held debrief sessions, one-to-one

	meetings and assessments with the maintenance engineer in preparation for a conference presentation. • Knowledge was being exchanged between the Bristol and Durban teams, with both partners learning from each other.
Performance of the electronic system	• The PEEPOWER had an efficient energy harvesting system. • The electronic system had useful features for data monitoring.
Performance of the MFC stacks	• The MFC stacks are robust and resistant in extreme environments and can continue to generate electricity whenever feedstock is added. • The MFC stacks could function independently of the electronic system.
Operating environment	• Despite maintenance challenges often faced (Nairobi), the operating environment emulated a real-world setting, and the team could observe how the system would perform outside a lab environment. • Mesh covers were added to the system to stop flies infestation.
Post-decommissioning (system disposal)	• In Durban, the system was dismantled and cleaned, reusable parts were kept by the UKZN WASH Centre and non-reusable parts were incinerated. • In Kisoro, the system was incinerated for IP protection as it could not be transported back to Bristol (regulations around waste import/export, carbon footprint). • The PEEPOWER enclosure built beside the toilet block in Thandanani (Durban) was kept for future use in other projects. In Kisoro, solar panels were installed on the rooftop to provide electricity.
Post-decommissioning (relationship management, giving back to the community)	• Some of the efforts made to maintain ties with local partners and give back to the local community include: - Nomination of partner schools in Kisoro and Nairobi to receive a copy of the book Pipe Dreams - Installation of solar panels post decommissioning of the PEEPOWER system in Kisoro - Funding applications to support Durban Maintenance Engineer in pursuing PhD research in Microbial Fuel Cells
Socio-cultural considerations	• Posters and workshops were used to address issues of improper toilet usage • The PEEPOWER could have been an incentive for men to use public urinals more often (which tends to be an issue, sometimes due to low hygiene conditions in public urinals).

WHAT WERE THE CHALLENGES FACED? WHAT COULD HAVE BEEN IMPROVED?	
Working environment	• The system was in an extreme operating environment with hardly any maintenance or cleaning in Nairobi. • The weather was very hot and humid, whilst staff wore full Personal Protective Equipment. • In Nairobi, there was no enclosure around staff members carrying installation work, and kids were gathering around, which was risky. • The system became infested with flies (Durban) and rodents (Nairobi).
Toilet configuration	• The system requires a purpose-built area for storing the PEEPOWER, and it needs to be at least a meter below the toilet to allow the feedstock to flow down into the system by way of gravity. • Although the two-storey container in Nairobi made it easy for the feedstock to flow from the toilets in the top storey into the system at the bottom storey, the system was exposed to cleaning water from the toilets above. • There was no workstation for the technicians in the two-storey container in Nairobi.
Knowledge transfer	• There was limited understanding from non-technical staff in Durban on the long-term vision for the PEEPOWER, its power capacity and the technology readiness level. • Local partners recommended the use of ‘the little but often’ approach when sharing knowledge, so they are not overwhelmed with lots of new information at once. • It would have been useful to involve all maintenance technicians during installation (however, this may not have been possible due to staffing logistics).
Expectations about the technology	• There were high expectations from the community about what the system could achieve. This could have been mitigated by ensuring good understanding of the system’s performance and capacity prior to installation.

	• Technical difficulties with the electronic systems made the lightings flicker, which affected users' perceptions and trust in the system's performance.
Performance of the electronic system	• There were challenges with corrosion and loose wiring in the electronic system, often causing lights to flicker and not switch on. • The electronic system had complex wiring and was delicate to maintain. • The lights used energy-efficient light bulbs, which are not locally available in the market. • The MFC stacks need regular feedstock to generate electricity, as the system relied on users sanitation habits.
Performance of the MFC stacks	• There was build-up of struvite at the bottom of the stacks when they were not regularly emptied. • The power capacity of the MFC system is currently lower than other renewable energy technologies. • A precise flowrate of the feedstock is needed for the system to work. • Regular maintenance and cleaning of the stacks needs to be ensured to avoid blockages. • There was voltage drop in cells when blockages occurred.
Socio-cultural considerations	• There were reported cases of improper toilet usage (Durban) and difficulties using Urine Diversion plates (Kisoro). • It is thus to be noted that electricity production with the PEEPOWER relies on local sanitation practices and behaviours. • Other socio-cultural challenges team members faced included language barriers and distressing first-time experiences in a slum environment for some technicians.
Local technical support	• In Nairobi, the lack of local technicians to support regular system maintenance was a major obstacle.
Post decom-missioning	• BBiC could not guarantee continuous maintenance of the solar panels installed in Kisoro.

RECOMMENDATIONS	
Community acceptance	• Local partners should first assess the project's feasibility in the chosen community. • Pre-installation visits from BBiC team members are recommended. • A good relationship should be established with the local community with the support of local partners. • The lesser change in habits required when using the PEEPOWER system, the easier it is for the community to adopt and use the technology.
Working environment	• Consider having a temporary enclosure/demarcation so staff members can carry out technical work safely. • Some of the safety measures when working in a slum environment were recommended as follows: stay accompanied by a designated local driver, avoid being on-site after sunset, keep car windows closed at all times, and work in a gated environment. • Cleanliness of surroundings and adequate coverage of the system must be ensured to prevent pest infestation.
Interest in Microbial Fuel Cell	• It was recommended to develop Microbial Fuel Cell education kits and resources for schools in the local community. • More educational outreach activities in schools were requested. • It was recommended to have public engagement workshops in local communities at the beginning of a field trial to raise awareness and initiate interest.
Knowledge transfer	• The team should provide more clarity on the long-term vision of the technology and should manage expectations about the system's power capacity. • The PEEPOWER system has a multidisciplinary aspect (electronics, microbiology, chemistry, social sciences) that needs to be taken into account, especially when delivering training or communicating with stakeholders from different specialities. • Exchange visits between research sites are recommended to foster relationships and facilitate knowledge transfer.

	• Knowledge is often transferred more effectively during casual conversations and informal meetings. • Maintenance technicians should be involved during installation. • Engagements with users about how the system works should be done proactively, not only because of improper usage. • It was recommended that a user manual is developed for local technicians and engineers in future trials. • Using the term 'knowledge exchange' may be more appropriate than 'knowledge transfer', as both parties are learning from each other. E.g. Local partners are better positioned to inform on local materials, spare parts and local manufacturing. • Local partners emphasised the importance of valuing community knowledge and consulting them. • Knowledge transfer needs to be done in a way that gives a sense of ownership to local technicians and end users.
Design	• It is important to understand users' needs when designing and developing the system. • Ensuring IP protection of the design innovation should be given high priority. • Propositions for further design improvements include increasing robustness of the electronic system, changing the system assembly to make it more accessible for maintenance and cleaning, and adding pest infestation protection measures (such as covers and nets).
Relationship management, giving back to the community	• Develop MFC educational kits to be given to schools in local communities, which would help enhance STEM education and raise awareness about Microbial Fuel Cell science.
Socio-cultural considerations	• Team members should be aware of social customs and etiquette • Liaising with local partners should be done by considering local socio-political hierarchies and approaching the right people. • Having a diverse team during decommissioning in Durban was said the facilitate communication between personnel. • It is important to understand local community practices and sensitivity around sanitation. • It is also important to understand the changes or disruptions a new technology may bring to the community. • There are ethical considerations regarding measuring or monitoring the amount of urine that feeds through the system from the toilets.
Suggestion for the PEEPOWER system going forward	• The PEEPOWER could be integrated with other sanitation systems (EOS, G2R toilets) for enhanced benefits. However, this may bring added complexity to the system. • Further modifications of the system were suggested to improve robustness and maintainability.

4.2 In-depth discussion of main themes from participants interview

The main findings from the three field trials (Kisoro, Nairobi and Durban) are based on transcript analysis of interviews with 80% of employees from the Tech Provider and Tech Recipient teams. These findings were then triangulated and supplemented with technical reports, posters and presentations provided by BBiC and UKZN, as well as notes taken during regular team meetings. The thematic analysis carried out using Nvivo generated 125 nodes grouped into 23 themes; nine of those themes were most relevant to the subject of the current paper –effectiveness of the transfer and Absorptive Capacity. A summary of those nine themes is presented in Figure 4.1 and further elaborated below. The theoretical framework developed from the literature review are mapped against empirical findings from the case study in Figures 4.7 and 4.8.

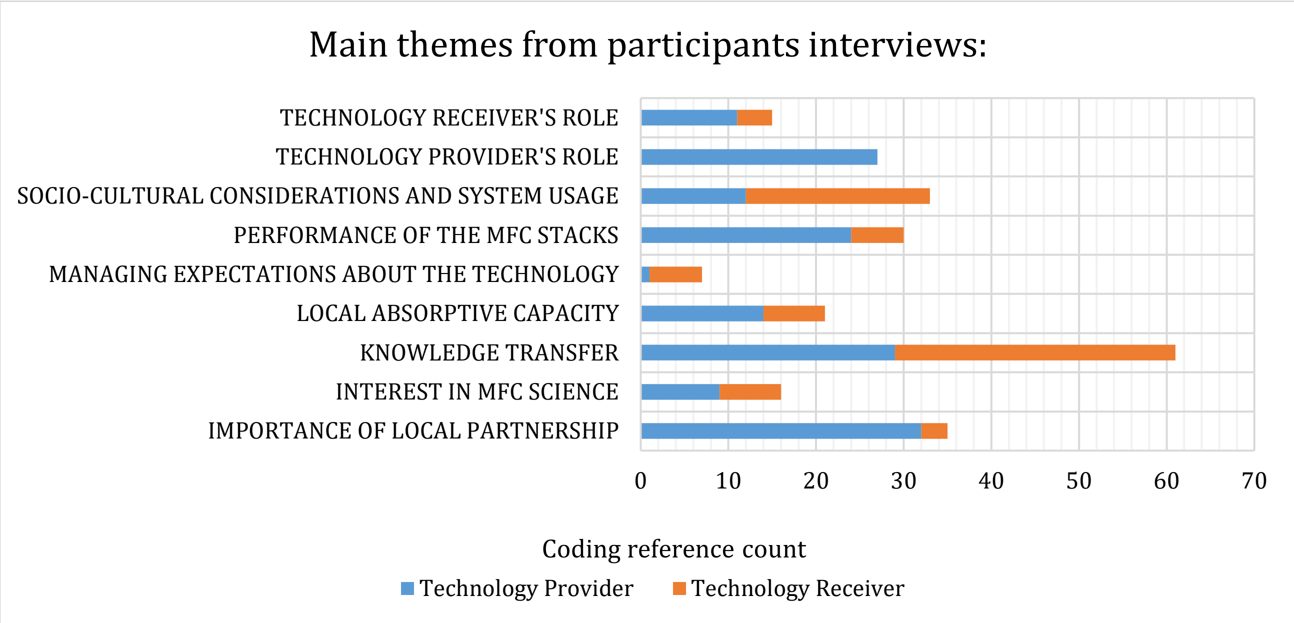

Figure 4.1: Thematic analysis of interview transcripts – presentation of main themes against coding reference count.

a. Roles of technology transfer parties:

In all three locations, the purpose of the transfer was for a fixed-term scientific trial in a real-world setting. The Tech Provider was responsible for installing the system, conducting need-driven maintenance visits and then decommissioning the system at the end of the trial. Maintenance tasks were carried out in a timely manner with the help of local technicians or unskilled local personnel provided by the technology recipient. Those maintenance visits were said to be valuable learning experiences for the Tech Provider, who was able to make continuous improvements on the system from lessons learnt during each field trial. In Kisoro and Nairobi, the PEEPOWER team did not have the opportunity to liaise with local technicians to carry out continuous maintenance tasks on the system, which was a real obstacle to the effective transfer of the technology. Durban was the exception, where the Tech Recipient provided a skilled maintenance engineer. The engineer was able to monitor and maintain the system during the whole trial effectively. Partnership was established in Durban with the

WASH R&D Centre (formerly known as Pollution Research Group – PRG) at the University of KwaZulu Natal and Khanyisa Projects, who carried out further experimental work in their laboratory facilities, provided the maintenance engineer and managed the relationship with the local community.

b. Importance of local partnership during international Tech Transfer:

This was a key factor for the successful implementation of the PEEPOWER project in all three locations. Local partners in Durban facilitated access to the community and coordinated the entire project implementation; a good relationship was established with the Tech Provider, who was "*impressed with the quality of support*" received. Access to communities in Nairobi and Kisoro and logistics were facilitated by collaborating with partners already working in the locality. However, the major obstacle in these two cases was the lack of available local technicians to maintain the system. The technology provider relied on schoolteachers on site to occasionally check the system and give updates. All the interviewees who worked on the Nairobi project commented on the difficulty faced from lacking a local technician to maintain the system in their absence.

c. Socio-cultural considerations during the PEEPOWER transfer:

Regarding collaborations between Tech Recipient and Tech Provider, there are local socio-political hierarchies to be aware of when establishing local partnerships. It needs to be done by approaching the right people. It is also good to be mindful of potential language barriers that may exist. Personnel from the Tech Provider team commented on the culture shock they experienced when visiting slum environments for the first time. They also commented on how they had to be mindful of local social customs and etiquette, especially when interacting with people. A staff member from the Tech Recipient team recommended having a diverse team, which may facilitate communication and interactions between personnel. These are considered non-technical knowledge and soft skills that are nonetheless needed (Saad, 2000; Li-Hua, 2007; Wahab et al., 2012).

With technology users, there were reported difficulties with using urine diversion plates added to the toilets when the PEEPOWER system was installed. Furthermore, waste other than urine was poured down the urinals, causing blockages in the system. There were also unexplained reasons for improper toilet usage. Posters and workshops had to be used to clarify correct toilet practices needed for the system to operate (see figure 4.2). In doing so, it is essential to acknowledge local community practices and sensitivity around sanitation discussions. One also needs to understand the level of changes or disruption in users' habits that the new technology may bring. With the PEEPOWER system, this is particularly important, as the system relies on correct use of the toilet in order to continuously generate electricity. Following a workshop with the local community, it was said that the PEEPOWER may have been an incentive for men to start using public toilets. Despite this formerly being an issue due to low hygiene conditions often found in public toilets. Another point highlighted by the interviewees were the ethical considerations that come with measuring urine flow rates in school toilets. Though this data was needed to monitor the system and adjust settings, an alternative measurement (power output) had to be taken instead and converted to meaningful data.

Figure 4.2: Usage poster with do's/don'ts signage, displayed by local partner Khanyisa Project and UKZN WASH Centrer, near the toilet cubicles in Durban. Image credit: UKZN WASH Centre.

d. Performance in real-world settings and public's expectations:

The PEEPOWER is an innovative Microbial Fuel Cell technology emerging from its R&D phase. As with the transfer of many innovative technologies, there are added challenges due to the fact that, the technology is transferred from one country to another, is also undergoing a vertical transfer from R&D to the market. It was thus important to observe how the PEEPOWER would perform in a non-controlled lab setting. Interview participants from the Tech Provider and Tech Recipient teams reported that the PEEPOWER's MFC stacks were robust and resistant in extreme environments and could continue generating electricity even with minimal to no maintenance. However, blockage of MFC stacks often occurred, resulting in voltage drop and poor system performance. As such, regular maintenance was still needed to avoid struvite build-up and pest infestation. The Tech Recipient's team tackled the issue of pest infestation in Durban by adding a steel mesh cover to the system.

In a real-world setting, the performance of the PEEPOWER relies on the sanitation habits of users. Awareness campaigns before the system installation and information posters near the system were thus paramount to encourage adequate usage (see figure 4.2). Another aspect to consider in a real-world application is the configuration of the installation area. The PEEPOWER system required a purpose-built area located at least one meter below the toilet to allow the feedstock to flow down by way of gravity. The system required regular cleaning to avoid blockages and infestation. Technicians needed to wear full Personal Protective Equipment before carrying out system maintenance and cleaning. This was reported to be challenging during long hours of maintenance sessions, especially in hot climates.

The PEEPOWER was said to have an efficient energy harvesting system. However, with a complex wiring, system maintenance was more challenging. It was also found that more anti-corrosive materials would need to be used for the wiring, especially in humid countries. The wiring connections also needed to be more secure to avoid disconnection during regular cleaning of the MFC stacks. With these technical challenges, the lights could not switch on at times, thus affecting users' perceptions and trust in the technology.

There was high expectation of the system from the local community. A lack of explanation of the system's capacity and limitations at the installation's onset caused unrealistic expectations of what the system could achieve. It is, therefore important to be clear about what the system can or cannot do. The Microbial Fuel Cell system was highly robust and could operate in extreme conditions, however, struvite build-ups often occurred when the system was not drained, causing blockages which affected its performance. The system also relied on frequent usage of toilets to produce enough electricity.

e. Interest in MFC science:

Staff, visitors, technology users and students alike were all fascinated by the idea of producing electricity from urine. There was much interest in the science of Microbial Fuel Cells, as shown in the following quotes from participants: *"the fact that you can get that (electricity) from urine to me despite being an engineer, it still kind of shocks me"* (Tech Recipient); *"as a technologist, I am fascinated by it"* (Tech Recipient); *"something I never thought would ever happen in my lifetime"* (Tech Recipient); *"the teachers were actually interested and were asking us lots of questions"* (Tech Provider); *"getting lots of interest from the girls from more of an academic point of view (…) they're really interested in the science"* (Tech Provider).

The Tech Provider and Tech Recipient teams organised outreach activities in schools in Kisoro and Durban to demonstrate to pupils how Microbial Fuel Cells work. Figure 4.3 below shows a photo taken during a school workshop in Kisoro. The WASH Centre in Durban also kept demo models of the Microbial Fuel Cells in their laboratory for use during educational school visits (see figure 4.4). Educational posters were used on the installation site in Durban for visitors to read about the PEEPOWER and the MFC technology (see figure 4.5). There was widespread demand for MFC educational activities in the secondary school where the system was installed in Nairobi. However, the technical team could not accommodate for that during their short maintenance visit.

Figure 4.3: PEEPOWER Project Manager delivering a workshop in a school in Kisoro on how the Microbial Fuel Cells technology works.
Photo credit: Bristol Biorenergy Centre BBiC.

Figure 4.4: Small windmill motorised toy powered by Microbial Fuel Cells presented by a technician at UKZN during a school visit.
Photo credit: UKZN WASH Centre.

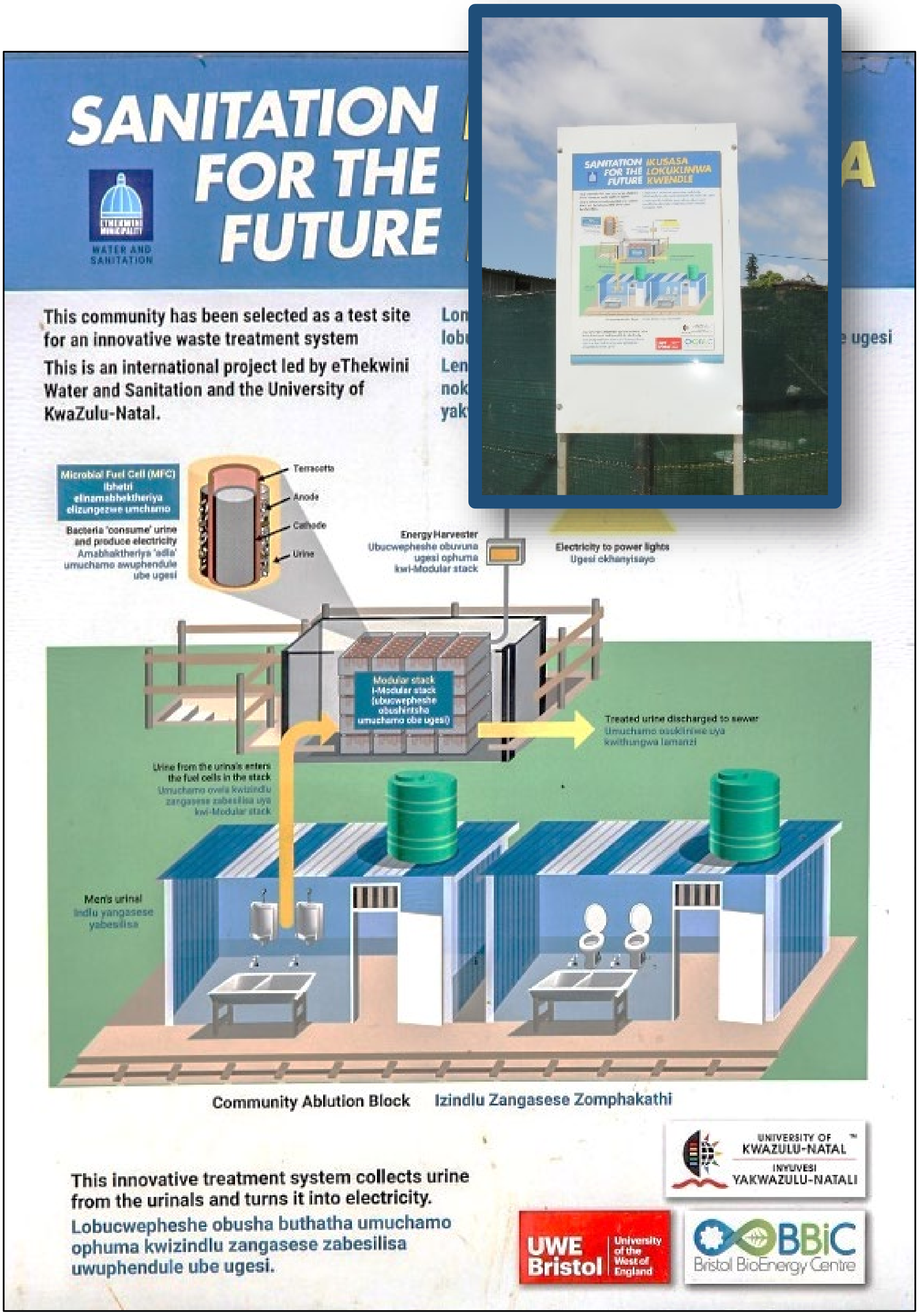

Figure 4.5: Poster displayed near the installation site in Durban explaining how the PEEPOWER works.
Photo credit: UKZN WASH Centre.

f. Knowledge transfer and absorptive capacity:

This was the most discussed theme (see coded reference in appendix 4), given that the interview questions were set to capture the extent of knowledge transfer between the technology provider and the technology recipient.
In Durban, extensive support was provided to the local maintenance engineer responsible for the PEEPOWER system. Knowledge transfer took place in the form of meetings, presentations and one-to-one discussions before system installation, during the project and post-decommissioning. One of the recommendations was to use the 'little but often' approach when it comes to knowledge transfer and training instead of only relying on intensive days of workshops and presentations. Communication between Tech Provider and Tech Recipient was said to be timely and effective throughout the project. Senior management personnel from the Tech Recipient team expressed the need to understand the long-term vision of the innovative PEEPOWER technology and for clearer communication about the power capacity of the system and its technology readiness level. Durban had a transdisciplinary platform that facilitated collaboration between the Tech Provider, the Tech Recipient and the municipality.

In Nairobi and Kisoro, knowledge transfer was minimal due to lack of availability of local technicians. The Tech Provider, however, recognised the potential for local manufacturing of key ceramic components of the systems, as ceramic materials were locally available at lower cost. There was also a recognition of the value of community knowledge, especially in helping the Tech Provider understand the local context and identify users' needs. It became apparent that when it comes to knowledge sharing during international Tech Transfer, there may need to be a shift from unidirectional knowledge transfer where knowledge is only expected to be transferred from the Tech Provider to the Tech Recipient. Instead, there is a need to emphasise the importance of knowledge exchange between Tech Provider and Tech Recipient, which can also give an empowering sense of ownership of the technology to the Tech Recipient.
Further recommendations were made by interviewees regarding the need for (1) IP protection of the technology before knowledge transfer/exchange, (2) more involvement of maintenance technicians during installation, (3) the use of the 'little but often' approach when sharing new and complex knowledge, (4) creation of a user manual or maintenance guide for local technicians and (5) exchange visits between universities.

With regards to absorptive capacity, local labour involved in the installation in Kisoro acquired a basic understanding of how the system works. In Nairobi, there was no local labour or technician involved; it was therefore difficult to comment on the level of absorptive capacity in this case. The highest level of absorptive capacity of all three locations was found in Durban; with an excellent understanding of how the systems works, the necessary facilities to independently carry out most maintenance and repair work and even adapt the system to the local environment (see figure 4.6). This made exchanges with the technology provider a lot easier.

What is important to note here is that this assessment of local absorptive capacity within the context of the PEEPOWER field trials, to a certain extent, focussed mainly on the skills, understanding and capabilities of individuals working with the technology and the availability of adequate facilities within partner organisations. As such, it cannot be generalised to represent absorptive capacities at national or regional levels (in Durban, Nairobi and Kisoro).

Figure 4.6: Lab facilities in the WASH Centre of UKZN, showing two cascades of the PEEPOWER system used for testing and training. Photo credit: UKZN WASH Centre.

4.2.1 Mapping of empirical findings to the theoretical framework:

Two theoretical frameworks were developed during the literature review phase of the research: a *"techberg"* and a model for assessing technology transfer effectiveness.
A good understanding of the PEEPOWER technology was acquired from interviewing and working with technicians and researchers who had developed the technology. The PEEPOWER could thus be presented on the *"techberg"* (see figure 4.7). At the summit of the iceberg model are the product, the hardware, and the PEEPOWER system. Then, underneath the iceberg are additional elements needed to transfer the technology. These are technical knowledge and skills required to operate, maintain, and manufacture the PEEPOWER and other non-technical knowledge skills needed for a successful transfer (e.g. effective communication with multidisciplinary stakeholders, socio-cultural consideration of users' practices). An observation from this mapping was that knowledge and skill transfer does not only occur from the Tech Provider to the Tech Recipient. Rather, the idea of knowledge exchange between partners may seem more appropriate. For instance, in the case of the PEEPOWER, knowledge of local materials and spare parts, local manufacturing methods, users' needs, and local market were all transferred from the local Tech Recipient to the Tech Provider.
A funnel diagram depicting levels of effectiveness of transfer was drawn from the conceptual framework mapping out absorptive capacity and technology transfer (see table 2.2). This funnel diagram (shown in figure 4.8) allows a simple visualisation of the technology transfer effectiveness model with a focus on levels of skills and knowledge transferred. A more elaborate list of what is considered non-technical knowledge and skills to be transferred is shown. These skills include social and cultural knowledge relating to the context –as was seen in the case of the PEEPOWER. Indeed, with the PEEPOWER, knowledge of local sanitation practices was a major factor to be taken into consideration by the Tech Provider; to be able to develop an appropriate technology that meets its users' needs.

The partitioning of the diagram in sections and the position of makers is not a proportional measure of level effectiveness, rather, it should be seen as a simplified, visual representation of the framework. The markers (K), (N) and (D) on the diagram are thus simple indications of the extent of technology transfer and knowledge sharing in Kisoro, Durban and Nairobi and the levels of absorptive capacity of the technology recipient with respect to the PEEPOWER. As pointed out previously, Tech Providers also have a lot to learn from Tech Recipients, such as sociocultural challenges and understanding the local market and materials. Although the model presented mainly focuses on elements transferred by the Tech Provider, the point remains that Tech Providers and Tech Recipients should consider effective technology transfer as a process involving knowledge exchange with mutual learning from partners, as opposed to a one-way knowledge transfer process.

It is to be clarified that the proposed framework is not a tool for measuring the effectiveness of a Tech Transfer. Rather, its purpose is to help Tech Transfer actors gauge and visualise their Tech Transfer effectiveness (using Bozeman's Scientific and Human Capital as the main criteria for effectiveness). It helps Tech Transfer actors identify what is needed from each party in order to facilitate knowledge sharing.

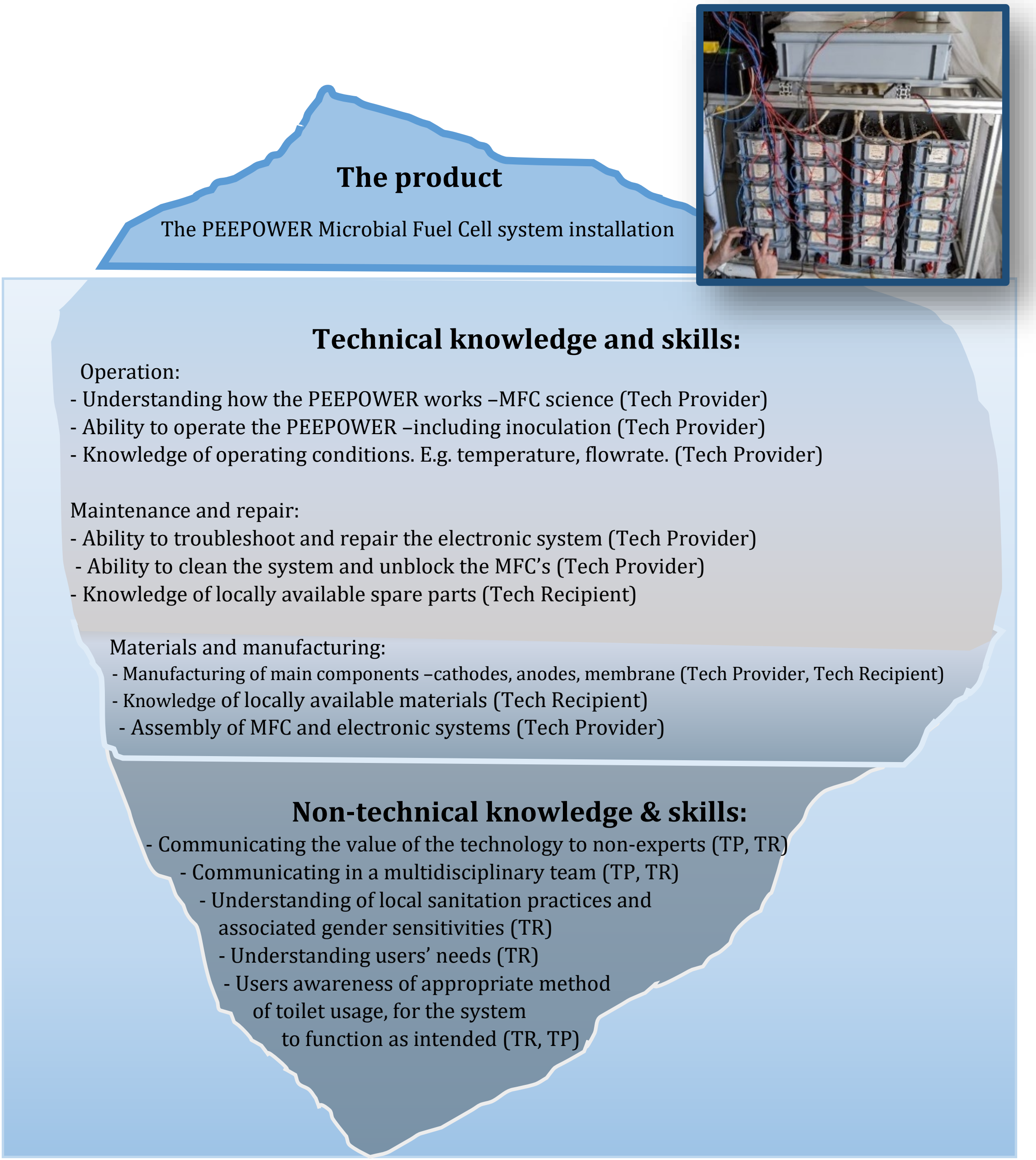

Figure 4.7: PEEPOWER technology represented on a *"techberg"* –TP and TR denote transfer from the technology provider and the technology recipient, respectively.

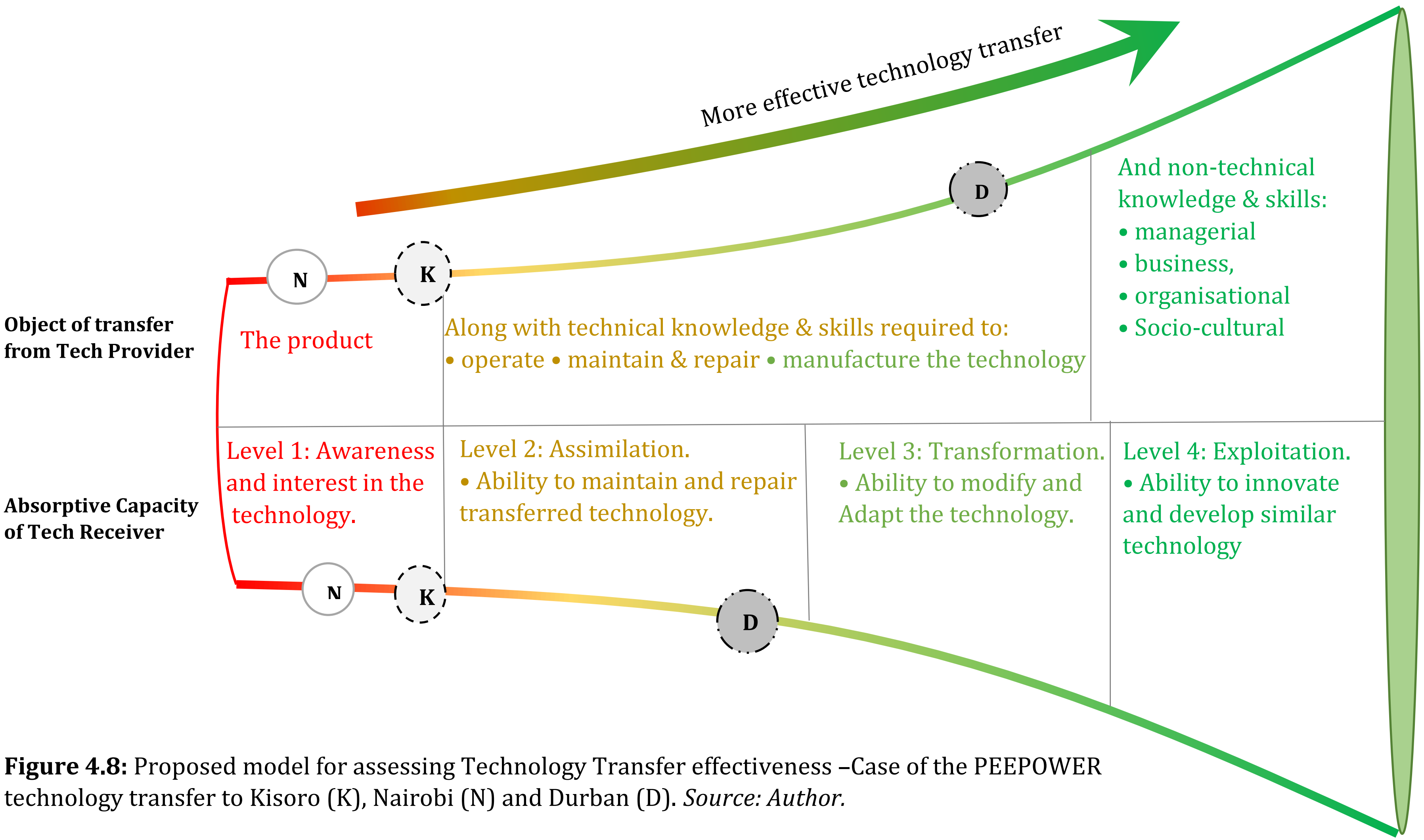

Figure 4.8: Proposed model for assessing Technology Transfer effectiveness –Case of the PEEPOWER technology transfer to Kisoro (K), Nairobi (N) and Durban (D). *Source: Author.*

4.3 Action Research implementation:

Key recommendations were drawn from the above data analysis regarding factors that would enable the effective transfer of the PEEPOWER technology. These included: the establishment of good relationships with local partners, consideration of the socio-cultural context in the design and implementation of the technology, public engagement to foster technology acceptance and adoption, education about MFC science to promote technology adoption and also increase absorptive capacity, management of expectation about what the technology can achieve, strong knowledge exchange between Tech Recipient and Tech Provider, use of locally available parts in the system to facilitate local maintenance and repair. These recommendations were then taken as key actions to be implemented in the research: (1) the development of educational MFC resources, (2) the design and development of an MFC toy, (3) strategic changes to enable independent maintenance and repair of the system by the Tech Recipient and (4) the development of a Monitoring, Evaluation and Learning (MEAL) questionnaire for future projects.

Figure 4.9 reiterates the research aim defined at the beginning, the main findings from the data analysis, key recommendations and main practical actions implemented during the research.

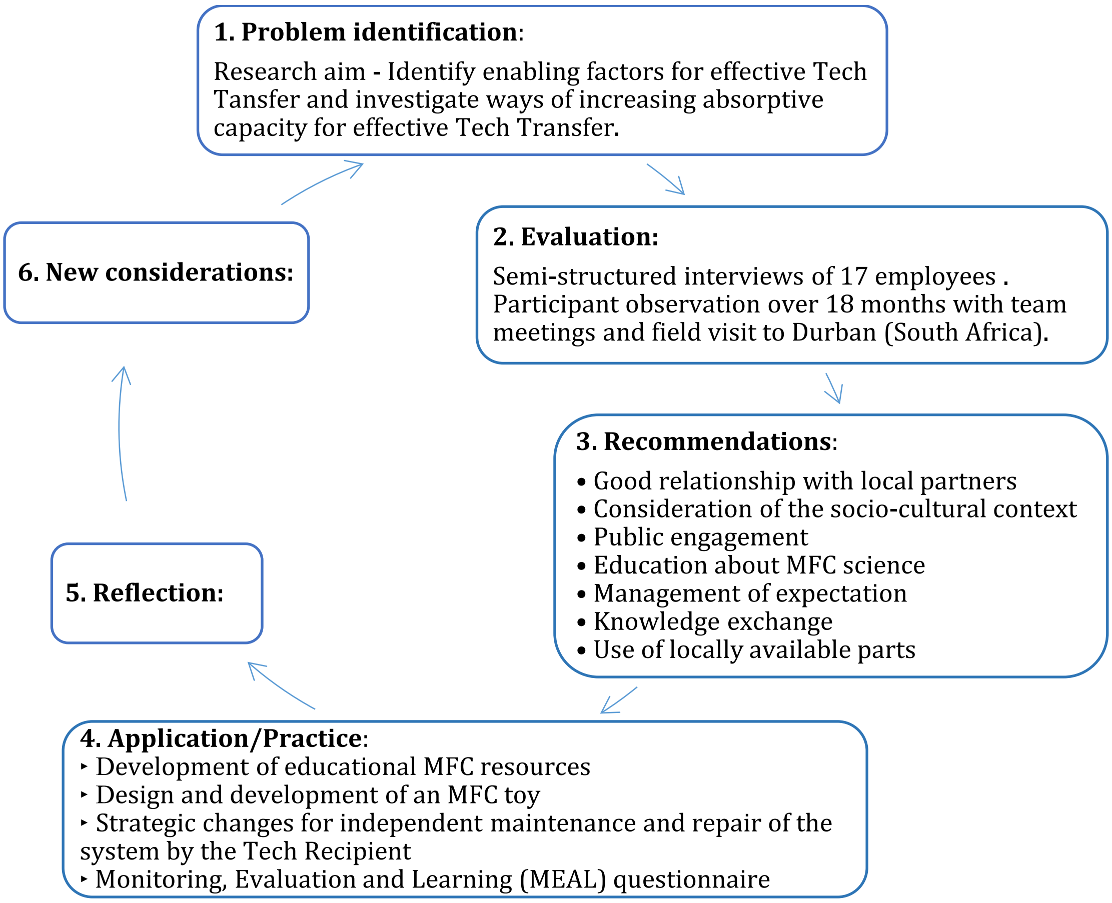

Figure 4.9: Action Research diagram –recommendations and strategic actions implemented.

4.3.1 Action 1 –Development of educational resources in collaboration with Siemens Stiftung and DETI:

Why?

The PEEPOWER technology generated a lot of curiosity about Microbial Fuel Cell science from Tech Recipients and the general public in Kisoro, Nairobi and Durban. The first action taken was thus to support the BBiC team in developing engaging educational resources on MFC science that can be used in schools worldwide. The Research Centre (BBiC) has been running outreach activities in schools for four years to help pupils gain more interest in MFC science and the PEEPOWER as an innovative green energy source. The current research gave further insights into the positive impact of these outreach activities on absorptive capacity and public engagement. These recommendations were taken on board by the BBiC.

How?

The researcher dedicated time and efforts to editing and refining learning resources provided by the Centre and then contacted various STEM organisations that would be interested in running similar workshops in schools. Going a step further, the researcher also partnered with the Communication Team of DETI (Digital Engineering Technology and Innovation), another university centre, to promote science and technology.

What outcome?

DETI's Communication Team edited the learning materials professionally, with added illustrations making it engaging and appealing to school pupils. Siemens Stiftung, the Social Corporate Responsibility (SCR) branch of Siemens in Germany, agreed to partner up with BBiC to translate the learning resources and make them available to schools in various parts of the World. This partnership was a major achievement. An overview of resources developed in collaboration with DETI and Siemens Stiftung is shown in figures 4.10 and 4.11.

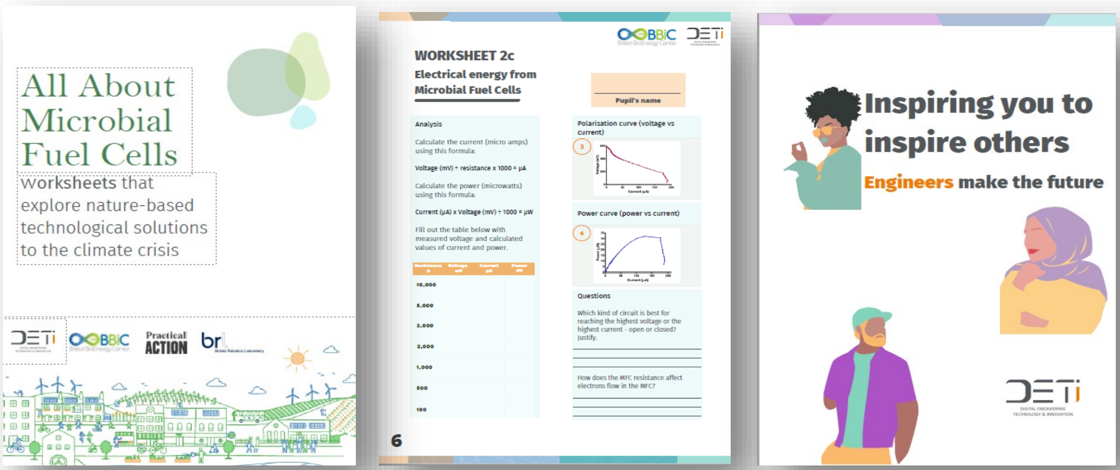

Figure 4.10: Learning resources developed in partnership with DETI.

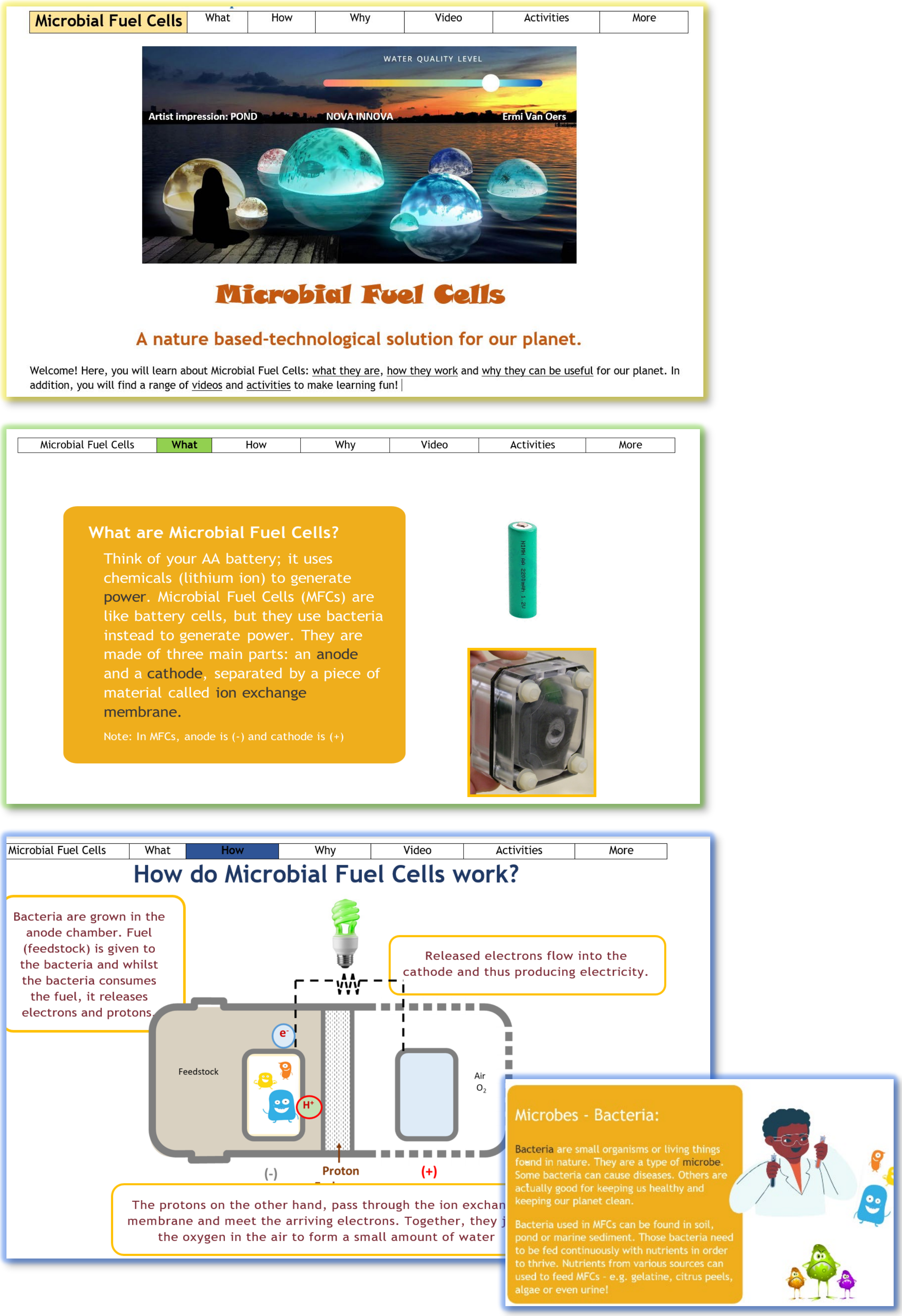

Figure 4.11: Overview of webpages to be published on Siemens Stiftung's learning platform and translated into several languages.

4.3.2 Action 2 –Design and development of an educational MFC toy:

Why?

With noticeable public interest in how the PEEPOWER technology works, the need to educate and raise awareness was important for BBiC. Developing an educational MFC toy for commercialisation was the first step in facilitating a vertical transfer of the PEEPOWER from R&D to the market. Furthermore, the educational toy would be a valuable resource for hands-on STEM education, thus further enhancing absorptive capacity and public engagement.

How?

The researcher played multiple roles in designing and developing the MFC toy and took major steps to reach a positive outcome. First acting as Design Facilitator, the researcher ran four Design Sprint workshops with BBiC staff members to gather ideas on how to turn current BBiC's educational resources into marketable products. Appendix 7a shows the Design Sprint brief given to BBiC staff members, and Appendix 7b shows staff contribution. The researcher also developed a design brief to be integrated into the Masters' Group Project module (see Appendix 7c), then supervised the student group project on the MFC toy design. Taking it a step further, the researcher proactively searched for funding opportunities and completed bidding applications. Appendix 8a shows a business case written by the Researcher for bids that would help recruit an Engineering Intern that would oversee the development and manufacturing of the toy (the job description created by the Researcher is shown in Appendix 8b). Throughout this process, the researcher also actively proposed possible design solutions, refining design concepts produced by participants, developing a costing plan for the toy and getting involved with the IP application process.

What outcome?

The Masters' students proposed an innovative toy that would allow users to learn about Microbial Fuel Cell science in an engaging manner (see figure 4.12). The toy was modelled as a giant bacteria that can light up when fed by muddy water over a few days. A mini voltmeter included in the kit would allow the user to measure how much electricity is generated as the Microbial Fuel Cells are fed. The design of the "Bio-Battery", as the toy was named, was further refined by the researcher who also proposed to have an App that can be used for graph plotting and other interactive learning games about MFCs. The researcher's design sketches and the proposed budget costing are shown in figure 4.13 and table 4.2, respectively. Application for the funding scheme, Student Engagement with Research Project, advertised by the Faculty, was successful. A total of £1,500 was given by the scheme to recruit an Engineer Intern. The Engineer Intern worked for a month on developing a toy prototype and was supervised by the Researcher and members of the BBiC team. After months of closely working with the University's Technology Transfer office, steps were taken to protect the product under the 'registered desi category'.

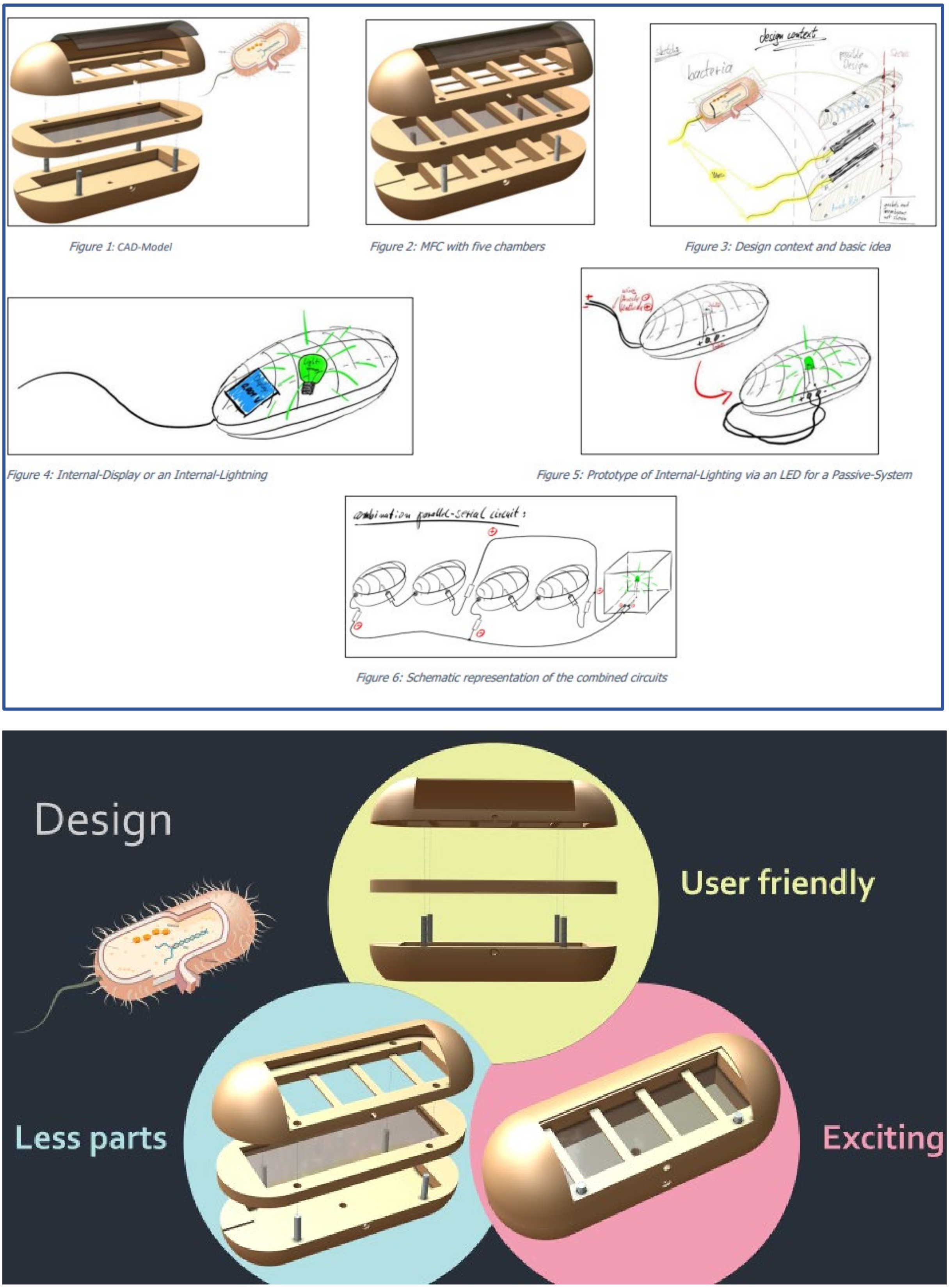

Figure 4.12: Design solutions proposed by Masters' students, showing different assemble options and final CAD model.

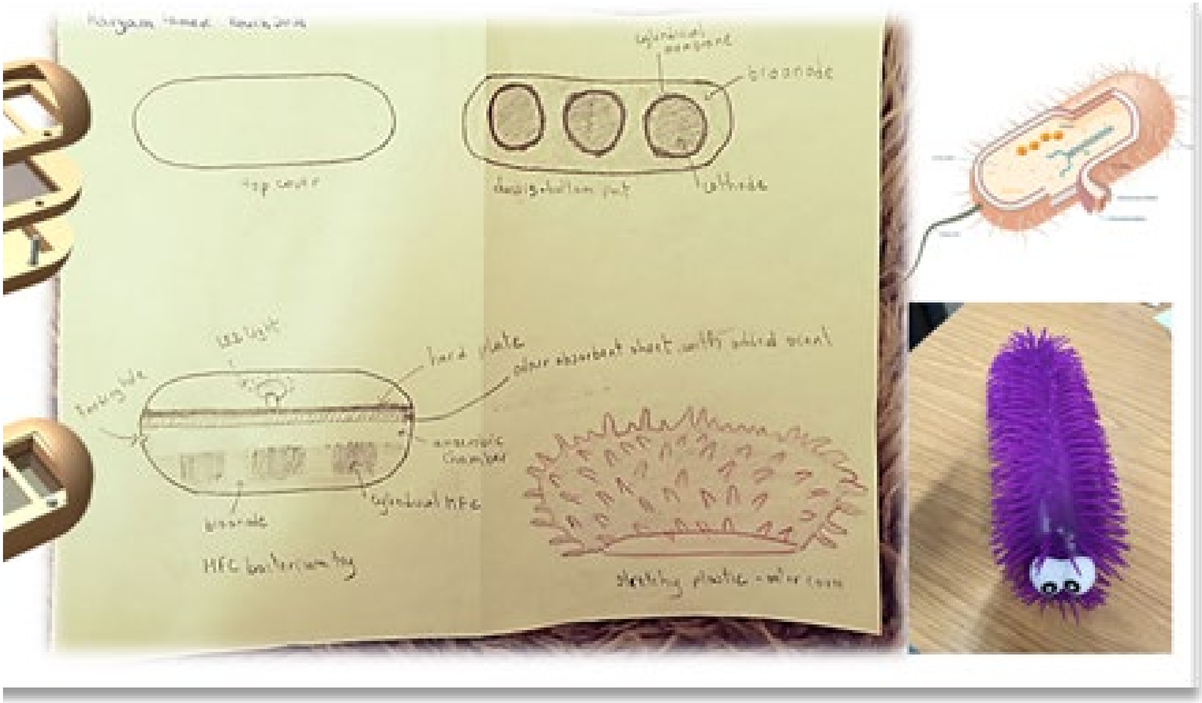

Figure 4.13: Further development of the design and material selection by the Researcher - soft, stretchy, rubbery cover for the bacterial look and feel, repurposed from existing toys.

Table 4.2: Costing and bill of materials of one prototype.

Parts	Material specification	Cost
Main parts		
Top cover	Plastic (transparent)	£1.00
Bottom cover	Plastic (sturdy)	£1.00
LED light		£4.00
Outer cover (bateria look)	Rubber (soft, stretchy)	£3.00
Microbial Fuel Cell	BBiC's Cylindrical MFC	£5.00
Intergrated digital voltmeter		£1.60
Dividing plate	Plastic	£1.00
Odour absorbent sheet	Sack filled with activated charcoal	£5.00
Possible add-ons		
App	For tablets and phones	
PH sensor	For soil	£7.00
Humidity and temperature gauge		£3.00
Packaging		
User manual	Printed booklet	£2.00
Packaging	Cardboard box	£3.00
Total		**£21.60**
Total with optional add-ons		***£36.60***

4.3.3 Action 3 – Strategic changes to enable independent maintenance and repair by the Tech Recipient:

Why?

In the literature review, it was pointed out that during International Technology Transfer, Tech Recipients often end up over-relying on Tech Providers for continuous maintenance and repair of the system installed. This was seen to be the case with the PEEPOWER in Nairobi and Kisoro (Durban being the exception). The Researcher took proactive steps to help mitigate this issue.

How?

The first step was to work with BBiC to update and edit their existing maintenance and repair manual. The researcher produced a clear and user-friendly version by making the following changes to the original draft provided by a BBiC Maintenance Engineer:

- Re-structuring the manual for clarity and ease of understanding.
- Proofreading and re-phrasing the text for ease of understanding by someone not familiar with the PEEPOWER system
- Adding health and safety instructions and hazard warning symbols where required.
- Incorporating feedback provided by local technicians in Durban during participant interviews.

The next step was to look for partners in Nairobi that could help with ongoing maintenance of the PEEPOWER. The Researcher contacted various UK charity organisations working in Nairobi and local universities to establish partnerships.

What outcome?

The outcome of the development of the maintenance and repair manual is presented in appendix 6. A copy of the original draft provided is shown, followed by the updated version produced by the Researcher. The researcher also managed to secure a successful partnership with the UK charity organisation Renewable World, agreeing for their local technician to dedicate part of his time to working on the PEEPOWER installed in Nairobi (See Non-Disclosure Agreement in appendix 9). This was a significant relief for BBiC, unable to access their system for a long period due to COVID travel restrictions. The researcher worked closely with BBiC throughout this partnership, organising and chairing meetings and overseeing the NDA drafting, signing, and following up on expense payments. The updated maintenance and repair manual developed was also given to the local technician in Nairobi for usability testing.

4.3.4 Action 4 – Development of a Monitoring, Evaluation and Learning (MEAL) questionnaire for future projects:

Why?

Monitoring, Evaluation and Learning (MEAL) is a best practice recommendation in large-scale projects. It allows informed decision-making by learning from what worked and went wrong, making it easy to replicate success.

How?

The interview questionnaire used during data collection allowed the researcher to understand what went well and what could have been done differently during the PEEPOWER transfer. The interview guide (from figure 3.2) was then turned into a template MEAL questionnaire, which not only evaluation the delivery/installation phase of the project but also considers the pre-installation phase, the maintenance phase and the decommissioning phase (shown in table 4.3)

What outcome?

The template MEAL questionnaire developed was given to BBiC for future project evaluation. It was passed on to the project funder, Gate's Foundation, as a best practice recommendation for similar projects. The MEAL questionnaire proposed puts an emphasis on evaluating knowledge sharing and community engagement in the preliminary phase of the project. It also highlights important steps to consider once the project has ended (post-decommissioning): sharing lessons learnt with partners, giving back to the community and maintaining good relationships for further collaboration opportunities.

Table 4.3: Proposed template questionnaire for Monitoring Evaluation and Learning (MEAL) during future projects.

1. PRE-INSTALLATION PHASE	
Consider the following: - Transport and logistics - System installation process - Teamwork and communication - Knowledge and skills sharing (during trainings, meetings, one-to-one exchanges) - Other	
WHAT WENT WELL?	**WHAT COULD HAVE BEEN DONE DIFFERENTLY?**
List 3 or more points • • •	List 3 or more points • • •

2. INSTALLATION PHASE	
Consider the following: - Transport and logistics - System installation process - Teamwork and communication - Knowledge and skills sharing (during trainings, meetings, one-to-one exchanges) - Other	
WHAT WENT WELL?	**WHAT COULD HAVE BEEN DONE DIFFERENTLY?**
List 3 or more points • • •	List 3 or more points • • •

3. MAINTENANCE PHASE	
Consider the following: -Transport and logistics - Maintenance tasks - System performance - Teamwork and communication - Knowledge and skills sharing - Other	
WHAT WENT WELL?	**WHAT COULD HAVE BEEN DONE DIFFERENTLY?**
List 3 or more points • • •	List 3 or more points • • •

4. DECOMMISSIONING PHASE	
Consider the following: - Transport and logistics - System decommissioning process - Overall achievement - Teamwork and communication - Knowledge and skills sharing - Other	
WHAT WENT WELL?	**WHAT COULD HAVE BEEN DONE DIFFERENTLY?**
List 3 or more points • • •	List 3 or more points • • •

5. POST-DECOMMISSIONING PHASE – MOVING FORWARD	
Collaboration and communication with the partner post-decommissioning: - Are there plans to maintain collaboration and communication with the partner post-decommissioning? C - If yes, what are the measures in plan for ongoing collaboration? - If no, what would you recommend?	**Yes / No / Unknown** Please expand on your answer:
Giving back to the community - Are there plans of giving back to the community involved in the field trial? - If yes, give examples of what has been / will be done - If no, what would you recommend?	**Yes / No / Unknown / Not applicable** Please expand on your answer:
Sharing lessons learned from the trial - Are there plans of sharing lessons during the field trial? - If yes, through what avenues (paper publications, conferences, other) - If no, why?	**Yes / No / Unknown / Not applicable** Please expand on your answer:

OTHER
Any other comment?

CHAPTER 5: CONCLUSION AND FURTHER WORK

This last chapter presents a summary of what was achieved in the research, from theoretical insights in the literature review to empirical findings and discussions, as well as the overarching methodology used.

5.1 Achievement of research aims and objectives:

The current research sought to answer the question of *"How can adequate knowledge transfer be facilitated to ensure effective technology transfer?"* The main aim was to investigate enabling factors for the effective transfer of the PEEPOWER with a particular emphasis on Absorptive Capacity. The following research objectives were addressed:

a) *To define key theoretical concepts: technology, technology transfer, effective technology transfer and absorptive capacity:*

A conceptual definition of technology was derived from an in-depth review of literature. In its broad sense, technology is an artificially created product or process (Morris, 2014). Beyond just the hardware, the concept of technology also includes associated skills, knowledge and expertise (Li-Hua, 2007). That was represented as a *"techberg"* in a conceptual framework (**figure 2.1**). Based on this comprehensive understanding, technology transfer was thus defined as the movement of technology along with associated knowledge and skills across geographical boundaries, sectors, firms (horizontal technology transfer) or from R&D to the market (vertical technology transfer). The research focussed on the international transfer of the PEEPOWER from the UK to Uganda, Kenya and South Africa, with discussions on the vertical transfer of the innovative PEEPOWER from R&D to the marker (see an overview of Tech Transfer models in **figure 2.2**). Effective technology transfer was defined using Bozeman's (2000) conceptual framework. The framework spanned across seven effectiveness criteria (Bozeman et al., 2016): (1) the reception of technology by the transferee, (2) the commercial impact of the technology transfer, (3) the impact on the wider regional or national economy, (4) the impact on scientific and human capital, (5) the effect of technology transfer on enhancing public values, (6) resulting political benefits and (7) other opportunity costs resulting from the technology transfer activities (see **figure 2.4**). The primary focus of this research was an in-depth look at the Scientific and Human Capital criterion for effective tech transfer. That led to further exploration of how knowledge sharing can improve scientific and human capital during tech transfer. A pre-requisite for effective knowledge and skills transfer was for the tech recipient to have high Absorptive Capacity in areas of expertise related to the technology. Absorptive Capacity was defined as the ability to acquire, assimilate, transform and exploit transferred knowledge. A chronological timeline showing the evolution of Absorptive Capacity was presented (see **figure 2.5**).

b) To investigate technology transfer channels used for energy technologies in Africa and identify the main enabling factors required for effective transfer:

Looking at energy technologies in particular and within the context of Africa, it was found that various channels are used for tech transfer: Trade, Licensing, Franchising, Subcontracting, Turnkey Agreements, Support Contracts, Foreign Direct Investment FDI and Foreign Aid. Several factors were identified as enablers of effective tech transfer (e.g. financial, political, environmental or human factors). In the context of the current research, where the focus was placed on scientific and human capital impact as effectiveness criteria (Bozeman et al., 2016), some tech transfer channels were found to be more effective in knowledge and skills sharing than others (see **Table 2.1**).

c) To investigate the role of capacity building as an enabler of technology transfer:

It was shown in **table 2.2** and **figure 2.5** that when the tech recipient has high Absorptive Capacity, it creates an enabling environment for adequate knowledge and skills sharing and, thus, effective technology transfer. That is because, with high Absorptive Capacity, Tech Recipients can easily acquire transferred knowledge and independently maintain, repair, modify and adapt the transferred technology.

d) To propose recommendations for effective technology transfer and capacity building based on the case study of the PEEPOWER technology:

A detailed insight into the case of the PEEPOWER technology transfer from Kisoro, Nairobi and Durban was presented (**sections 4.2** and **4.2.1**). Data were collected and analysed using a qualitative approach, as summarised in the methodological framework in **figure 3.5**. **Table 4.1** showed a summary of what went well during the PEEPOWER transfer, what could have been done differently and key recommendations made as follows: good relationship with local partners, consideration of socio-cultural context, public engagement, education about MFC science, management of expectation, knowledge exchange and use of locally available parts.

e) And finally, to implement key recommendations from the PEEPOWER case study and reflect on the outcome:

As an Action Research Case Study, implementing the research recommendations was central to the work. The researcher took pro-active steps to implement the following strategic actions:

- Establishing partnerships with institutions at national and international levels for the development of user-friendly, educational MFC resources for schools.
- Leading the design and development of an innovative MFC educational toy through design sprint facilitation (with staff, students and an engineer intern), IP protection and bidding.
- Implementing strategic changes to enable independent maintenance and repair by the Tech Recipient through the development of the PEEPOWER maintenance and repair manual and the facilitation of an agreement with Renewable World to support the maintenance of the system in Nairobi.
- Developing a Monitoring, Evaluation and Learning (MEAL) questionnaire for future projects.

5.2 Concluding remarks from empirical findings:

Using semi-structure interviews, participants' observations and a field visit to Durban as primary methods of data collection. Empirical findings in the PEEPOWER case study were obtained from a combination of deductive and inductive analyses using both computational and manual coding. It ensured robustness of findings. Concluding remarks of the research can be summarised as follows:

- *The 'Techberg':*

The researcher proposed this conceptual model to illustrate how the concept of technology is comprehensive. Technology was defined as the hardware or artefact (tip of the iceberg) and the associated skills, knowledge and expertise needed to develop, maintain, operate and manage the technology (hidden part of the iceberg).

- *Knowledge transfer is essential for effective technology transfer:*

During a tech transfer process, the focus should go beyond the mere transfer of hardware, and there should be an exchange of knowledge and skills required to install, maintain and manage the technology.

- *The extent of knowledge and skills transfer depends on the tech transfer channel used:*

Technology transfer mechanisms such as trade, licensing, subcontracting and some turnkey agreements were found to accentuate technological hardware acquisition. For better transfer of technical and non-technical knowledge and skills, integrated support contracts and franchising agreements were found to be more appropriate. With FDI and foreign aid, platforms for knowledge and skills that enhance local capabilities could be created if technology transfer parties agreed.

- *Knowledge and skills transfer is more effective when technology recipients already have high absorptive capacity:*

Technology recipients need to have prior R&D knowledge relating to the technology, as well as skilled personnel and adequate infrastructures, to be able to assimilate and exploit external knowledge acquired. In the case of the PEEPOWER technology, Durban was found to have the highest absorptive capacity compared to Kisoro and Nairobi, which resulted in a more successful transfer (see **figure 4.8**).

- *The effectiveness of the Tech Transfer process is not only defined by the level of knowledge and skilled transferred to the technology recipient:*

Though the scope of the research was limited to knowledge and skills sharing as main parameters for defining effective Tech Transfer, Bozeman's comprehensive model was acknowledged, highlighting other effectiveness criteria that could be accounted for.

- *Importance of good local partnerships during international technology transfer:*

Interview participants pointed to the fact that having strong local partnerships was a key factor for the successful implementation of the PEEPOWER project in Kisoro, Nairobi and Durban. Local partners in Durban facilitated access to the community and coordinated the entire project implementation. Nairobi's and Kisoro's local partners also enabled community access and helped with logistics.

- *Socio-cultural considerations during the PEEPOWER transfer:*

There were local socio-political hierarchies to be aware of when establishing local partnerships. Language and cultural differences were also a challenge at times. With technology users, there were reported difficulties with using urine diversion plates added to the toilets, along with other challenges around correct system usage; these were addressed through the information posters and community workshop (see **figure 4.2**). Adoption of innovative technologies is more successful when it brings minimal disruption to current habits of the technology users. Another socio-cultural point to consider was the local population's sensitivity to discussing sanitation issues.

- *Management of expectations about innovative technologies:*

There were high expectations from the local community about the PEEPOWER performance. A lack of explanation of the system's capacity and limitations at the onset of installation caused unrealistic expectations of what the system could achieve. Though the Microbial Fuel Cell system was found to be highly robust and could operate in extreme conditions, there were reported issues of waste build-ups when the system was not drained, causing blockages and affecting system's performance.

- *Interest in MFC science.*

Staff, visitors, users and students alike were all fascinated by the idea of producing electricity from urine. The Tech Provider and Tech Recipient teams organised outreach activities in schools in Kisoro and Durban to demonstrate to pupils how Microbial Fuel Cells work. The WASH Centre in Durban also kept demo models of the Microbial Fuel Cells in their laboratory for use during education visits by local schools. Educational posters were used on the installation site in Durban for visitors to read about the PEEPOWER and the MFC technology (see **figures 4.2** and **4.5**)

- *Knowledge transfer/exchange between Tech Providers and tech recipients in Durban, Kisoro and Nairobi:*

In Durban, extensive support was provided to the local maintenance engineer responsible for the PEEPOWER system. Knowledge transfer took place in the form of meetings, presentations and one-to-one discussions before system installation, during the project and post-decommissioning. In Nairobi and Kisoro, however, knowledge transfer was minimal due to the lack of availability of local technicians. Recommendations made for knowledge sharing were: (1) ensuring IP protection of the technology before knowledge transfer/exchange, (2) having more involvement of maintenance technicians during installation, (3) using the 'little but often' approach when sharing new and complex knowledge, (4) creating simple maintenance and repair manual for local technicians and (5) having exchange visits between universities. Lastly, it was highlighted that knowledge and skill transfer does not only take place from the Tech Provider to the Tech Recipient. Instead, the idea of knowledge exchange between partners may seem more appropriate. For instance, in the case of the PEEPOWER, knowledge of local materials and spare parts, local manufacturing methods, users' needs, and local market were all transferred from the local Tech Recipient to the Tech Provider.

- *Absorptive capacity in Kisoro, Nairobi and Durban:*

Local labour involved in the installation in Kisoro acquired a basic understanding of how the system works. The highest level of absorptive capacity of all three locations was found in Durban. In Durban, UKZN had the necessary facilities to maintain the system independently; staff understood how the system works and could adapt it to the local environment (see **figure 4.6**). It made exchanges with the technology provider a lot easier. Durban had a transdisciplinary platform that facilitated collaboration between Tech Provider, Tech Recipient and the municipality.

- *Framework for assessing Tech Transfer effectiveness:*

A funnel diagram depicting levels of effectiveness (shown in **figure 4.8**) was presented. The model allowed a simple visualisation of technology transfer effectiveness levels in Kisoro, Nairobi and Durban. It also presented an elaborated list of what was considered non-technical knowledge and skills for the PEEPOWER transfer.

5.3 Suggestions for further work:

One of the main areas of contribution of this research was the development of theoretical frameworks and models. The *'techberg'*, representing the concept of technology on an iceberg, was tested with the PEEPOWER. This model could be used with other technologies and would make it easy for Tech Transfer parties to visualise technical and non-technical skills to be transferred. An area of further work would be the use of the *'techberg'* to represent other technologies.

The researcher also proposed a model that can help Tech Transfer parties to assess the level of effectiveness of their Tech Transfer visually. It is to be noted whilst the model presented does not serve the purpose of measuring Tech Transfer effectiveness, it can certainly help gauge and visualise how well knowledge transfer is being incorporated and received. This model can be used during planning phases, throughout the Tech Transfer process or/and after completion. One main limitation of the model is the fact that it does not account for knowledge exchange between parties, but only focusses on knowledge transfer from the Technology Provider to the Technology Recipient. Furthermore, whilst the models developed were tested with the innovative PEEPOWER during an international Tech Transfer, implementation with different technologies and different types of Tech Transfer would determine how practical the tools are and whether it needs to be refined and adapted to each case. This would be an area of further research.

Further implementation and testing of the proposed framework for assessing Tech Transfer effectiveness in various projects would be insightful.

The main limitations with the research methodology includes a level of subjectivity associated with qualitative research. This was mitigated through triangulation of data to allow for increased reliability of findings and generalisation. Time limitations also meant the full Action Research cycle could not be completed or repeated during the study. This could be a follow-on research project to complement this research.
Furthermore, with regards to data collection, travel constrains during the COVID-19 pandemic, limited availability of travel funds, meant field visits could not be carried out to Kisoro and Nairobi, as it was done in Durban. Most interviews also had to be conducted online (as opposed to face-to-face). However, a part for technical challenges associated with online interviews, such as sound quality (which can affect accuracy of interview transcripts) there was no considerable impact on the data collected; and the triangulation methods used also ensured validity of findings.

Lastly, as the research scope was limited to one particular criterion of Tech Transfer effectiveness, an area of further work could involve exploring other effectiveness criteria from Bozeman's comprehensive model. Highlighting these opportunities for new considerations thus completes the Action Research cycle, as shown in figure 5.1.

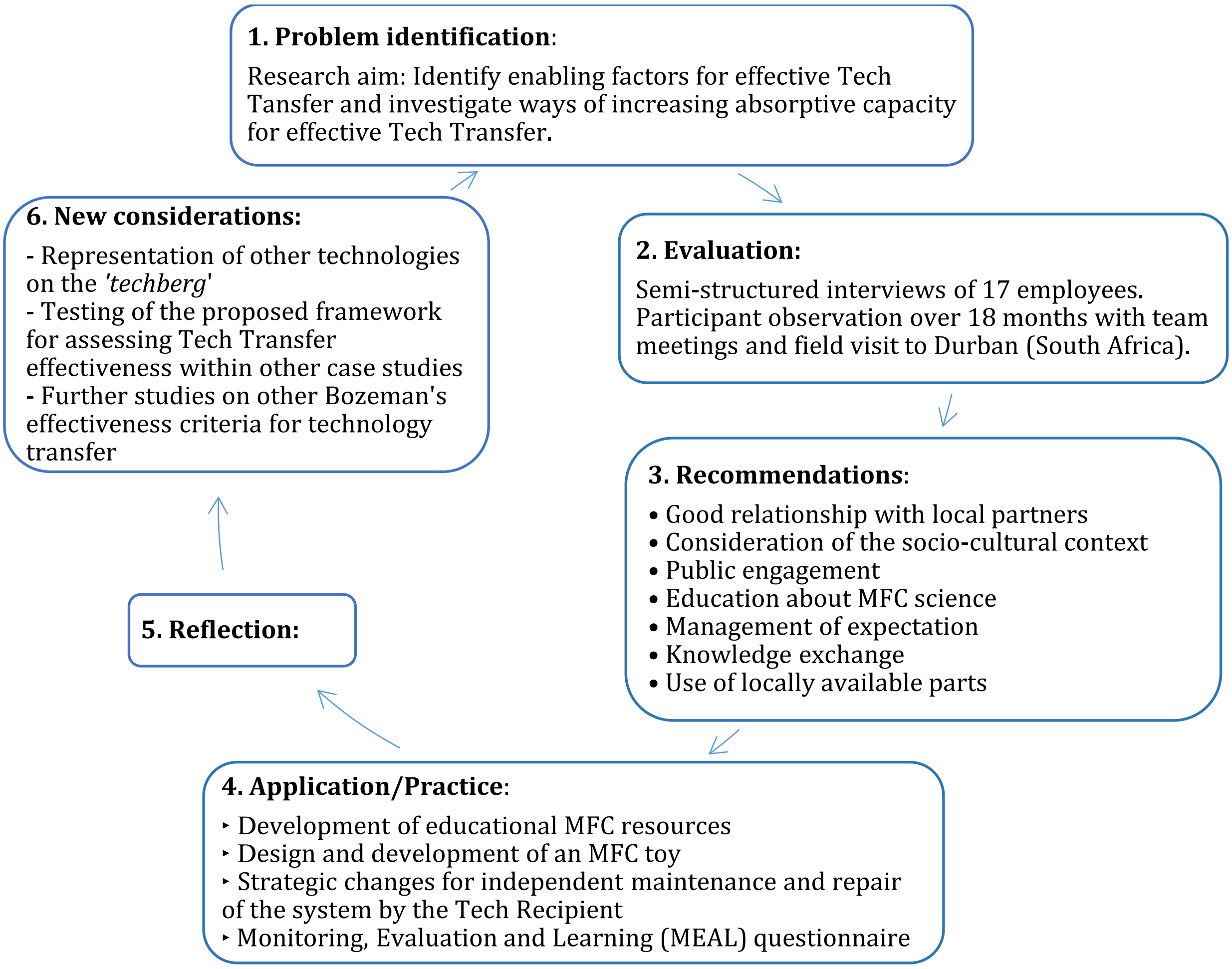

Figure 5.1: Summary of Action Research process and findings.

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APPENDIX 1: Consent form – Interview participation

Consent form:

Project title: Local capacity building and the transfer of energy technologies for electricity access – the context of Africa.

This consent form is provided with the Participant Information Sheet. Please ensure that you have read and understood the information contained in the Participant Information Sheet. If you have any questions please contact the researcher at **Maryam.Lamere@uwe.ac.uk.**
If you are happy to take part in the **interview**, please read the following statement, then sign and date the form:

- I have read and understood the information in the Participant Information Sheet which I have been given to read before asked to sign this form;
- I have been given the opportunity to ask questions about the study;
- I have had my questions answered satisfactorily by the research team;
- I agree that anonymised quotes may be used in the final Report of this study;
- I understand that my participation is voluntary and that I am free to withdraw at any time until the data has been anonymised, without giving a reason;
- I agree to take part in the research

Name (Printed)……………………………………………………………………………

Signature…………………………………………………… Date…………………….

Thank you for agreeing to take part in this study.

You will be given a copy of this Participant Information Sheet and your signed Consent Form to keep.

APPENDIX 2a: List of codes or themes generated from manual coding

1. Local contacts (participant number: 001, 004, 006, 008, 009, 011)
    a. Gaining access by integrating an existing project –Kisoro, Nairobi (001, 008, 009)
    b. Lack of local technicians has been a major obstacle –Nairobi (004, 006, 008, 011)
    c. Feedback about system's performance provided by local teacher –Nairobi (006, 009, 011)
    d. Having local contacts to support transport logistics, installation, maintenance and decommissioning, was helpful –Kisoro, Durban (001, 007)
    e. Good relationship between Durban team and UK team
2. Interest in the MFC science and technology (Ref: 001, 006, 009, 011, 014, 017)
    a. Users/visitors were interested in (fascinated by) the MFC science/technology –Kisoro, Nairobi, Durban (001, 006, 009, 011, 014, 017)
    b. Recommendation for more educational outreach to educate about MFC science –Kisoro, Durban (001, 009, 014)
    c. Recommendation for MFC educational kit and textbook for schools
3. Toilet configuration (Ref: 001, 006. 009)
    a. Advantage of toilet configuration in Nairobi: two-storey toilet so easy flow of the feedstock into the system. (001, 009)
    b. Disadvantages of the toilet configuration in Nairobi: Exposed to cleaning water above (001)
    c. Disadvantages of the toilet configuration in Nairobi: No workstation for the technicians (006, 009)
    d. Purpose built area for system storage –Kisoro, Durban (001)
4. Description of the environment where the system operated (Ref: 006, 004)
    a. Extreme environment, hardly any maintenance or cleaning of the system –Nairobi (006)
    b. Hot weather whilst wearing lab coats –Nairobi, Durban (006, Patrick/Josh, my own observation in Durban)
    c. Similar to real word setting –Nairobi (004, 008)
    d. Settlement with illegal electicity – Durban (013)
5. Task carried out by Technology Provider –Nairobi (Ref: 011)
    a. System restored to working order during maintenance visit (011)
    b. Maintenance work carried out in timely manner (011)
    c. Very good collaboration with the Durban team
6. Pest infestation (Ref: 004, 006, 011, 016, 017)
    a. By rats –Nairobi (011)
    b. By flies –Durban (004, 016, 017)
    c. Solution: Covering the top boxes with steel mesh (011)
    d. ***Recommendation: Ensure cleanliness of the system surrounding, to avoid pest infestation***
7. Performance of the MFC stacks (Ref: 006, 003, 012, 017)
    a. Resistant and can operate in extreme conditions –Nairobi (006)
    b. Works independently of the electronic system –Nairobi, Durban
    c. Produces electricity so as long as the urinals are used, continuous feedstock is needed for power generation –Nairobi, Durban (Ref: 001, 004)
    d. Regular maintenance requirement –Kisoro, Nairobi, Durban (006, 009)
    e. Require precise flow rate of feedstock
    f. Stacks assembly makes it difficult to service
    g. Voltage dropping in single cells due to blockage
8. Performance of the electronic system (006, 009, 012, 017)
    a. Lights not turning on

b. Batteries or new components required to get lights back on
c. The electronic system was complex and delicate/fiddly/ not robust (012, 014, 017)
d. Useful features for data monitoring (004, 006, 005)
e. Wiring of the electronic system –Durban
f. Impact of users trust in the technology performance
g. Corrosion issues

9. Positive about learning experience
    a. Able to observe how the system performs in a real environment (006)
    b. Know what kind of maintenance is required for the system (006)
    c. Improvements made to the system following lessons learnt from previous trials (009)
    d. Learning from obstacles in previous trials –Durban, Nairobi
10. Safety considerations in slum environment (Ref: 009)
    a. Avoid working after sunset (009)
    b. Always stay accompanied with designated local driver (009)
    c. Work in a gated environment (009)
    d. Keep car windows closed at all time (009)
11. Socio-cultural considerations (Ref: 001, 009, 004, 005, 008, 016)
    a. First time experience in a slum environment for some technician –Nairobi (004, 009)
    b. Being respectful of local socio-political hierarchies and approaching the right people –Kisoro (001)
    c. Ethics –Nairobi (008)
    d. Being aware of social etiquettes –Kisoro (009)
    e. Language barrier
    f. Important to understand what changes/disruptions a new technology will bring in the community
    g. PeePower electricity productions relies on local sanitation practices and behaviours. E.g. Men using urinals or not; people knowing how to use urine diversion toilets. (Ref: Cathy 013, Gill 001) **(theme 16 to 11)**
    h. Importance of understanding local community practices and behaviour around sanitation
    i. Gender element associated with the technology
    j. Recommendation for my Technology iceberg: add 'other social, cultural knowledge' E.g. Local sanitation practices
    k. Being sensitive about sanitation

12. Community acceptance (Ref: 001, 011)
    a. Pre-installation visits recommended
    b. Local partners to first assess feasibility of the project in the community
    c. The lesser the change in habits the easier it is for the community to adopt and use the technology

13. Other- Location of the field trial
    a. Working in a remote village (Kisoro) vs slum (Durban, Nairobi) (009)
    b. Kids gathering around, which made it hard to carry out installation
    c. Not clear if Nairobi some teachers and students had dorms within the school premises or if it was just a day school.
14. Role of Technology Receiver (Ref: 001,
    a. In Durban: planning and organising; monitoring and analysing from a scientific point of view (001)

b. Positive feedback about maintenance engineer –Durban (004)
c. Liase with the community

15. Integrating the PeePower to other sanitation technologies. E.g. EOS toilet (Ref: Becky 012, Cathy 013)
    a. Enhances benefit of the system (PeePower + EOS toilet)
    b. Addresses the issue of lack usage of urinals by men, therefore limited amount of urine obtained
    c. "where you've got urinals, you have other facilities such as hand washing and other"
    d. Level of complexity associated with integrating systems
    e. ***Recommendation: Have a field trial with PeePower integrated into the EOS toilet or the G2RT (Generation 2 Reinvented Toilet) to see the benefits and possible challenges.***
16. Knowledge exchange platform between Tech Provider, Tech receiver (intermediate agents) and Tech Users
    a. Transdisciplinary platform
    b. Valuing community knowledge
17. Post-decommissioning
    a. Community disappointed and sad
    b. Giving back to the community post-decommissioning
    c. Giving back with MFC kits to educate and empower children in the community
18. Logistics of system transportation (Ref: 001
19. The system brought social benefits to the pupils in Kisoro (Ref: 001, 003, Jiseon's article)
20. System usage
    a. Difficulties with using Urine Diversion plates and improper toilet usage (Ref: 001, 012)
    b. Posters and workshops used to address issues of improper toilet usage (001)
    c. PeePower may have been an incentive for male to start using the urinals more often, therefore address hygiene issues associated with weeing around in the neighbourhood/ bushes. (Cathy 013)
    d. Grey water down the urinal
    e. Low usage of urinals due to hygiene and sanitary conditions
    f. Recommendation: These should be done proactively, before installation. Not as a response to improper usage.
    g. [27] Unexplained reason for toilet misuse
21. Local absorptive capacity (Ref: 001)
    a. Understanding of how the system works by locals –Kisoro, Durban
    b. Ability to maintain and repair the system
    c. Ability to adapt and innovate
    d. What makes Durban's Absorptive Capacity high
    e. Two layers of Absorptive Capacity (the intermediate agent and the users)
22. Knowledge transfer (Ref: 001)
    a. Subjects needed to understand the PeePower system
    b. Recommendations made for further improvement
    c. knowledge exchange, transfer from Durban team to the UK team
    d. Timely and effective communication between Durban team and UK team
    e. Knowledge transfer post installation in Durban
    f. Knowledge transfer at the end of the Durban project
    g. Support provided to local maintenance engineer
    h. Involving local engineers during installation
    i. Use the little an often approach in teaching the community how the system works, how to use it; so as not overwhelm people with new information
    j. Knowledge often transferred more effectively during casual conversations and informal meetings
    k. **Invite local technicians to visit MFC labs in the UK**

l. **Selling the vision, the big picture**

23. MFC technology going forward
    a. Further modification needed
    b. Improve robustness
24. Relationship with the local community
25. Managing expectations about the technology
    a. Lack of understanding of the system causes unrealistic expectations
    b. Issues with electronics affected people's perception of the system
    c. The need to be clear about what the system can or cannot do
    d. High expectation for lighting provision (beyond trial, free of charge)
26. Technology Receiver (management staff) wanting to understand more about the technology
    a. Technology readiness level
    b. Power capacity
    c. Long term goal of the PeePower, what's the vision for the next stage?

APPENDIX 2b: Codebook generated with NVivo.

COMMUNITY ACCEPTANCE
Enthusiasm of the public about the technology
Local partners to first assess feasibility of the project in the community
More installations requested in Kisoro
Pre-installation visits recommended
The lesser the change in habits the easier it is for the community to adopt and use the technology
DESCRIPTION OF THE OF THE WORKING ENVIRONMENT
Comparison between remote rural village and urban slum
Extreme environment, hardly any maintenance or cleaning of the system
Hot weather whilst wearing lab coats
Kids gathering around which made it hard to carry out installation
Settlement with illegal electricity
Similar to real word setting
IMPORTANCE OF HAVING LOCAL CONTACTS
Access gained by integrating an existing project
Establishing good relationship with the local community
Feedback about system's performance provided by local teacher
Good relationship between Durban team and UK team
Having local contacts to support transport logistics, installation, maintenance and decommissioning, was helpful
Lack of local technicians has been a major obstacle
School teacher giving updates about the system
INTEGRATING THE PEEPOWER TO OTHER SANITATION TECHNOLOGIES
Encouraging more frequent usage of the toilet and therfore increased feedstock
Include necessary additional facilities such as hand washing
Integrating with the EOS toilet to enhance benefits of the system
Level of complexity associated with integrating systems
Recommendation - PEEPOWER integrated into the EOS toilet or the G2RT to see the benefits and possible challenges
INTEREST IN MFC SCIENCE
Recommendation for MFC educational kit and textbook for schools
Recommendation for more educational outreach to educate about MFC science
Recommendation for public engagement workshop at the beginning of trials
Staff, visitors, students and users fascinated by the MFC science
KNOWLEDGE TRANSFER
Disciplines needed to understand the PEEPOWER system
Exchange visits recommended
Involving local engineers during installation
knowledge exchange with transfer from Durban team to the UK team
Knowledge of locally available materials
Knowledge often transferred more effectively during casual conversations and informal meetings
Knowledge Transfer takes place at an individual level
Knowledge transfer post installation in Durban
Knowledge transfer pre-installation

Need for IP Protection
Needs to be done in a way that empowers and gives a sense of ownership to local Tech Receivers End Users
Recommendation for communicating long term vision of the PEEPOWER technology
Recommendation to produce a system user manual
Recommendations made for further improvement
Support provided to local maintenance engineer
Timely and effective communication between Durban team and UK team
Transdisciplinary platform
Use the little an often approach in teaching the community so as not overwhelm people with lots of new information at once
Useful to involve maintenance technicians during installation
Valuing community knowledge
LOCAL ABSORPTIVE CAPACITY
Ability to adapt and innovate
Ability to maintain and repair the system
Key factors for high Absorptive Capacity in Durban
Two layers of Absorptive Capacity
Understanding of how the system works
MANAGING EXPECTATIONS ABOUT THE TECHNOLOGY
High expectations from the community
Issues with the electronics system affected users perception of the system
Lack of understanding of the system causes unrealistic expectations
The need to be clear about what the system can or cannot do
PERFORMANCE OF THE ELECTRONIC SYSTEM
Batteries or new components required to get lights back on
Corrosion and loose wiring issues with the electronics
Impact of users trust on the technology performance
Lights not turning on
Lights used were different to locally available ones
The electronic system has useful features for data monitoring
The electronic system was complex and delicate - not robust
Wiring of the electronic system was complex
PERFORMANCE OF THE MFC STACKS
Build-up of struvite in bottom stack if not emptied regularly
MFC system works independently of the electronic system
Precise flow rate of feedstock is required for the system to work
Regular maintenance required
Stacks assembly configuration makes it difficult to service
The MFC system is resistant and can operate in extreme conditions
The system produces electricity so as long as the urinals are used - Continuous feedstock is needed for power generation
Voltage dropping in cells due to blockage
PEST INFESTATION
Flies infestation
Rats infestation

- Recommendation - Ensure cleanliness of the system surrounding to avoid pest infestation
- Solution - Covering the top boxes with steel mesh or net

POST-DECOMMISSIONING
- Community disappointed and sad
- Disposal of the system post-decommissioning
- Giving back to the community post-decommissioning
- Providing the community with MFC kits to educate and empower youngsters
- Relationship management post-decommissioning

ROLE OF THE TECHNOLOGY RECEIVER
- Liaising with the community
- Planning - organising - monitoring and analysing
- Positive feedback about maintenance engineer

SAFETY CONSIDERATIONS IN SLUM ENVIRONMENTS
- Always stay accompanied with designated local driver
- Avoid working after sunset
- Keep car windows closed at all time
- Safety measures to protect the system
- Work in a gated environment

SOCIAL BENEFITS TO COMMUNITIES

SOCIO-CULTURAL CONSIDERATIONS
- Being aware of social customs and etiquettes
- Being respectful of local socio-political hierarchies and approaching the right people
- Ethics
- First time experience in a slum environment for some technician
- Gender element associated with the technology
- Having a diverse team can facilitate communication between personnel
- Importance of understanding local community practices and sensitivity around sanitation
- Importance of understanding what changes or disruptions a new technology can bring in the community
- Language barrier
- PEEPOWER electricity productions relies on local sanitation practices and behaviours

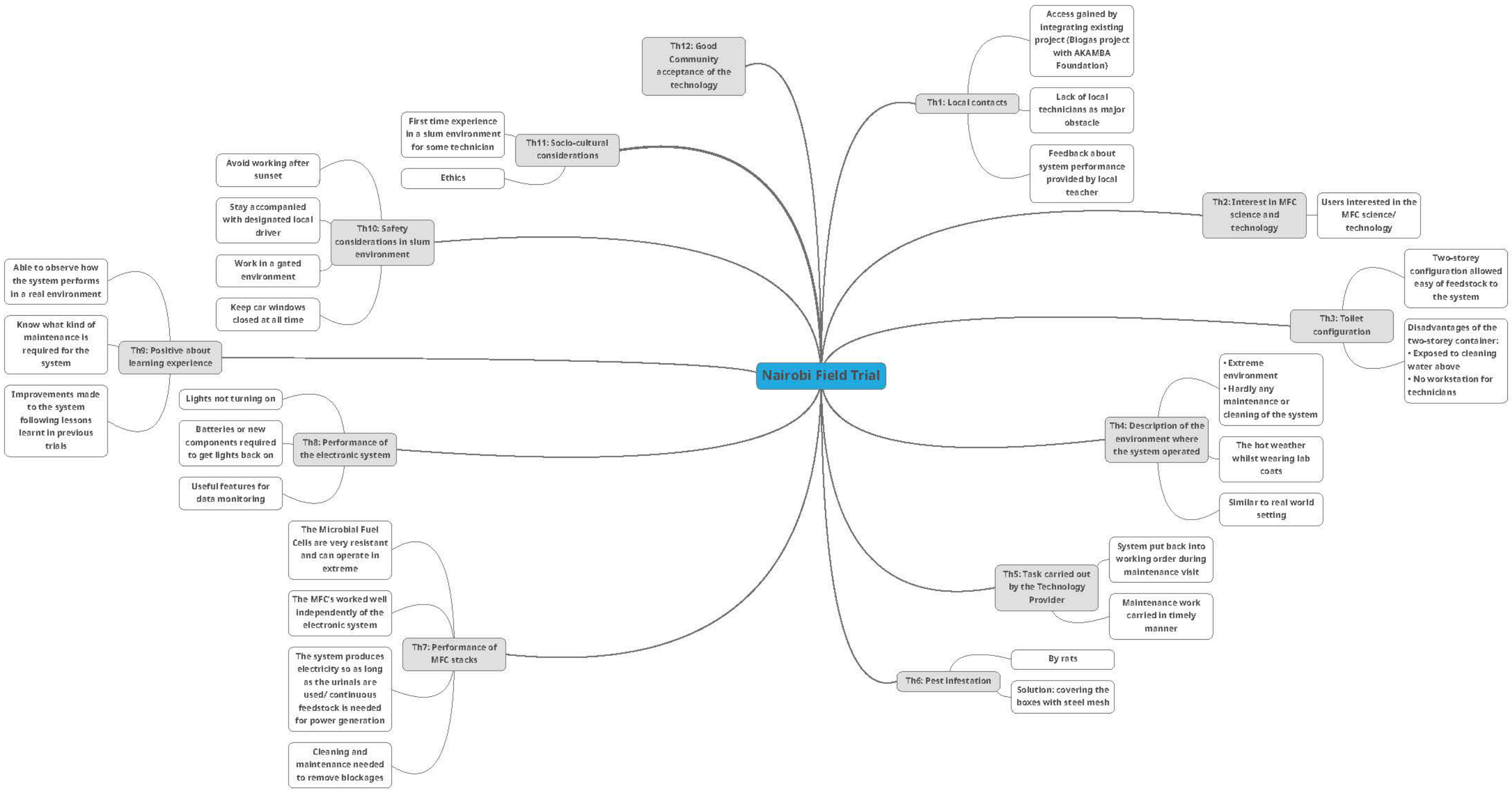
STAFF POSITIVE ATTITUDE ABOUT THE LEARNING EXPERIENCE
- Able to observe how the system performs in a real environment
- Improvements made to the system following lessons learnt from previous trials
- Learning from obstacles faced in previous trials
- Learning what type of maintenance is required for the system

SUGGESTION FOR THE MFC GOING FORWARD
- Further modification needed
- Improve robustness of the system

SYSTEM USAGE
- Difficulties with using Urine Diversion plates and improper toilet usage
- Grey water down the urinal
- Low usage of urinals due to hygiene and sanitary conditions
- PEEPOWER may have been an incentive for men to start using the urinals more often
- Posters and workshops used to address issues of improper toilet usage

Recommendation - Being proactive and using posters and workshop before installation and not as a response to improper usage
Unexplained reason for toilet misuse
TASK CARRIED OUT BY TECHNOLOGY PROVIDER
Decommissioning
Maintenance work carried out in timely manner
Purpose of the trial - scientific research
System restored to working order during maintenance visit
TECHNOLOGY RECEIVER WANTING TO UNDERSTAND MORE ABOUT THE TECHNOLOGY
Long term vision of the PEEPOWER
Power capacity
Technology readiness level
TOILET CONFIGURATION
Advantage of two-storey toilet configuration
Exposed to cleaning water above the top storey
No workstation for the technicians - Nairobi
Purpose built area for system storage
The system needs to be more than meter below the toilet
TRANSPORTATION LOGISTICS

APPENDIX 3: Nairobi themes mapping visualisation



APPENDIX 4: Knowledge transfer coded references

Multidisciplinary: You need to understand basic **electronic concepts, energy harvesting** and how that's done by electronics. And then **fluid mechanics, chemistry**, how the flow may change with the build-up of biofilm and other forms of salt that may be in the urine and may cause blockages in the pipework." (TP) " basic knowledge **fluid flow**, just in case there is an obstruction in the system (...) So, being able to understand all the **bio-electrochemistry** going on inside the MFC system and the **mechanical engineering** and **electronics." (TP)** "to install, run and maintain an energy system, you don't need to have a great understanding of **microbiology.** You can apply it quite easily. But then to get more in depth understanding of what's going on and why then, of course, it would be helpful to have an enhanced understanding that the **microbiology** that's happening," (TP)
Exchange visits: " he can be here in Bristol. And we can give him like a training for two or one weeks and show him how we install the system, how we can maintain the system" (TP) "I would say that one of the **good ways of transferring the knowledge before the field trial would be to have the (local) engineer who will be working with us to spend maybe three days with us in the lab (in Bristol)**. So that even before us going there for an installation, they could get a deep knowledge and get a deep understanding of the system and the lab here. And that would be a great learning experience for the person coming to visit us. And then once a field trial start, they would already have a very good understanding of it. So it wouldn't be as much of a new thing. And that would make the whole installation go very smoothly because they would already have the knowledge for it." (TP) " **I think it's essential that we have someone from here (in Durban) that goes to UWE to get trained in microbial fuel cells.** Through the stage of making them, troubleshooting them and understanding it. And I'm talking about a local Zulu speaking person. I think the important thing is that there should be someone to say they've had opportunity of going to Britain, they can see things." (TR) "I'd say maybe half of the amount of **people who were involved in developing (the PEEPOWER) can come down and meet people from down here (in Durban)**" (TR)
Users needs: "We were just trying to provide lighting on the outside so that you can feel secure to go out at night. But it was later on that we realised that sometimes, it was only the light in the community when there was power outage. So (the pupils from the boarding school) would then congregate around the external lights that we had, to read. **Maybe if we knew that it might have been the case, we might have provided lights for reading (instead of lighting toilets)."** (TP) "**Maybe we could have given them light to read at night**. Because the way the MFC system is set up, as long as they keep using the toilet, there will be light. So, it's supposed to be a constant source of power. I don't know if we could have made it bigger. Because logistically, that was what we could do at the time, due to finance, and shipping logistics." (TP) "I'm thinking that (the pupils at the boarding school) might have wanted **(lights installed) inside the dormitories rather than outside**." (TP)

Learning during installation: "having engineers around while that installation happens is really important because **it means they see how the different bits of the system fit together**." (TR) when the systems are being installed. So from then you get a better view of how things should be done, and how things should be if they should be done in the future. This is the approach you must go through, but with that system, I wasn't that much involved in it when it was installed and when it came in. (TR)
Knowledge transfer from TR: "There was a community sensitisation meeting when the team were to installing, to explain all about the system. (TP) "Even during our time there, we were already trying to get them to make the ceramic (cathodes) for the MFC system. So, when we came back, we took some of the ceramics. And now we have a lot of ceramics that are made in Kisoro, and that we're using for the MFC's. Because they make very good ceramic and they use local techniques (...) So we are using some of their ceramic materials. Some of them are working really good, but the problem is standardisation." (TP) "after the interaction and the visits, we had regular visits after six months ... we sent people down to go and do some repairs. At that point, we involved some of the local guys, so that if goes wrong in the future, we could just send them to go and fix it. Now, there's one of the guys on the ground who can actually fix and repair most of the things that can go wrong. He was the driver assigned to us to help us move things around. He knows some of these things and he can fix them. We have actually sent him to do a few for us. (TP)
Local materials and spare parts: "To understand how you could support something in a remote location, the designer needs to understand clearly the actual ability to source materials in that location. It may be that, through prejudice, you could make assumptions which are incorrect." (TR) "I also believe having a true understanding of the market or actually providing a sufficient set of spares and a spares return system for the modules, that would allow for a fit mechanism or for someone in the field to support it." (TR) When (the tech developpers) come to South Africa, some of them will actually come with a list (parts/tools)t they would need. **And when you look at the list half of the things that they're looking for, we do not have them in South Africa.** So that's also local challenges we usually face here. (TR)
Casual interactions: "Interviewer: So (you're saying) learnt more from that one-to-one interaction that you had with (a UK staff member) as compared to presentations and posters? Particiapant: Right." (TR)
Knowledge transfer post-installation: I think it's been really useful that the UWE team were here at the beginning of the project and **then when the changes were made to put the lights in**.

Knowledge transfer post-installation: "What helps me a lot is to have presentation style with visual cues. What helps me is to have a visual description of the system. That's actually what the Durban team asked me to prepare. Everything that needed to be installed, I had to describe them in detail using visual aids, images, pointing to every single part of the system. So that if our service engineer was not able to look after it, anybody else could pick up the diagram and know where the cathode connection is, where the data logger is (for instance). So, that kind of guidance for the system description." Reference 2 - 1.34% Coverage a few other diagrams to help look after the analysis of the samples. So, basically where you take samples from, needs to be properly described: where, what and where from. Reference 3 - 5.98% Coverage system description to help with troubleshooting. If there is an issue, they would know what to check, where to look for. So, describing everything as if we were there and describing what steps we would take in order to address (troubleshooting issues). So the diagram will describe the system like this: "we've got this connection, this cable, where it's going to, what it's doing so?" Very simple diagrams, with lots of images to show what component is where. asking the local person (Technology Receiver) to prepare diagrams by themselves. Because, being actively involved in describing the system would make them more engaged. Rather than remembering something that somebody else said, doing it yourself makes you a bit more aware and responsible to know how it's built. <Files\\Participant 07> - § 3 references coded [5.69% Coverage] Reference 1 - 1.11% Coverage So one thing we could have done differently was making the explanation easier for them to understand in terms of how to work with it, how to manage it, how to use it from time to time. Reference 2 - 1.97% Coverage So I'm thinking that it is because we were not very explicit in explaining how these issues interact with the MFC system. So, because they didn't have a full understanding, these things made it difficult to keep it running. It was at some point disrupted because they didn't actually understand what to do or what not to do. Reference 3 - 2.61% Coverage we were teaching them about it (the MFC system) and talking to them about it. How the microorganisms when they break down the waste in their urine, they release electrons and these electrons are transferred to the cathode. So they understand the chain of events and then the question was, why urine and then we explained to them the uniqueness of urine, the composition, the pH, everything that is suitable and the microbes like it. <Files\\Participant 11> - § 2 references coded [3.88% Coverage] Refrence 1 - 1.90% Coverage In Durban, we were greeted by the University of Kwazulu Natal on the first day. We had an induction and a briefing on how to act in the community. Reference 2 - 1.98% Coverage However, we could have spent more time transferring all of the knowledge at the beginning of the field trial. I think that would have been very helpful.
Need for IP Protection: There is a bit of a challenge around IP there for us because with if they did have that level of

detailed understanding and knowledge, then there's kind of that needs to be more formal NDA's.

<u>Empowerment and sense of ownership:</u> Otherwise… by empowering people through knowledge they get an advantage, again, to make sure it works, you want people to, to take in, but you want, you want them to identify with the technology and want it to work. It's not… it's been imposed upon us, we've gotta do it.

<u>Being proactive:</u> Well, I'm thinking that we should have used sketches and images, like around the MFC system and the toilet.

<Files\\Participant 09> - § 1 reference coded [4.91% Coverage]
Reference 1 - 4.91% Coverage
I think before the trial, there could have been examples with the students about how to properly use the PeePower and why only urine needs to go down there. Because when we went for the maintenance visit, there was a lot of paper debris, number two, and even though the squat press were separated (Urine Diversion Toilet), still other things were going down there. So if we had had an information session before the installation, saying that "now we're installing these, only urine needs to go in there, otherwise it's going to get blocked and you're not going to have light". I think that would have helped.

<u>Communicating the long-term vision of the technology:</u> So if you want… probably needs to have someone here to be more a part of your team, to be able to talk a little bit more expansively about your prices. 'Cause if we are the, if we are your advocates, you want to make sure that we can, as eloquently as possible… So for the next phase, I think that closer, closer collaboration and communication. And that could happen through just like one to one conversation

Reference 2 - 0.35% Coverage
I couldn't have helped in getting you there if I wasn't aware of…The big vision. … the big vision and this is where you wanted to go. but if I don't know what you're doing… I can't help.

<u>Produce a user manual:</u> We need to prepare manuals. How we can use the system, how we can maintain the system, how we can decommission the system.

Reference 2 - 1.17% Coverage
And you can use it actually with other people to show how our system works. We have (one of our technician) working on it. She still works on this with our team.

<Files\\Participant 03> - § 1 reference coded [1.90% Coverage]

Reference 1 - 1.90% Coverage
The other thing, the support in the field is only as good as the documentation that you provide for anybody that may have to look at this. Because it is a very puzzling… unless you've worked with fuel cells, you're looking at a very odd thing indeed.

Towards the end of the testing, you're getting a lot more of "We came across this fault, we rectified it in this way, we're informing you so that you know that this has happened. Rather than we had this fault, what do we do to rectify it?"

<Files\\Participant 17> - § 1 reference coded [4.14% Coverage]

Reference 1 - 4.14% Coverage

I think Pee Power can be a good option or addition to other electricity generating technologies. And even if it does produce very little power, it can be optimised and you can

still use it. And that's what this trial showed. The optimisation would be on whatever little power that's produced, how do we make it useful? So in this case, the fact that the lights were on at night in a place where there are no lights but are needed and they switch on only when they are needed and switch off when they are not means they be- that's how they optimise. And the system was still able to, to power those, those toilets that didn't have. So it's like if you were to set up a system like that and different community ablution blocks that don't have lights at night, they don't need lights during the day, but they can have lights at night, so it means it's become useful. Even with that 0.1-milliwatt hour, 0.1-watt hour being produced, it's still enough to light up a community ablution block. And that makes a difference.
<u>Support provided to local engineers:</u> Because I remember with (the maintenance engineer), she received many documents from our researcher. But, you know, it's not like something like manual. It's presentation and how the system, it works. <Files\\Participant 12> - § 3 references coded [2.68% Coverage] Reference 1 - 1.57% Coverage The UWE team has been very supportive of the engineers working on the technology. 22.d And they've been really good at communicating with us about what they want, what they want to see happen around the testing. And when there's been issues with the system, they're very good at giving feedback. Reference 2 - 0.48% Coverage And then the UWE team trained the engineers here on operation of the system and maintenance Reference 3 - 0.63% Coverage Over that six month period, our engineers were in a much better position to handle the system without support from UWE. <Files\\Participant 17> - § 1 reference coded [4.88% Coverage] Reference 1 - 4.88% Coverage I honestly think they really put in a lot of effort to help us understand the system. I mean, they took time initially- during first installation, they took time, sat down with us and spoke to us. [They] spent a couple of hours in the meeting room, trying to explain to us how the MFCs work. And then even during installation, they would be explaining. During the course of the testing period, they were also explaining. Whenever we had questions, we had a WhatsApp group with Yvonne and Agnes, and if anything seemed off or disconnections seemed off or something that would have happened, any pictures, we'd be able to send them, ask them questions, emails, WhatsApp, they would respond. And then now we're doing decommissioning. When Alexis came, you know, they were still able to explain to us better. Also now, because now it's like, we're looking at the data and trying to understand what it's saying and how it makes sense. So the fact that they kept on explaining to us is… I think they were very helpful. Instead of just saying, "Oh, the systems over so it doesn't matter. We'll process the data on our own." They really took the time to [explain] so I can also interpret the data in my own way.

Long term vision of the PEEPOWER, Power capacity, technology readiness level.
<Files\\Participant 14> - § 6 references coded [4.04% Coverage]

Reference 1 - 0.51% Coverage
But I, I think along the technology readiness level, you know, the technology readiness level stages, I'm not too sure where they are. Are there three or four? Have they actually got a product, or is it still in the conceptualisation and product development stage, I think.

Reference 2 - 0.69% Coverage
So I mean you're… when it comes to electricity you have a direct, direct competitor of solar power.
So I suppose the question is where, where does the one fit in preference to the other? And I don't actually know the answer to that. Probably it gives you continuous power, and then the question is, is it gonna be less expensive and what power can you get out of it?

Reference 3 - 0.21% Coverage
So in trying to imagine where one would have it, I, I'm not sure how much power you're going to get out of it.

Reference 4 - 1.57% Coverage
And, and so are we looking just at lighting, or are we looking…
Lighting, mobile phone charging.
How many? How many? So I know I'm asking you technical questions… but if you're talking about technology, technology transfer, I think those are the sorts of things people need to know.
So, one person's urine would be able to do what?
In, in other words, it could provide a light for so many hours... so one person's urine, is there so much during the day?
They could provide light for four hours, but could it charge one cell phone? So how much amp hours is available to, to charge your cell phone? So you know, you need to charge your cell phone every day, let's say you need to have, I dunno, 500 amp hours to do it, milliamp hours to do it, so what could one person's urine provide in terms of the potential energy that could be done.

Reference 5 - 0.45% Coverage
So that's… And at a school, generally lights, lights in the school toilet are not very important. And is charging a cell phone at school important? I don't know how many school kids have cell phones, but it could be used more in the community.

Reference 6 - 0.61% Coverage
So, so it's sort of, in my mind, it's a bit of technology looking for a solution?
I don't see its immediate, its immediate use. So in the, in the vision, I'm not too sure where the vision of… and I found it very interesting last night talking to xxx
I'm still unclear as to what, what is envisioned in the future of this.

<Files\\Participant 15> - § 3 references coded [5.67% Coverage]
Reference 1 - 3.65% Coverage

there are a lot of visitors who come to site and they're interested. And so as visitors are there, it's nice to be able to say to them concretely, this is how this prototype could fit into the operational environments that you're seeing. And this is how it relevant to you. And this is how these are the really good aspects of it. And I think with the UW system, and there's obviously lots of potential there, but but I think it would have been nice to be able to say, Well, this is how this system could be added on to something else to give you kind of added value

Reference 2 - 0.69% Coverage
it would have been nice to have a concrete example to give to the potential clients when they were coming.

Reference 3 - 1.32% Coverage
about understanding where this could now be applied and implemented in the real world and not in a test site,
and looking at potentially linking it to another system and employing them both as a package.

Timely and effective communcation: <Files\\Participant 02> - § 1 reference coded [1.25% Coverage]
Reference 1 - 1.25% Coverage
(communication was) very well; because when we received something from (the maintenance engineer), Our technical team replied promptly, on the same day. So,it's really good

<Files\\Participant 12> - § 4 references coded [3.66% Coverage]
Reference 1 - 0.57% Coverage
So when the engineers asked questions, they had quite quick responses around either problem solving options

Reference 2 - 0.59% Coverage
Or when maintenance or fixes have been needed, they're very good at making sure that information is available.

Reference 3 - 1.51% Coverage
If they've checked all everything that they can check, and they still can't see what the issue is, then they would send an email to the UWE team, who were very quick at responding. I mean, if we send an email at the end of the day, normally by the next morning, we've got our response

Reference 4 - 0.99% Coverage
That communication was very quick. It was very thorough. And the UWE team were very accommodating in that if it was something was urgent, they would take phone call or WhatsApp message.

Transdisciplinary platform: <Files\\Participant 13> - § 2 references coded [1.65% Coverage]
Reference 1 - 1.35% Coverage
So the important thing about the EFT is(...) it's transdisciplinary in many ways, because you've got scientists, engineers and social scientists working very closely together. You've got University engineering consultancy Khaniysa support team (...) And then you've got the municipalities taking ultimate responsibility and also very engaged (...) That is really a learning platform

Reference 2 - 0.30% Coverage
So, the universities always had a strong relationship with municipalities through PRG.

Little but often approach: I think that maybe one thing that we could have done differently is having almost a little and often approach to showing people how the system works, how it benefits them, what they can do to help make sure the system runs as well as possible. I think that better understanding of the system for the community means that they're more likely to do things that they can, to take care of it. So things like making sure that laundry water is not being tipped down the urinals for example. And the balance there is trying to make sure that people have a good enough understanding of the system and that they are able to support it, without overloading them in terms of every week, someone's showing up "let's have a chat about the system". Because people have got so many other things going on in their life, they want that technology to be something that runs in the background.
Valueing community knowledge: So, the first and foremost role that we play is to ensure that the communities that are part of these testing programmes are respected, that the knowledge is respected that they are seen as being part of the co-production of knowledge, so that it's not an extractive process. Because you can have these kind of processes where innovators or technology, developers can extract a lot of information from communities that are critical to their products, but not acknowledging always the value of that community based knowledge. So I think my primary role myself is to advocate for that and to ensure that community voices are heard, that community knowledge is seen as important and as critical in the transfer process.

APPENDIX 5: Research diary

Date: 04/09/20
Meeting: Collaboration Proposal with Siemens-Stiftung
Attendance: Maryam Lamere, BBiC Technical team (Jiseon, Iwona, Elena), Siemens-Stiftung Prorgramme Coordinator (Jacqueline Wiafe)
With additional post-meeting notes.

A. Purpose of the meeting

- Discuss possibility of using Opens Source platform Experimento to make MFC science education accessible to all
- Discuss opportunities for wider collaboration with Siemens-Stiftung

B. Main points discussed:

- Welcome and introduction
- BBiC team's presentation (see attached Powerpoint slides)
  - Research on Technology Transfer and Knowledge Transfer
  - BBiC educational outreach activities with schools
  - BBiC's Ecobot-II
- Siemens Stiftung's needs and priorities
  Three main branches:
  - Development cooperation: Supporting innovative technologies that provide high social impact
  - Culture: Creating opportunities for social dialogues, and mutual cultural understanding
  - Education: Supporting STEM and inquiry based learning, providing open educational Resources.
  -

C. Agreement reached

Siemens-Stiftung willing to add MFC science materials to Experimento platform
Siemens-Stiftung open to further collaboration beyond Experimento, notably more around their Development Cooperation branch

D. Questions raised:

Are parts needed for the MFC kit available locally? Can it be assembled by local science teachers for their lab sessions? Are there IP issues to consider?

D. Next steps:

- Development of MFC science materials to go on Experimento (with translation in Spanish)
  4 months timeline (?): October-January
- Research on the use of local materials for making demo MFC kits
  Timeline (?)
  Researcher to be allocated (?)
- Application for Siemens-Stiftung Empowering People award
  More information from Jacqueline

Date: 29/07/20
Meeting: Using the MFC kit for Prototype and Play Lab
Attendance: ML, Public Engagement Representative, EDM Lecturer

A. Proposed educational kit
1. MFC Educational Kit/Ecobot:
Showcases UWE research and innovation; real world application of STEM (inclusivity factor); sustainable, years of outreach experience in schools; autonomous battery powered robot; sets of boxes already available (PeePower kits and some ecobots) and more can be made by the BBiC team if required.

2. Planete Sciences education box: https://www.planete-sciences.org/robot/boiteabots/fiches/
Versatile educational box with activities relating to Electrical Engineering, Robotics, Mechanical engineering and more; detailed instructions available; tailored made for schools; can be altered to meet P&P Lab's needs; Resources produced by an external organisation. Bi
Note: boxes needs to be made from scratch (materials to be purchased, staff to be allocated for making the boxes), instruction manuals are to be translated from French to English.

3.Way forward: Integrate MFC kit with Planete Sciences educational box for an engaging educational box that meets P&P Lab needs.

B. Note about the commercialisation of the MFC educational kit:
This is being carried out independently of the P&P Lab.
Link between P&P Lab and Maryam's PhD on Technology Transfer: Putting my research findings into action (Action Research). Research data pointed to public interest in the MFC science and in understanding how it works.
C. Questions raised:
-Training/briefing required for Students Ambassadors to prepare them for P&P Lab session. How long will it take? Will it be before each session?
-Do we need all the activities in the Planete Sciences learning journey? Bearing in mind the structure of our Prototype and Play Lab session.

Next action:
-Get confirmation from Laura about:
Session duration
Targeted age group
- Laura/Abdul to put us in contact with the new Science Communication Officer.

Next meeting: September 2020
With the new Science Communication Officer and others to discuss if/how the Bot in a Box kit can be integrated with the MFC kit for the Prototype and Play Lab (resources needed, timescale, role allocation).

Page Break

Date: 24/07/20
Reflections on learning

What I have learned so far:

- Most common question asked by the public: "How much power can it produce?"
    - Be clear from the onset about power generation capacity of the technology in order to manage expectations
    - Specify that power generation is only of the benefits of the MFC technology. There are four in total: (1) Power generation, (2) waste treatment, (3) fertiliser by-product and (4) disinfectant by-product
- Other questions: How long will it take for the MFC technology to be able to produce consistent amount of energy (5-10years?)
- User requirements for educational kits:
    - At schools: robust, durable, very easy to set up, easy to operate
    - At home: maybe more about being to self-assemble the kit, easy to understand.

- Involve Public Engagement Rep, Science Communication Officer in future bids (as co-applicants)

Action Plan:
Short term

- Create virtual online Electrolysis Lab to teach MFC related chemistry (to be published on Go-Lab and/ or other platforms)
- Manufacture a few MFC educational kits (demonstrators)
- Launch an MFC Open Source website for teachers and educators
- Contact potential funders:
    - Horizon 2020 Research and Innovation Funding Scheme (Cara Ryan)
- Contact potential partners:
    - Experimento, Siemens-Stiftung (Barbara Filtzinger) to develop a lesson for their portal, similar to their Solar cell/Renewable energy lesson
    - Go-Lab Goes Africa GO-GA

Long term

- Explore other applications of the EcoBot:
    - a lawnmower toy: an Ecobot that cuts grass and is powered by mud
    - vacuum cleaner, carpet cleaner
- Contact potential investors such as Dyson, Karter, Bosch

Refining our mission statement:

- Mission statement V1:

Spark interest in the next generation of scientists and engineers in the UK and Worldwide!

- Mission statement V2:

"Provide resources that support inquiry-based learning of STEM subjects, by making it fun and relevant to everyday life."
Or *"Make STEM learning fun and show its relevance to everyday life"*
Or "We *want to make MFC educational products that support STEM learning in a way that is engaging and relevant to everyday life."*

More on potential partners/funders:
Experimento Siemens
- mediaportal@siemens-stiftung.org
- https://medienportal.siemens-stiftung.org/de/experimento-matrix?id=experimento_matrix
- Program manager

Dr. Barbara Filtzinger
barbara.filtzinger@siemens-stiftung.org
+49 89 540487 0

Horizon 2020 funding:
- Extended to 2021
- Funding scheme: Innovation actions
- Live funding: Science with and for society
- Cara Ryan (Science with and for society, UK National Contact Point)

Telephone: 01793 413 030
Email: SWAFSNCP@ukri.org

UNICEF Innovation (partner)
UNESCO OER (partner)
Edutopia

Page Break

Date: 21/07/20
Subject: MFC educational kit –commercial venture.
Meeting attendance: Science Communication team, Public Engagement Representative, and PhD Supervisor.

I delivered a presentation covering the points below:
Motivation for MFC Educational Kit
Proposed Business model (following the example of Mobysa-Thymio)
Possible sales and marketing strategies
Further work required to commercialise the MFC kit

Feedback/Suggestions:
From Director of Studies (pre-meeting)
- An EcoBot that works as toy lawnmower and is powered by mud
  Further lab testing to be set up to confirm possibility
- Run workshops with BBiC team to develop educational MFC products
- Find out more about curriculum mapping and funding stream of Mobysa

Science Communication team

- Schools' would need a kit that is very easy to understand and set up, i.e. "idiot-proofed".
- Curriculum mapping exercise to be done by new Science Communication Officer (due to start work in September)

Public Engagement Representative

- Be specific about target market (schools, museums or subscription boxes), as they have completely different product requirements
- Thymio's success comes from the product robustness and their very specific target market (empowering primary school teachers)
- Perhaps target low-income countries, as students there can relate more to the benefits of an MFC system (electricity access, sanitation).

Next point action:

- Follow up with first supervisor for further feedback/questions
- Liaise with BBiC team for workshops on developing MFC education products (they first need to be introduced to the initiative by Prof Ioannis or me)

Page Break

Date: 13/07/20
Subject: Using MFC educational kits in the Prototype and Play Lab.
Meeting with Programme Leader, Science Communication Leader and Supervisor.
Prof Ioannis' comments in blue.

Requirements for the MFC Educational kit:

- User-friendly *– it is user friendly by design*
- Self-explanatory, no prior specialist knowledge or skill required in order to manipulate the kit *– the instructions are self-explanatory but one cannot expect everyone to be instantly a MFC expert so a brief intro is always useful and appreciated*
- Easy to clean up and maintain *- yes*
- How long can it stay unused, yet still be operational? *– once a demo is finished and the kit is cleaned, it can stay on the shelf for ever; it's plastic and carbon*
- Preferences: mud powered cells as safer alternative, easier risk assessment. *– exactly how we have been running the school demos*
- Suggestion: Connect the kit to an LED that lights up a doll house for instance. More meaningful for the pupils, in comparison to connecting the kit to a voltmeter to demonstrate electricity generation *– we have always connected the kit to either an LED module (lighting up a custom-made BRL logo) or a digital weather station. The voltmeter is only used by the expert to monitor MFC health*

Recommended contacts:
Jon Winfield, Debbie Lewis, *and Yannis Ieropoulos*

Recommended resources:

- Practical Action Schools: Educational outreach in schools, focussed on real world application of STEM subjects
- Raspberry Pi: Education digital kit already in use in several schools around the UK. Is there a way to link the PeePower kit to the Raspberry Pi? *– A question we have already asked many times, but the power requirements of a Raspberry Pi are higher than what an individual MFC can generate. It is something we are looking at with stacks*

Next point action: Meeting with Severin Lemaigne to decide if PeePower kit will be used in the Prototype and Play Lab.

APPENDIX 6: PEEPOWER Maintenance and repair manual

Original Version provided by the Centre:

PeePower system user manual guidance (DRAFT)

WRITTEN INFORMATION GATHERING.

Product description: PeePower systems use Microbial Fuel Cells (MFCs) to produce electricity (off-grid power) from urine and offers an on-site waste sanitation treatment.

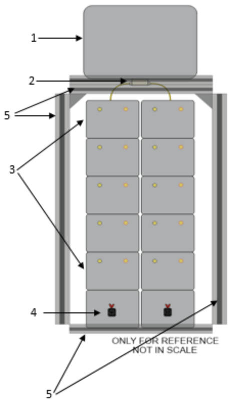
PeePower systems are fuelled with urine collected directly from urinals. Integrating the MFC technology in (waterless urinals?) offers wastewater treatment and electric production near the source (phone charging point, providing light or peripherals).

(**Expected reader for the manual**: Basic knowledge on MFC systems, knowledge/ability on how to manipulate waste water (maintenance purposes) and drainage, basic technical skills).

PeePower can vary its system size, having from 20 – 40 – 80 modules per system depending on the purposes or needs. (Based on different field trials, smaller systems available too but feeding box size changes) (This user manual will focus on a 20 module system)

Individual MFC modules and the feeding tank reservoir with the feeding distributor come built already.

Product design and legend (PeePower system).



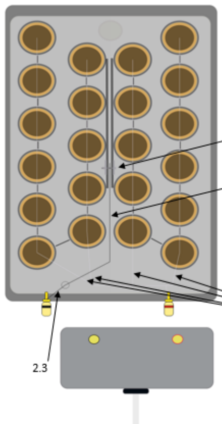
1. **Feeding reservoir tank (Buffer tank) System's inlet from urinals. ~ 43 L**
2. **Feeding distributor.**
3. **MFC modules (20 in total). 4 cascades (4 stacks) of 5 modules each.** Individual numbering of modules to ensure correct positioning.
4. **Effluent modules (4 bottom boxes) System's outlet to soakaway.**
5. **System frame.**

MFC MODULE:

Each MFC module contains 22 MFCs connected in parallel where the anode is underneath the acrylic lid, wrapped around the ceramic cylinders and connected towards the outer connector (black), the connector part of the wire comes from below the acrylic to the top through a hole in the top acrylic.

Cathodes are placed within ceramic cylinders, exposed to air, with stainless steel crocodile clips gripping onto a stainless steel mesh which is pressed onto the cathode, connecting each row. The four rows are then connected in parallel to the outer connector (red). The ending wire has heat shrink on to avoid any possible contact with the anode wire.

The two outer connectors are golden plated female plugs. Each module can hold ~ 3 L per module.



1. Cathode connector (red) golden female
   1.1 4 rows of 316 stainless steel wire (0.5 mm diam.) with 316 crocodile clips gripped onto the cathode found inside the ceramic.
2. Anode connector (black)
   2.1 Submerged connector (through the carbon veil) 316 Stainless steel washers, screws and nuts.
   2.2 Submerged 316 stainless steel wire.
   2.3 316 stainless steel wire above the acrylic.
3. Ceramic cylinder
4. MFC outlet PVC pipe (~ 10 mm diam.)

There are two types of MFC modules regarding the positioning of the outlet pipe, this is because of the cascade stacking of the modules.

Outlet pipe close to the connector — Outlet pipe opposite end of the connector

Feeding tank reservoir

Feeding reservoir tank is continuously fed with urine directly from the urinals. It has an auto syphon mechanism that will automatically trigger feed-pulses when ~ 40 L of urine has reached within it, ensuring the same amount of urine flows into the four cascade stacks evenly. The syphon is a pressure flush valve mechanism, when liquid reaches a certain level, in this case ~ 40 L, it triggers.

Energy harvester and peripherals (sensors, lighting, etc...)

The connections to the EHPM board are labeled and correspond as follows:

GND - Connection for negative wire (Ground).

MFC IN - Connection for positive MFC wire.

MFC Current - Point for measuring current from MFCs using a multimeter.

Light 5V - Positive connection for main LED spotlights and their respective PIR sensors.

Light Current - Point for measuring current going from the EHPM to the spotlights and sensors.

PIR + Lights - Positive connection for secondary spotlights and sensors (may be left unconnected).

PIR + Lights Current - Point for measuring current for secondary spotlights and sensors.

Bat A - Point for measuring battery A voltage.

Bat B - Point for measuring battery B voltage.

Vref - Potentiometer to adjust the reference voltage.

The position of these points is shown in the figure below (fig. 1).

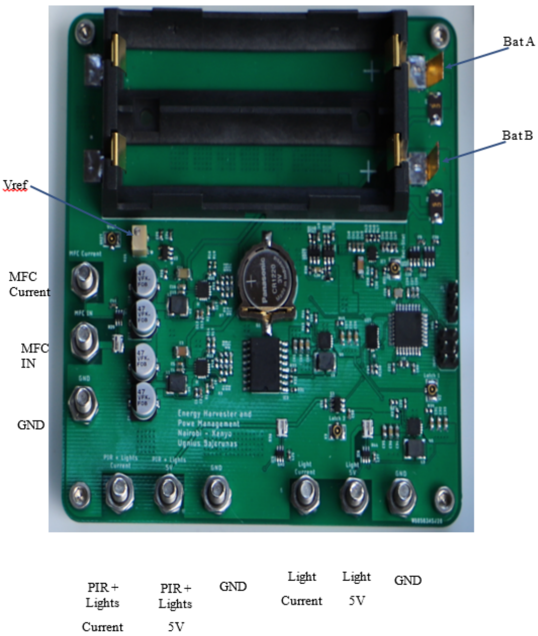
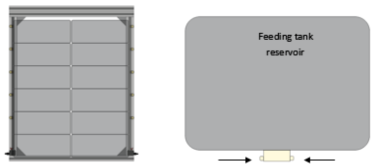


Figure 1. Connections on the Energy Harvester and Power Management board

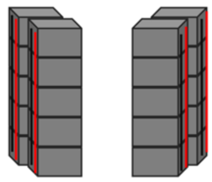


- Place the feeding tank reservoir on top of the system and ensure pipes from the feeding distributor outlets are inside the inlet of the individual top modules. It should look similar to the picture below.

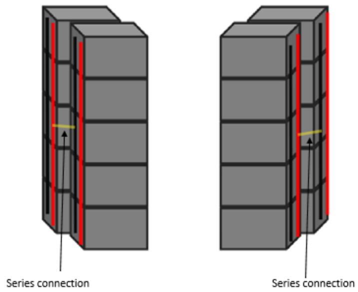
d. Connect effluent modules to the soakaway with the silicon pipe (~15 mm diam.). Press the silicon pipe into the valves outlet pipe (as far in as possible until is entirely tight) from system outlet to soakaway (as far as 1 m.).

e. Connect the electric wires as shown below, ensure that the connections are firm and that they plug in smoothly;

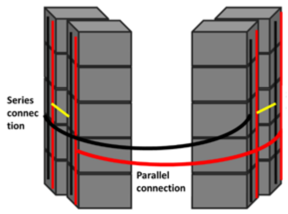
1) MFC Modules assembled into cascades are electrically connected in **parallel**:



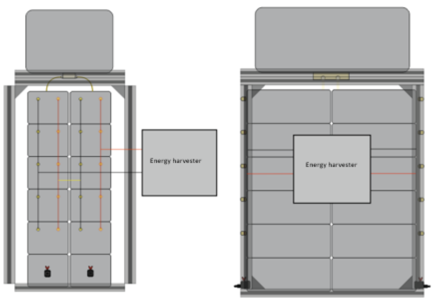
2) Two cascades on each side connected in **series:**



3) Two pairs of serially connected cascades are again connected in **parallel**, here is where the main input electrical connection for the Energy harvester is found.



f. Connect the Energy Harvester and the system should look similar to the image below;



STARTING SYSTEM UP:

1. Inoculation. (wastewater (sludge)), procedures, timings and expected results to connect the external loads).
(Double check info with previous articles and Iwona)
Will need ~ 54 – 60 L to fill all 20 modules in a system.

a. Waste water sludge. Connect the system to loads (loads) until its output reaches certain voltage level.

b. Connect the pipe from the urinal once system performance is optimum in order to start harvesting and producing power.

MAINTENANCE AND TROUBLESHOOTING

ALWAYS wear PPE for maintenance of the PeePower system.

1) MFC system:

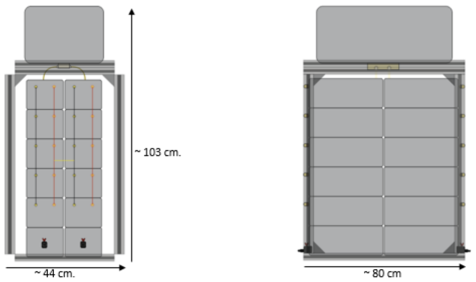
a. Blocked outlet silicon pipe from the feeding distributor: press and release the silicon pipe to observe if it unblocks allowing the urine to flow evenly. If not, it will need cleaning out to ensure the pipes are unblocked and any remains of accumulated struvite precipitation are discharged. Refer to cleaning section.

b. Leakage observed from the module cascades (stacks), possible causes;

- Feeding supply is not even (meaning that one cascade receives more urine than others in the same amount of time, whilst the syphon is activated).
Solution:
    1. Feeding box could be slightly tilted, check and level.
    2. A pipe from the feeding distributor could be blocked, if so, refer to cleaning section.

- Possible pipe obstruction or blockage from individual modules within the cascades.
Solution:
    1. Observe which module the leakage is coming from. If not possible to identify, dismantle the system and observe the state of the modules.
    2. If there is any debris blocking the outlet PVC pipe of the module, remove it in order to facilitate urine flow. If not possible to remove debris or it's found underneath the acrylics, the module will need cleaning out. Repeat this step for all the modules within the cascade. Refer to cleaning section.

<u>System measurements and total footprint (20 module system, 40 module system, 80 module system)</u> (Double check once back in the lab measurements. Nairobi measurements used, but it does not have a frame)



<u>Materials/ tool list needed (replacement?)</u> (Double check back in the lab)

- Silicon piping 15 mm diam. (outlet urinal to inlet of feeding reservoir tank, outlet system to soakaway)
- PVC Pipe 10 mm (between modules).
- Connectors. (Golden plug female golden connectors). Spanner size ~
- Cathode wiring = 316 Stainless steel crocodile clips + 316 stainless steel 0.5 mm wire.
- T –screws + triangle joints for frame (Allen key size ~ 7 – 8)

<u>SYSTEM INSTALLATION</u>.

Pre requisites to take into account before installing PeePower system:

1. Access to activated sludge and urine. Planning ahead with a local waste water treatment plant (or any other similar facility with waste water access) to ensure enough amount of activated sludge for the inoculum.
2. Urine/sludge collection and storage availability prior to the installation. Ideally, urine has to be refrigerated for storage and have an easy access when the inoculation process occurs.
3. Complying with the local health and safety regulations for waste water manipulation, staff working with the system to have the qualifications and skills needed (biochemistry – technical skills)
4. Location of the system and waste water facilities. System should be placed on a flat surface, urinals should be above the system and outlet soakaway below the system (using gravity for fluidics flow). There should be enough space to access all points of the system easily, for maintenance purposes.
5. Access to running water, for cleaning purposes.

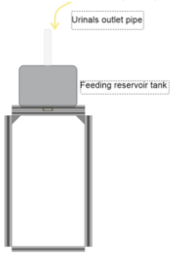
<u>RECOMMENDATIONS/WARNINGS:</u>

MANIPULATE URINE USING ALL RECOMMENDED PPE DURING INSTALLATION, CLEANING AND MAINTENANCE. (RECOMMENDED PPE FOR MANIPULATING SYSTEM USING URINE: gloves, lab coat, respiratory mask, protective glasses).

<u>INSTALLATION:</u>

a. System location:

- Place system where there is an easy access from the outlet pipe of the urinals to the inlet of the feeding reservoir tank (Outlet pipe of urinals has to match inlet hole of the feeding reservoir tank). Easier to match with the frame already built (Without the MFC modules).

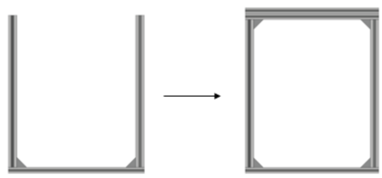


- Take into account distance from the effluent boxes to the soakaway for silicon pipe reference.

b. Build the frame:

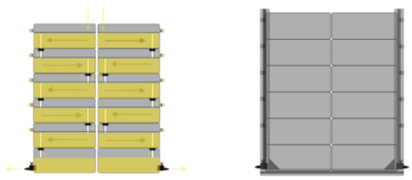
- Build the whole frame to start with without the MFC modules in order to observe which will be the final positioning of the system, ensuring that the inlet hole of the feeding reservoir tank matches the urinal outlet pipe and there is enough space to perform maintenance if needed.

- Feeding reservoir tank test build. Build bottom to top. Components needed (Rexroth, triangle joints, T screws, Allen key (size 7-8?, double check in the lab):
  1) First, build bottom square
  2) One by one, connect the vertical parts of the frame using the triangle joint and the T screws which will hold it in place. Ensure fittings are tight.
  3) Once all the vertical parts of the frame are built, place the top part of the frame using the triangle joints and T screws.



- After the test build, dismantle top part of the frame, leaving the bottom and side parts of the frame, then, proceed to stack the modules.

c. Stack up module cascades following numbers shown, (1-5, 1 bottom 5 top, etc…). The modules in the stack will be built up in such manner that the connectors are facing the same way, and the urine flow emulates a cascade.



- Place top part of the frame. Before putting the reservoir tank on top, ensure that the silicon pipes from the feeding distributor are tight, if not, push the pipes further into the outlet until it's completely tight.

3. Stack the clean MFC modules back into cascades, following its order.
4. Ensure to run a water test through the MFC cascades before feeding with urine in order to ensure that the cascade/system urine flow works as expected.

c. External connectors Anode (black) Cathode (red);

- Check the state of the connectors, by gently moving them and pulling the wires on both sides of the module, inside and outside:
  1) Inner connections: Gently pull the wire to ensure it is tight. If not, using a size 8(?) Spanner tighten the nut. Check the tightness of the screw, could loosen after certain time.
  2) Outer connections: Gently move the connections and check if they are tight, if not, tighten from the inside with the spanner. Pull the wires to check if they plug in smoothly and if they don't, the cable will need replacing.
  3) Corroded outer connectors: Unscrew the golden connectors, wash out with water and scrub with a metallic brush. If it is very badly corroded that can't be cleaned, the connector will need replacing.
- Voltage check of the system: Measure the systems voltage output (MFC IN on the energy harvester) If it less than ~ 600 mV, refer to Harvester section.

- Low output voltage from individual modules (Reference from Nairobi report):

d. Blocked silicon pipe from the effluent boxes. Possible cause:

- Accumulated struvite precipitation. Solution:

  1) Disassemble out system in order to access the effluent boxes. Refer to cleaning section.
  2) Pour out effluent module by eliminating any possible accumulated struvite precipitation and wash out with water.
  3) Assemble the system back into place.

2) MFC individual modules

Connections to be checked as follow:

- Check anode and cathode main connection points within and outside the box.

  1) Observe the state of the golden connectors, if they are corroded, disconnect and scrub with water and a metallic brush. If they are heavily corroded, the connector will need replacing.
  2) Ensure that connectors are tight, with cables tightly connected too. Nuts can loosen over time, so check by gently moving them and if they are loose, tighten up with a spanner.

- Check the cathode parallel wiring using a multimeter:

1) Cathode wire resistance (Ω). Check the Ohms value of the 4 parallel wire rows connected to the cathode with crocodile clips, from the first one to the last one. Connect the outer cathode (Red) connector and check the resistance of each crocodile clip. Values should be lower than 3 Ω (Furthest one from the connector, closest ones should be less than the further one). If the value

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is higher, ensure there is no contact within the wires and that the crocodile clip is well gripped on to the small mesh found within the cathode.

2) Cathode wire conductivity (Ω). Check the conductivity from the connector to the last crocodile clip connector. It should beep. If it doesn't, move slightly the crocodile clip and check again. If it still doesn't beep, the row will need replacing.

3) Observe the state of the crocodile clips and the wires. Check if the crocodile clip is properly gripped on to the metallic mesh and if loose, gently grip it in place. If they are heavily corroded or any broken wires, the whole row will need replacing.

4) Check that there is no contact between anode and cathode connections. If so, remove and ensure there is no contact.

- If any pipe blockages within the module occur, remove any possible debris found blocking the pipe. If the blockage is found underneath the acrylic, clean out module. Refer to cleaning section.

- Individual cathode check:
  Each cylinder has the cathode inside which is in direct contact with the ceramic, the crocodile clip is connecting to the cathode through a small piece of stainless steel mesh which is pressed onto the cathode in order to avoid ripping of the cathode and to stabilise the connection.

  1) Observe if the ceramics cylinders show any damage such as cracks, if so, replace. (If cathode in optimal condition, can pull out with pliers and replace into the new cylinder.)
  2) Check if the crocodile clips are well gripped and not loose. If so, ensure to clip on back on place gently and onto the small piece of stainless steel.
  3) Individual visual observations that the anolyte has not flooded the cathodes. If there is any debris observed, remove.

3) Energy harvester maintenance

Start by checking the battery A and B voltages. The values should be very similar to each other.

a) If the values for these are between 3.6V and 4.2V, it indicates normal EHPM operation.

b) If the value for either A or B is between 3.3V and 3.6V, while the other one is ~3.6V, the power coming from the MFCs is low and batteries aren't being fully recharged. If this is the case, then EHPM is close to entering Hibernation mode.

c) If both batteries are at around 3.2V - 3.4V, then the EHPM has entered the Hibernation mode and all functions are suspended. This would either indicate very low power coming from the MFCs, a bad connection between the MFCs, a bad connection to the EHPM or a fault in the harvesting hardware.

d) If there's a significant difference in voltage between battery A and B (more than 0.5V), then this indicates that either the battery with lower voltage needs to be replaced or that one of the two harvesting circuits malfunctioned and the another one took over to harvest all of the energy from the MFCs. It's recommended to first replace the battery with significantly lower voltage with a new battery.

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e) If either or both batteries are below 3.2V, then the one or both batteries should be replaced.

Next, a measurement at MFC IN and MFC Current connections should be taken.

a) The voltage at MFC IN should be steady and equal to Vref (~600mV).

b) If the voltage at MFC IN point is above Vref and the voltage at MFC Current point is above ~1.2V (corresponding to ~120mA) then this indicates that the MFCs are performing very well, thus saturating the current levels and pushing up the Vref.

c) If the voltage at MFC IN point is above Vref and the voltage at MFC Current point is ~0V (corresponding to 0mA/no current flowing) indicates that no energy is being harvested and the MFCs are in open circuit. This could be due to bad connections to the EHPM or MFCs are not producing enough energy. In such case, voltages at MFC IN and MFC Current should be observed for a little longer to see if value at MFC IN fluctuates by dropping to Vref value and jumping back up again, which would indicate that MFCs aren't producing enough energy (harvester letting MFCs to recover allowing them to go to open circuit and start harvesting when they start recovering causing an oscillation between the two) and MFC modules should be fed if possible. If the voltage stays floating above Vref and no voltage occurs at MFC Current, then it's an indication that there could be a loose connection to EHPM or a fault with the both harvesting circuits at the same time.

d) If the voltage at MFC IN is below Vref (~600mV) then MFC should be fed (if possible) to see if after the feed the value for MFC IN starts to increase eventually reaching Vref. If this doesn't happen after feeding the stack, then the connections between modules should be examined. If such examination doesn't reveal a fault with the connections, then MFC modules should be examined for blockage or shorts.

The best way to troubleshoot the EHPM board to see if it turns on the LED spotlights at the right time is to leave Light 5V and Light Current points connected to a data logger over night, when possible. When this method is used, the collected data would show if the hardware turned on the lights.

a) If the voltage at the point Light 5V has changed from 0V to ~5V (up to 5.5V) at the time that the lights were set to turn on and switched back to 0V when they were set to turn off, then it's a clear indication that the EHPM is working normally.

b) If the above (a) doesn't happen, the value read at Light Current point should be examined. If it has changed from 0V to a fluctuating and noisy levels at specific times, then this indicates that there's likely to be a short connection between the wires connecting spotlights and sensors to the EHPM. Advise on finding faults in such case will be described in a later section.

c) If the above (a) happens, but Light Current stays at 0V then it indicates a faulty connection from EHPM to spotlights and sensors.

d) If both Light 5V and Light Current stay low (at 0V), the EHPM might need to be replaced. It might be sufficient to reprogram the board if there's a possibility to do so.

e) If the Light 5V changes as described (a), the Light Current should be examined. If the Light Current value changes by the same incremental difference of the maximum value (which usually should be ~1V, corresponding to ~100mA) then all lights and sensors are working. As an example if 4 spotlights are connected, the maximum value at Light Current is ~1V and it changes between ~0.25V (1/4 spotlights triggered), ~0.5V (2/4 spotlights triggered), ~0.75V (3/4 spotlights are triggered) and ~1V (4/4 spotlights are triggered) then there are no faults and the EHPM operates as it should. The Light Current can also indicate if any and/or how many of the spotlights or sensors are not working. If the maximum value reaches ~0.75V then it shows that

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one spotlight/sensors have stopped working, if it's ~0.5V then two have stopped working and if it's ~0.25V then three have stopped working.

4) Peripherals (Harvester to peripherals) Lights, PIR sensors,

SYSTEM CLEANING.

Always wear PPE when manipulating urine or cleaning.

1. FEEDING BOX SUPPLY.

- Avoid using/close the urinals feeding the system.
- Carefully take out the outlet pipes from the feeding distributor from the top modules (if there is any remaining urine in the feeding reservoir tank, empty it out using its outlet pipes pouring it into a container (Feeding reservoir tank can hold ~ 43 L)).
- Pour out any waste remain and accumulated struvite precipitation. Clean out (USE PPE) and if needed, scrub down any remainder washing it out with water, ensuring outlets are unblocked.
- Run a water test (will need ~ 43 L of water), observing if the syphon activates when full and if so, the flow distribution from the outlets are even.
- Place the feeding reservoir tank back into place on top of the system frame and put the pipes back into the inlet of the top modules.
- Feed the system with urine (if any of the left over urine kept in containers is clean, can be poured back into the feeding reservoir tank, recycling the urine).

2. MFC cascade system.

Clean out modules by following these steps:

a. Take off feeding reservoir tank from above the system (When full can be heavy, ensure its empty before dismantling, urine can be collected into containers and poured back in when cleaning has finished).
b. Dismantle top part of the frame, after, take out gently the MFC modules one by one (careful with outlet pipes as it could get stuck with the acrylic or the wires from the module that is underneath) and pour out the waste water.
c. Disconnect the Anode and the cathode front connectors, from the inside of the individual module using a spanner (size ~ 7 and 8)
d. Take out MFCs without dismantling the acrylics (ceramics cylinders kept in place), and wash the anode through with water (underneath acrylic only, do not wash cathode).
e. Pour out remaining accumulated struvite precipitation and run water through the module to ensure PVC pipe is cleared.
f. Connect the Anode and the Cathode wires to the outer connectors. Stack back up in the same order.

Contact our technical team if further assistance is needed.

BBiC
Bristol
BioEnergy
Centre

PEEPOWER MICROBIAL FUEL CELL SYTEM

Maintenance and repair manual

Updated by the Researcher

Getting started:

Who is this manual for?

This manual provides information about installation, maintenance and troubleshooting as guidance for technicians working with the PeePower system. Below are useful prerequisites knowledge and skills that may be needed:

- ✓ Knowledge and ability to manipulate wastewater for maintenance purpose
- ✓ Basic technical skills
- ✓ Basic understanding of Microbial Fuel Cell working principle
- ✓ Any other?

Scope of the manual:

The PeePower system comes in different sizes, with 20, 40 or 80 modules per system depending on needs. Smaller systems have also been used in field trials, but with different feeding box size.
Note: **This user manual focusses on the 20-module system.**

Materials and tools needed:

The following materials tools will be needed to carry out installation and maintenance tasks on the system:

- Silicon piping 15 mm diam. - PVC Pipe 10 mm - 316 Stainless steel 0.5m - Crocodile clips - Golden plug female connectors -	a. T –screws b. Triangle joints c. Allen key size 7- 8 d. Spanner size e.

Warning:

Personal Protective Equipment (PPE) must be worn during installation, maintenance and cleaning of the PeePower System. Recommended PPE kit: gloves, lab coat, respiratory mask, protective glasses.

Product description:

The PEEPOWER is an innovative Microbial Fuel Cell (MFC) technology which uses liquid waste (such as urine, muddy water, grey water) to generate enough electricity for lighting or phone charging, whilst performing on-site wastewater treatment. Useful by-products such as fertilisers and disinfectants can also be obtained from this process.

Figure 1: System Overview

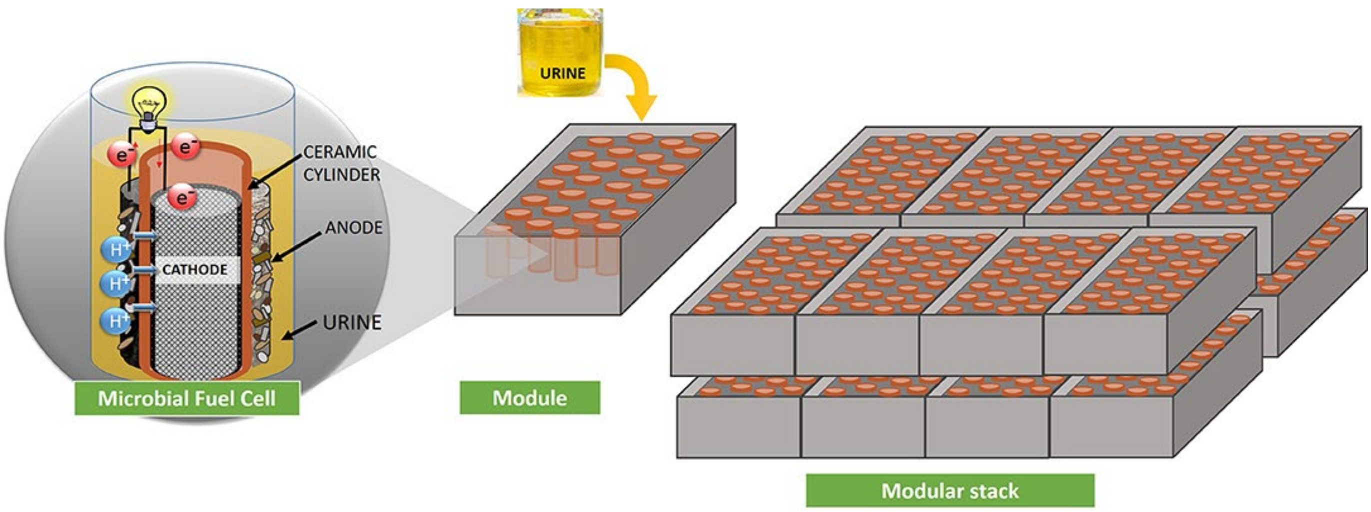
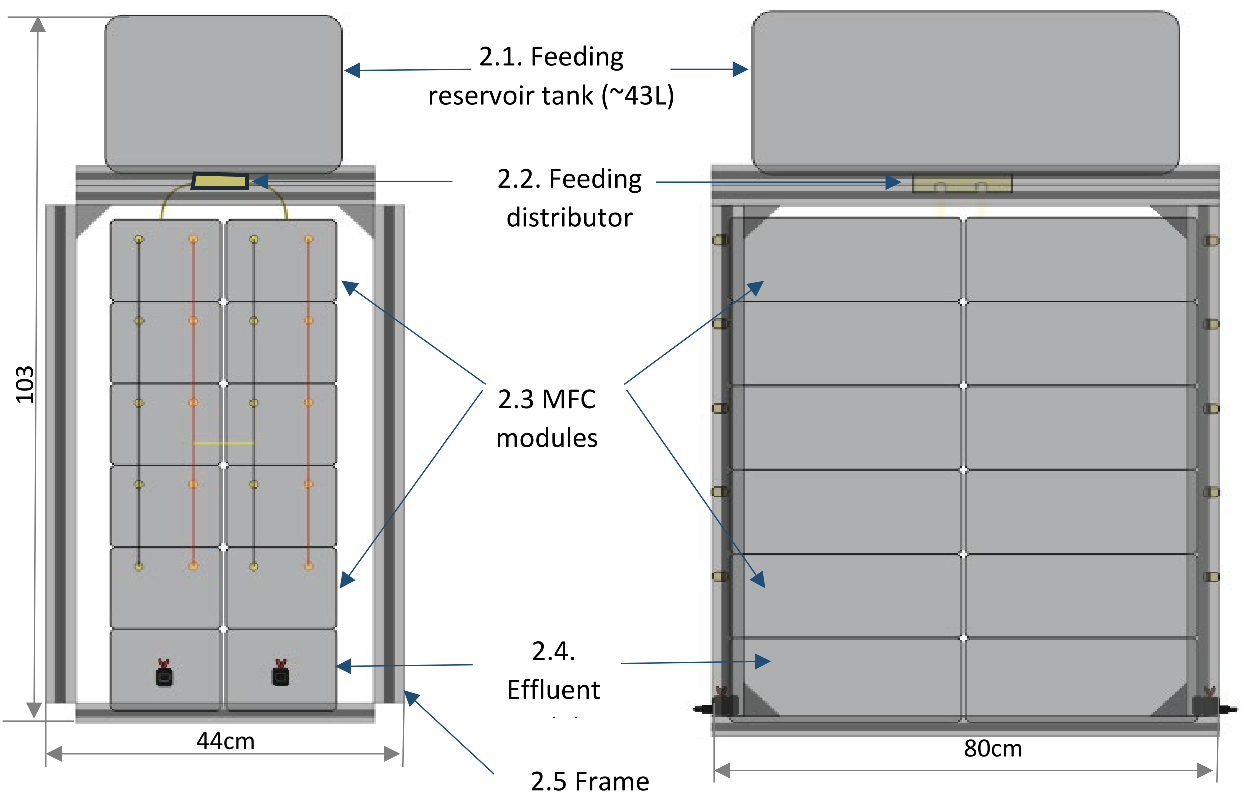


Figure 2: System Annotation



Front view **Side view**

Feeding reservoir tank and Feeding distributor:

The *feeding reservoir tank [2.1]* is fed with urine directly from the urinals. It has an auto syphon mechanism, a pressure flush valve that triggers feed-pulses when a capacity of ~ 40 L of urine is reached. A constant flow rate of urine into the cascade stacks in ensured via the *feeding distributor [2.2].*

MFC modules:

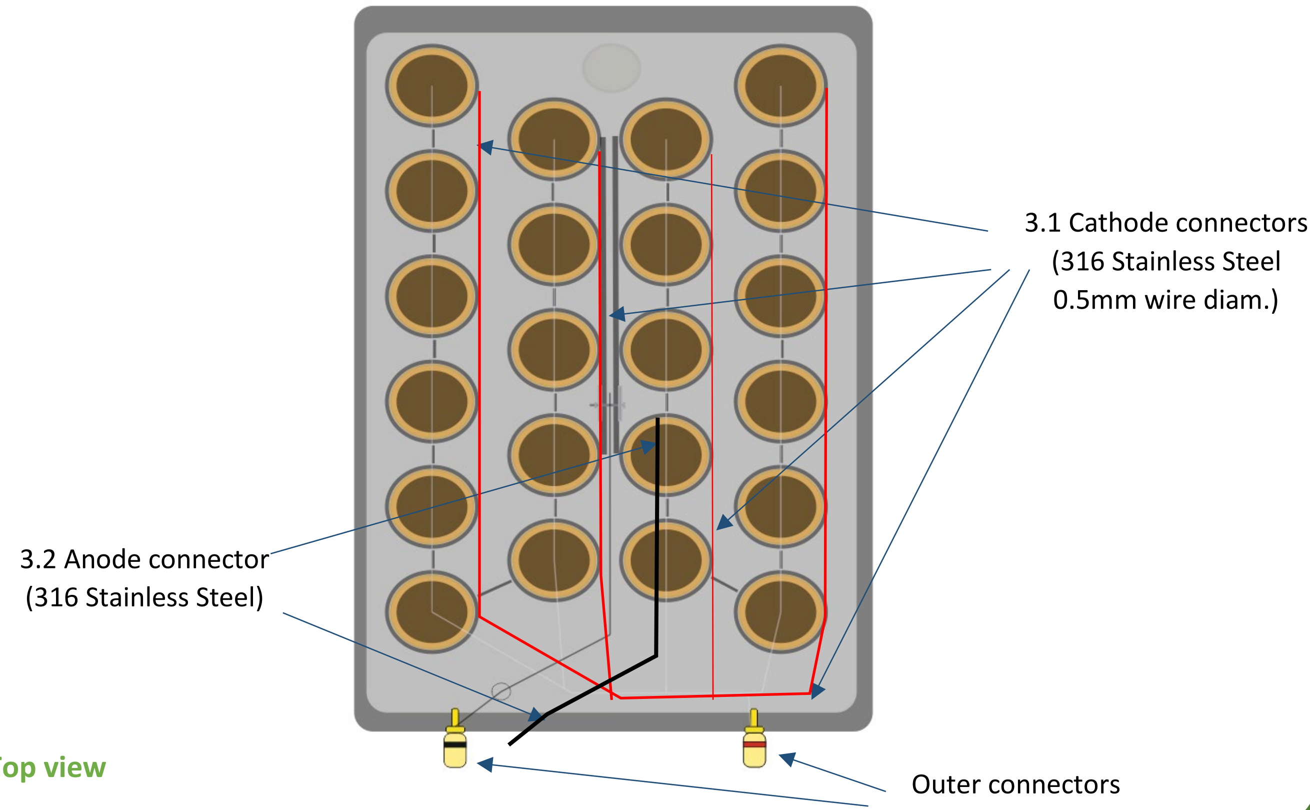
There are 20 *MFC modules [2.3]* arranged in stacks or cascades (four stacks of five *MFC modules*). These stacks rest on top of four *effluent modules [2.4]* that used to drain the system. Each module can hold ~ 3 L of urine. Individual numbering of the modules is recommended to ensure correct positioning.

An MFC module contains 22 *Microbial Fuel Cells*. Within the *Microbial Fuel Cell*, the anode underneath the acrylic lid is wrapped around a ceramic cylinder and the cathode is placed within that ceramic cylinder (see figure 1).

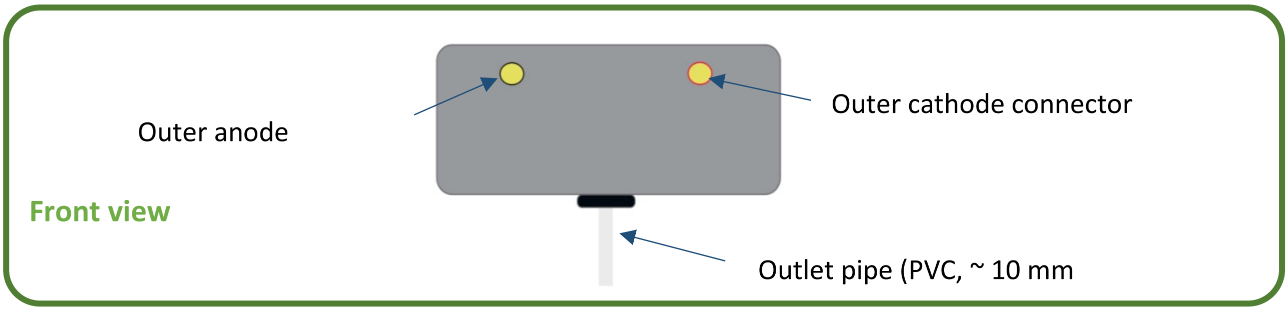
Figure 3 below shows a detailed layout of the MFCs' connections inside the MFC module:

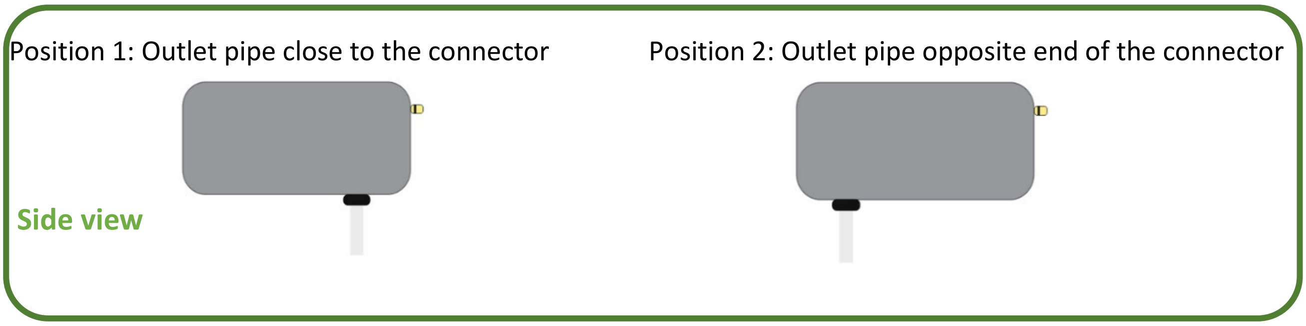
- *The cathode connector [3.2]* is made of steel mesh that is pressed against the cathode. The ceramic cylinder, partly exposed to air, grips onto the steel mesh using crocodile clips. There are four rows of steel mesh connecting the MFC's in parallel and leading to an *outer connector* (shown in red). The ending wire of *cathode connector* has heat shrink on to avoid any possible contact with the anode wire.
- *The anode connector [3.1]* is the submerged steel wire that is screwed onto to the carbon veil. The wire is directed out through a hole in the acrylic lid and then links to an *outer connector* (shown in black).
- *The MFC outlet and outer connectors* are shown in the front and side views. The two outer connectors are golden plated female plugs. There are two outlet positions, depending on cascade stacking.

Figure 3: MFCs' connections inside each module



Top view





Energy harvester and peripherals:
A photo of the actual energy harvester (vs. EHPM board) would be useful. Along with a diagram showing how the energy harvester and peripherals are linked to the system (similar to figure 1).

System installation:

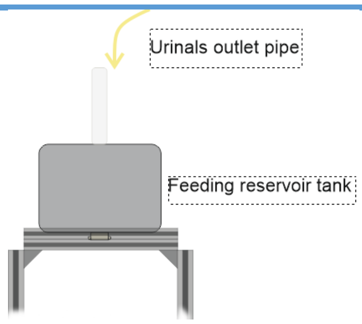
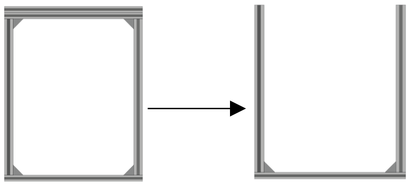
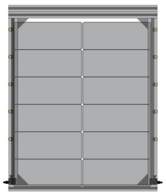
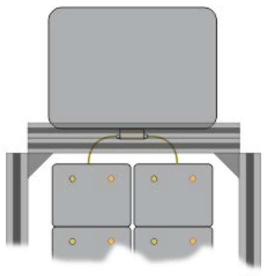
Personal Protective Equipment (PPE) must be worn: gloves, lab coat, respiratory mask, protective glasses.

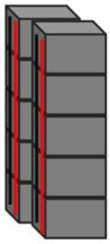
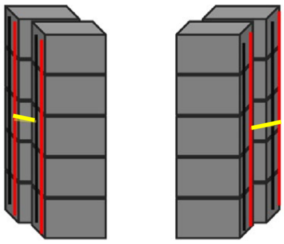
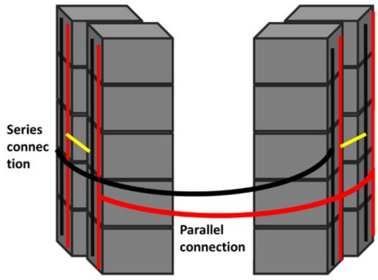
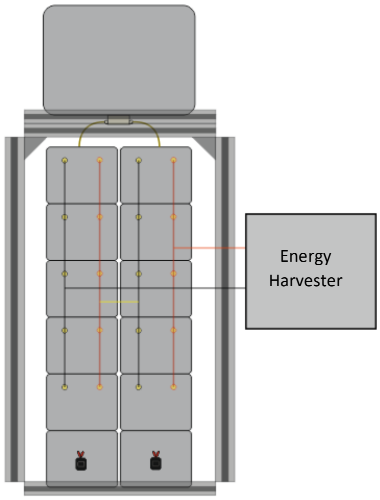
The system may come with the feeding reservoir tank, feeding distributor and MFC modules already assembled.

Before installation
Prerequisites to take into account before installing the PeePower system:

a. Access to activated sludge and urine. Planning ahead with a local waste water treatment plant (or any other similar facility with waste water access) to ensure enough amount of activated sludge for the inoculum.
b. Urine/sludge collection and storage availability prior to the installation. Ideally, urine has to be refrigerated for storage and have an easy access when the inoculation process occurs.
c. Complying with the local health and safety regulations for waste water manipulation, staff working with the system to have the qualifications and skills needed (biochemistry – technical skills)
d. Location of the system and waste water facilities. System should be placed on a flat surface, urinals should be above the system and outlet soakaway below the system (using gravity for fluidics flow). There should be enough space to access all points of the system easily, for maintenance purposes.
e. Access to running water, for cleaning purposes.

Installation procedure:

0. System location a. The outlet pipe of the urinals would need to align with the inlet of the *feeding reservoir tank* (exact height can be measured after assembly of the system). b. Also take into account the distance from the *effluent modules* to the soakaway (this determines the length of the silicon pipe needed).	
1. Building the *frame* a. Build bottom up. Whilst assembling the *frame*, ensure enough space is left to perform maintenance if needed. b. Connect the vertical parts of the frame one by one using the *triangle joint* and the *T screws* to hold it in place. Ensure tight fittings. c. Test build: Connect the top part of the frame using the *triangle joints* and *T screws*, then dismantle.	
2. Stacking up the module cascades a. Stack from Module 1 at the bottom to Module 5 at the top, making sure connectors on modules face the same way, and the urine flow emulates a cascade. More description of image below	
b. Place top part of the *frame*.	
c. Before putting the *reservoir tank* on top, ensure that the silicon pipes from the *feeding distributor* are tight. If not, push the pipes further into the outlet until it is completely tight. d. Place the *feeding tank reservoir* on top of the *frame* and ensure pipes from the *feeding distributor* outlets are fitted into the inlet of the top modules.	
3. **Connecting the *effluent modules* to the soakaway** Press the silicon pipe (~15 mm diam.) into the valves outlet of the *effluent modules* (all the way in, until entirely tight). Connect the other end of the silicon pipe to the soakaway (as far as 1m).	

4. **Connecting the electric wires** *Ensure all connections are firm and plugged in smoothly.* a. Stacked MFC Modules are electrically connected in **parallel**.	
b. The two stacks/cascades on each side of the system are connected in **series**.	
c. The two pairs of serially connected cascades from each side are connected in **parallel**.	
5. **Connecting the *Energy Harvester*** Connect the main electrical input of the *Energy Harvester* to the side of the cascade. More information needed.	

Starting up the system:

Personal Protective Equipment (PPE) must be worn: gloves, lab coat, respiratory mask, protective glasses.

Further editing and proofreading needed.

Inoculation. (wastewater (sludge), procedures, timings and expected results to connect the external loads).
Will need ~ 54 – 60 L to fill all 20 modules in a system.
Waste water sludge. Connect the system to loads until its output reaches certain voltage level.
Connect the pipe from the urinal once system performance is optimum in order to start harvesting and producing power.

Maintenance and troubleshooting:

Personal Protective Equipment (PPE) must be worn: gloves, lab coat, respiratory mask, protective glasses.

Further editing and proofreading needed.

Blocked outlet silicon pipe from the feeding distributor:

Press and release the silicon pipe, then observe if it
Unblocks or allows urine to flow evenly. If not, it will need cleaning out to ensure any remains of accumulated struvite precipitation are discharged. Refer to SYSTEM CLEANING.

Leakage observed from the MFC module cascades (stacks):

Possible causes:

- Feeding supply is not even; meaning that urine is flowing into one cascade faster than the others, whilst the syphon is activated.
  - Solution:
    a. Feeding box could be slightly tilted, check and level.
    b. A pipe from the feeding distributor could be blocked. If so, refer to SYSTEM CLEANING.
- Pipe obstruction or blockage from individual modules within the cascades.
  - Solution:
    a. Observe which module the leakage is coming from. If not possible to identify, dismantle the system and observe the state of the modules.
    b. If there is any debris blocking the outlet PVC pipe of the module, remove it in order to facilitate urine flow. If not possible to remove debris or if the debris is found underneath the acrylics, the module will need cleaning out. Refer to SYSTEM CLEANING.
    c. Repeat this step for all the blocked modules within the cascade.
    d. Then stack the modules back into cascades, following the correct number ordering.
    e. Run a water test through the MFC cascades before feeding with urine in order to ensure that the urine flow works as expected.

Blocked silicon pipe from the effluent boxes:

Possible cause:

- Accumulated struvite precipitation.
  - Solution:
    a. Disassemble the system in order to access the effluent boxes. Refer to SYSTEM CLEANING.
    b. Pour out the content of effluent module to eliminate possible accumulated struvite precipitation.
    c. Wash the module with water
    d. Assemble the system back into place.

Checking the state of anode (black) and cathode (red) connectors:

Do this by gently moving them and pulling the wires on both sides of the module, inside and outside.

a. Inner connections: Gently pull the wire to ensure it is tight. If not, using a size 8(?) Spanner tighten the nut. Check the tightness of the screw, it can loosen up over time.
b. Outer connections: Gently move the connections and check if they are tight, if not, tighten from the inside with the spanner. Pull the wires to check if they plug in smoothly; if they do not, the cable will need replacing.

c. Golden connectors: if they are corroded, unscrew and scrub with water and a metallic brush. If they are heavily corroded, the connector will need replacing.

Checking the individual Microbial Fuel Cell:

a. Check the ceramics cylinders for any damage such as cracks. If damaged, replace. If cathode in optimal condition, pull it out with pliers and replace into the new cylinder.
b. Check that the crocodile clips are well gripped and not loose. If not, clip them back gently onto the small piece of stainless steel.
c. Check that the anolyte has not flooded the cathodes. If there is any debris observed, remove.

Checking the modules parallel wiring using a multimeter:

a. Cathode wire resistance (Ω): Check the Ohms value of the 4 parallel wire rows connected to the cathode with crocodile clips, from the first one to the last one. Connect the outer cathode (Red) connector and check the resistance of each crocodile clip. Values should be lower than 3 Ω (Furthest one from the connector, closest ones should be less than the further one). If the value is higher, ensure there is no contact within the wires and that the crocodile clip is well gripped on to the steel mesh.
b. Cathode wire conductivity (Ω): Check the conductivity from the connector to the last crocodile clip connector. It should beep. If it does not, move slightly the crocodile clip and check again. If it still does not beep, the row will need replacing.
c. Observe the state of the crocodile clips and the wires: Check if the crocodile clip is properly gripped on to the metallic mesh and if loose, gently grip it in place. If they are heavily corroded or if there are any broken wires, the whole row will need replacing.
d. Check that there is no contact between anode and cathode connections. If so, separate and ensure there is no contact.

Checking voltage:

- Measure the systems voltage output (MFC IN on the energy harvester). If it less than ~ 600 mV, refer to the Energy Harvester section below.
- Low output voltage from individual modules (Reference from Nairobi report)

Checking battery A and B voltages of the energy harvester: Troubleshooting Step 1

a. The values should be very similar to each other.
b. If the values for these are between 3.6V and 4.2V, it indicates normal EHPM operation.
c. If the value for either A or B is between 3.3V and 3.6V, while the other one is ~3.6V, the power coming from the MFCs is low and batteries aren't being fully recharged. If this is the case, then EHPM is close to entering Hibernation mode.
d. If both batteries are at around 3.2V - 3.4V, then the EHPM has entered the Hibernation mode and all functions are suspended. This would either indicate very low power coming from the MFCs, a bad connection between the MFCs, a bad connection to the EHPM or a fault in the harvesting hardware.
e. If there's a significant difference in voltage between battery A and B (more than 0.5V), then this indicates that either the battery with lower voltage needs to be replaced or that one of the two harvesting circuits malfunctioned and the another one took over to harvest all of the energy from the MFCs. It's recommended to first replace the battery with significantly lower voltage with a new battery.

f. If either or both batteries are below 3.2V, then the one or both batteries should be replaced.

Taking measurements at MFC IN and MFC Current connections on the Energy Harvester: Troubleshooting step 2

a. The voltage at MFC IN should be steady and equal to Vref (~600mV).

b. If the voltage at MFC IN point is above Vref and the voltage at MFC Current point is above ~1.2V (corresponding to ~120mA) then this indicates that the MFCs are performing very well, thus saturating the current levels and pushing up the Vref.

c. If the voltage at MFC IN point is above Vref and the voltage at MFC Current point is ~0V (corresponding to 0mA/no current flowing) indicates that no energy is being harvested and the MFCs are in open circuit. This could be due to bad connections to the EHPM or MFCs are not producing enough energy. In such case, voltages at MFC IN and MFC Current should be observed for a little longer to see if value at MFC IN fluctuates by dropping to Vref value and jumping back up again, which would indicate that MFCs aren't producing enough energy (harvester letting MFCs to recover allowing them to go to open circuit and start harvesting when they start recovering causing an oscillation between the two) and MFC modules should be fed if possible. If the voltage stays floating above Vref and no voltage occurs at MFC Current, then it's an indication that there could be a loose connection to EHPM or a fault with the both harvesting circuits at the same time.

d. If the voltage at MFC IN is below Vref (~600mV) then MFC should be fed (if possible) to see if after the feed the value for MFC IN starts to increase eventually reaching Vref. If this doesn't happen after feeding the stack, then the connections between modules should be examined. If such examination doesn't reveal a fault with the connections, then MFC modules should be examined for blockage or shorts.

Troubleshooting the EHPM board:

To see if it turns on the LED spotlights at the right time is to leave Light 5V and Light Current points connected to a data logger over night, when possible. When this method is used, the collected data would show if the hardware turned on the lights.

a. If the voltage at the point Light 5V has changed from 0V to ~5V (up to 5.5V) at the time that the lights were set to turn on and switched back to 0V when they were set to turn off, then it's a clear indication that the EHPM is working normally.

b. If the above (a) doesn't happen, the value read at Light Current point should be examined. If it has changed from 0V to a fluctuating and noisy levels at specific times, then this indicates that there's likely to be a short connection between the wires connecting spotlights and sensors to the EHPM. Advise on finding faults in such case will be described in a later section.

c. If the above (a) happens, but Light Current stays at 0V then it indicates a faulty connection from EHPM to spotlights and sensors.

d. If both Light 5V and Light Current stay low (at 0V), the EHPM might need to be replaced. It might be sufficient to reprogram the board if there's a possibility to do so.

e. If the Light 5V changes as described (a), the Light Current should be examined. If the Light Current value changes by the same incremental difference of the maximum value (which usually should be ~1V, corresponding to ~100mA) then all lights and sensors are working. As an example if 4 spotlights are connected, the maximum value at Light Current is ~1V and it changes between ~0.25V (1/4 spotlights triggered), ~0.5V (2/4 spotlights triggered), ~0.75V (3/4 spotlights are triggered) and ~1V (4/4 spotlights are triggered) then there are no faults and the EHPM operates as it should. The Light Current can also indicate if any and/or how many of the spotlights or sensors are not working.

If the maximum value reaches ~0.75V then it shows that one spotlight/sensors have stopped working, if it is ~0.5V then two have stopped working and if it's ~0.25V then three have stopped working.

Peripherals (Lights, PIR sensors):

System cleaning:

Further editing and proofreading recommended.

Feeding box supply:

a. Avoid using/close the urinals feeding the system.
b. If there is any remaining urine in the *feeding reservoir tank*, empty it out via its outlet pipes and pour it into a container.
c. Carefully take out the outlet pipes of the *feeding distributor* from the top modules.
d. Pour out remaining waste and accumulated struvite precipitation and a do deep clean with water ensure outlets are unblocked.
e. Run a water test (will need ~ 43 L of water), observing if the syphon activates when full and if so, the flow distribution from the outlets are even.
f. Place the feeding reservoir tank back into place on top of the system frame and put the pipes back into the inlet of the top modules.
g. Feed the system with urine (if any of the left over urine kept in containers is clean, can be poured back into the feeding reservoir tank, recycling the urine).

MFC cascade system:

Clean out modules following these steps:

a. Take off feeding reservoir tank from above the system (When full can be heavy, ensure its empty before dismantling, urine can be collected into containers and poured back in when cleaning has finished).
b. Dismantle top part of the frame, after, take out gently the MFC modules one by one (careful with outlet pipes as it could get stuck with the acrylic or the wires from the module that is underneath) and pour out the waste water.
c. Disconnect the Anode and the cathode front connectors, from the inside of the individual module using a spanner (size ~ 7 and 8)
d. Take out MFCs without dismantling the acrylics (ceramics cylinders kept in place), and wash the anode through with water (underneath acrylic only, do not wash cathode).
e. Pour out remaining accumulated struvite precipitation and run water through the module to ensure PVC pipe is cleared.
f. Connect the Anode and the Cathode wires to the outer connectors. Stack back up in the same order.

Contacts:

Contact our technical team for further assistance if needed.

APPENDIX 7 a: Design sprint brief provided to BBiC staff members

Design Sprint Schedule

Refining the design of the MFC Educational Kit for commercialisation

Maryam M. Lamere, 2020

Time commitment required from team members: ***2-3hours/months (if delivered in over 4 months),*** *including 1 hr group meeting.*

All the resources will be available on ***MS Team: BIT MFC Educational Kit - Design Workshops***
Click on the ***Files*** *tab for videos and ppt slides. Click on* ***Notes*** *for the design exercises. Click on* ***Meet*** *tab (located in the top right corner of the MS Team window).*

<table>
<tr><td>Date TBC</td><td>Presentation: Overview of the Design Sprint</td></tr>
<tr><td>Month 0
September</td><td>

Watch the video on ‘Week 0 –Discover’ (under the Files tab)
Do the design exercise ‘Workshop 0 –Discover’ (under the Notes tab)
Present work to the group on Friday (date to be confirmed) (via the Meet tab).

<u>Agenda for the Friday group meetings:</u>
<table>
<tr><td>10:00-10:05</td><td>Welcome and introduction</td></tr>
<tr><td>10:05-10:30</td><td>Each team member presents their work (5min)
Facilitator collect ideas shared</td></tr>
<tr><td>10:30-10:40</td><td>General discussion by the team about ideas shared</td></tr>
<tr><td>10:40-10:45</td><td>Overview of next design task</td></tr>
</table>
</td></tr>
<tr><td>Month 1
October</td><td>

Watch the video on ‘Week 1 –Empathise (under the Files tab)
Do the design exercise ‘Workshop 1 –Empathise’ (under the Notes tab)
Present work to the group Friday 25th, 10:00 (via the Meet tab).

</td></tr>
<tr><td>Month 2
November</td><td>

Watch the video on ‘Week 2 –Define’ (under the Files tab)
Do the design exercise ‘Workshop 2 –Define’ (under the Notes tab)
Present work to the group Friday 2nd, 10:00 (via the Meet tab).

</td></tr>
<tr><td>Month 3
December</td><td>

Watch the video on ‘Week 3 –Ideate’ (under the Files tab)
Do the design exercise ‘Workshop 3 –Ideate’ (under the Notes tab)
Present work to the group Friday 9th, 10:00 (via the Meet tab).

</td></tr>
</table>

Key mindset!

- Focus on the user (user-centred design)
- Embrace ambiguity (we do not know what the final outcome would be)
- The design process is cyclic (go back and revise previous tasks whenever needed)

Facilitator
Maryam Lamere
September 2020

Refining the design of the MFC Educational Kit for commercialisation

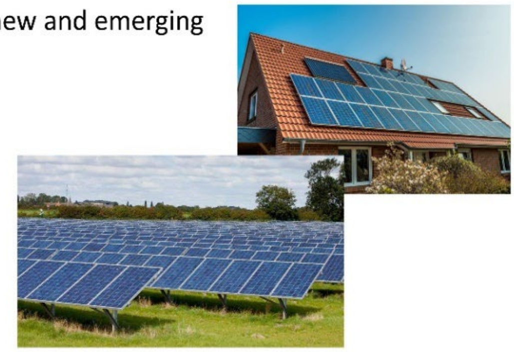
Design Sprint

UWE Bristol University of the West of England

Motivation - Why an MFC Educational Kit

- Microbial Fuel Cell technology – new and emerging

Solar PV, 1950's

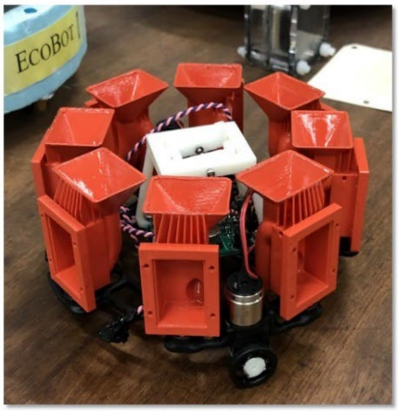


Solar PV, now

Vision: Spark interest in the next generation of scientists and engineers, in the UK and worldwide!

What's the product?

MFC kit



EcoBot

The Task

- **What is the task?**

  To refine the design of our PeePower BoxEd kit and EcoBot and turn them into commercial products.

- **How do we this?**

  By going through a step by step design process.

M. Lamere, UWE, 2020

Week 0

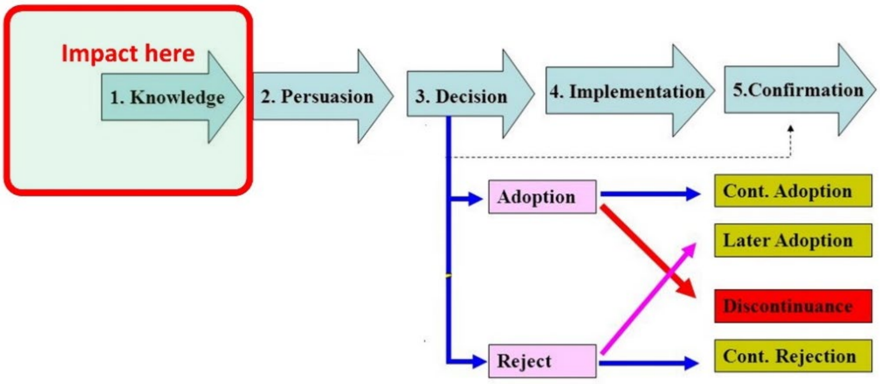
0. Discover

Let's start by exploring the wider context of the task, understand what problem we're trying to solve and why.

- Microbial Fuel Cell Technology
  - ➢New and emerging technology with great potentials
  - ➢(1) Green energy, (2) Waste water treatment, (3) Fertilisers, (4) Disinfectants.
- BBiC: a leading research institution in MFC science
  - ➢We want to also lead the way in MFC education for the younger generation
- Why an MFC educational kit?
  - ➢Enhances STEM education
  - ➢Helps diffusion of innovation

M. Lamere, UWE, 2020

0. Discover | Stages in the Innovation-Decision process



Adapted from Rogers, 2003 p.170 & Chamard, 2003 p.19

Prompt Questions | Workshop 0 – Discover

Evaluate your prior knowledge and assumptions about the design problem

1. First Impressions

What are your initial impressions of the task?
How do you feel about it?

2. Your Assumptions

What solutions do you already think might solve the problem?
How might stop you from seeing other people's perspectives?
What information are you guessing, until told otherwise?

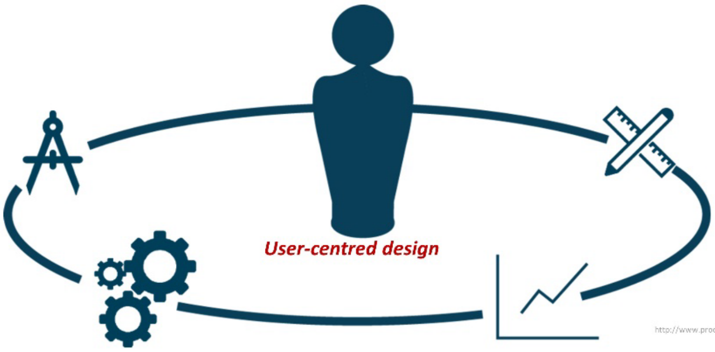
3. Constraints and Barriers

What might prevent you from tackling the problem?
What challenges are likely to make the project fail?

Week 1

1. Empathise

Who are the potential users of the MFC kit? Let's look at the problem from their perspectives.



Note:

✓ At this stage, you may be eager to start brainstorming solutions and may feel like you are not making progress.
✓ Remember you would need to slow down to speed up (key mindset!).
✓ This is an important step in a user centred design process.

Stakeholder list | Workshop 1 –Empathise

Write down a list of those that might be interested in using/purchasing the MFC educational kit.

Stakeholder personas | Workshop 1 –Empathise

Who are they?

E.g:

Mrs Smith, Science teacher in a Secondary school in Durban ...etc

Mr James, Primary school teacher in Bristol...etc

Tobi, Year 10 student in Nairobi. He aspires to become an Engineer. ...etc

How might they use the MFC Educational Kit?

What challenges could they face?

What might they like about an MFC educational kit?

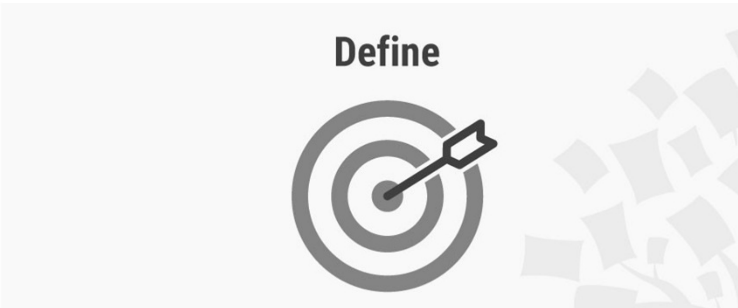
Are there reasons why they might not want to use/purchase the MFC educational kit?

Week 2

2. Define

Before we start exploring possible design solutions, we need to:

- ➢ Define a clear problem statement that keeps us focussed throughout the design process.
- ➢ Define key criteria that will be used to assess our design solutions.



https://www.interaction-design.org/literature/article/5-stages-in-the-design-thinking-process

Key mindset:

- ✓ Embrace ambiguity
- ✓ Remember that the design process is iterative

Problem Statement | Workshop 2 –Define

Here is the proposed problem statement:

"How might we refine the design of our PeePower BoxEd kit and EcoBot and turn them into commercial products?"

Is it too narrow or too broad? How could you change it?

Can you reframe the question in a different way?

Design Criteria | Workshop 2 –Define

Based on your understanding of the users' needs (see User's Persona), how would they like the final product to be?

Write down a list of criteria (up to 10!) you will use to assess your design ideas and decide on final design solution.

Week 3

3. Ideate

What could the commercial product look like? Think outside the box! Come up with lots of different ideas. What changes would the current kit need to have?

M. Lamere, UWE, 2020

Conceptual design | Workshop 3 –Ideate

Brainstorming design ideas:

What existing MFC educational kits (or other science kits) are there in the market?

Can you propose new ones?

Concept sketching:

Get visual, doodle, use diagrams or headlines to jot down your design ideas.

It does not have to be neat, but try to make it self-explanatory by adding words and phrases where needed.

Decision Matrix | Workshop 3 –Ideate

Use a decision matrix to evaluate your design solutions and vote for the best design.

The top design solution is nominated based on ratings assigned in the design decision matrix.

M. Lamere, UWE, 2020

Next step…

M. Lamere, UWE, 2020

APPENDIX 7 b: Design Sprint workshops outcome

Workshop 1: Empathise

Identifying potential users and creating a User Personas

MARYAM LAMERE OCT 14, 2020 12:50PM

User Persona 1: Tia, a Y5 primary school student who likes science. Her teacher has introduced her this kit so she asked her mum to purchase it.

User Persona 2: Tobi, year 10 pupil in secondary school in Nairobi. He loves science and would like to become and engineer when he grows up. STEM is currently taught in a theoretical/boring way in his school. He would love to be able to do fun STEM experiments, especially if sees how it's relevant to his everyday life.

User Persona 3: 1st year secondary school student (age 11 -12), Bristol. Interested in environmental causes and as such is interested in a renewable energy technology.

User persona 4: A researcher associate/PhD student that is doing "Bath Taps into Science" to demonstrate the concept of microbial fuel cell to kids. Or a teacher of science in a high school that wants to demonstrate how microbes can transfer electrons. Or young kids for school projects.

A. Who are the potential users of the MFC Educational product (MFC /EcoBot)?

- *Teachers (in Europe and lower income countries), teenagers*
- *Teachers _ Parents with kids_High school students*
- *I see this a product that is used within schools or another educational setting, therefore the users would be teachers and primary or secondary school age pupils. In addition, it may also be used by school aged individuals in a home setting.*

B. How might they use the MFC Educational product?

- *As a learning tool, as a "pet".*
- *As a toy that provides a learning experience. As a tamagotchi style pet!*
- *As demonstrator in schools - for experiments in schools/at home - as a learning gadget - to support STEM teaching in schools/at home*

C. Are there reasons why they might not want to use/purchase the MFC educational kit?

- *Smell_ safety issues*
- *Health and safety - if the kit is not robust enough - if it's too expensive - if it's not engaging enough*
- *The technology may not provide enough of a "WOW" factor to provide an engaging learning experience.*
- *Difficult to setup or maintain?*
- *The working concept might be too new for educators (not familiar)*
- *Single use (if it is)*

D. What challenges could they face?

- *Lack of spare parts (?), too complex to use/understand, health and safety*
- *Maybe a bad inoculation thus no energy...no results...frustration (?)*

- *Inappropriate maintenance thus no output...*
- *Slow to see results - waiting for inoculation, may become bored.*
- *Doesn't provide instant gratification.*

E. What might they like about an MFC educational kit?
- *The energy production using waste and microbes (?).*
- *It's innovative - the idea of producing electricity from waste - being able to make something themselves - learning something new - MFC science is cool - The toy/kit looks cool.*
- *The production of a useful amount of energy from "waste" may provide a very engaging experience, which could then influence the users to explore and study MFC technology further, or other alternative power sources.*

Workshop 2: Define

- List of key criteria that the final product needs to fulfil (compiled by SL). Please add yours.

Design Criteria	**Users needs**
Function	-To provide a learning experience in MFC technology -MFC to generate a useful amount of power
Aesthetic	-Engaging -Toy-like appearance. -Not overly technical like a piece of scientific lab equipment.
Installation/Setup	-Simple enough to set-up without specialist tools. -Clear and concise instructions, not much prior technical knowledge in electronics, mechanics and chemistry required.
Maintenance	-Easy to 'feed' the MFC without specialist tools.
Durability	-Made from strong materials that can resist being dropped from desk height
Ecological	-Easy to dispose of at the end of the life-cycle. -Ideally made from recyclable materials.
Safety	-Safe to install, maintain and use. -Will not expose the users to sharp edges, electrical or biological hazards.
Cost	-Affordable enough to be purchased in bulk by educational institutions or private individuals.

Workshop 3: Ideate

- Brainstorm possible solutions.
- SL: MFC connected to a garden composter and powers a temperature probe and data logger
- ML: Adapting existing solutions such as the Thymio toy, MudWatt, KiwiCo's electrical kit, MelScience electrical kit.
- UB: the new Ecobot II

APPENDIX 7 c: Design brief for Masters' Group Project

Project Title: Design of a Microbial Fuel Cell educational kit for commercialisation		
Brief Owner: Mrs Maryam Lamere Dr Jonathan Winfield	**Module Leader:** Dr Amir Bolouri	
Date of issue: September 2020	**Module Code:** UFMFXC-15-M	

Brief: This project is based on a real world design problem, which consists in refining the design of the **Microbial Fuel Cell educational kit** and **EcoBot II**, developed by the Bristol Bioenergy Centre (BBiC), for non-profit commercialisation. The kit, in its basic form, has been used in school outreach activities in the UK, Uganda and South Africa over the past years. There is now a case for integrating the kit into educational products that enhance STEM education.

Background: The PeePower is an innovative Microbial Fuel Cell (MFC) technology which uses liquid waste (such as urine, muddy water, grey water) to generate electricity, whilst performing wastewater treatment. Useful by-products such as fertilisers and disinfectants are also obtained from this process.
The PeePower system was first used at the Glastonbury Festival (UK) in 2015. Since then, there has been a number of field trials in Uganda (Kisoro), Kenya (Nairobi) and South Africa (Durban), to test how the system performs when installed in schools toilets and community toilet blocks. Recent advancement in MFC research has also seen the development of the EcoBot II, an autonomous robot powered by muddy water.
Although, Microbial Fuel Cell technologies are relatively new and emerging from their R&D phase, there has been interest and fascination from the public in the science of "*how is it possible to generate electricity from urine*?" A mini Ecobot II and Microbial Fuel Cell kit have been used for various educational purposes. The Microbial Fuel Cell educational kit currently used in outreach activities comprises a box with all the components necessary to build, feed and monitor a microbial fuel cell. These include MFC parts, voltmeter, syringe, tubing, resistor, cables and powdered nutrient for making bacterial feedstock. The children (normally aged 9-10) build the MFC, then collect mud (source of bacteria) from playground, mix with liquid nutrient and feed into the MFC. The MFC's are fed and voltage monitored by the children over few weeks. By week 5, the children connect all their MFC's together and use it to power a device (e.g. A digital weather station). The MFC parts need to be suitable for children to use and assemble.

The Problem: The Microbial Fuel Cell kit and Ecobot II are in their basic architectural forms and do demonstrate the working principle of MFC's. A redesign of the kits is needed in order to: (1) find innovative ways to turn them into to engaging educational toys, (2) give them an overall appearance that is attractive for the target market and (3) most importantly, ensure they are safe, particularly in respect to the culturing of bacteria in a system that will be handled by children. This can also lead to unpleasant smells in the classroom especially in summer!
A human-centred design process is to be used in this project. A good understanding of the target users and their needs is thus key in this design task. The aim of the task is not limited to producing detailed CAD drawings; and as such, a thorough methodical approach used to develop the final design solution(s) would need to be demonstrated. Additional resources on the design process are available for guidance.

The Objectives

- Present an overview of the design context, which should include a rationale behind the MFC educational kit and an overview of the target market or potential users.
- Define the problem being tackled by the MFC educational kit using a clear problem statement and identify the main design criteria/requirements based on understanding of users' needs.
- Explore possible ways to incorporate the MFC kit into an educational product; then use a decision matrix to select the best design solution(s). You can research existing products in the market, as well as propose innovative design ideas.
- Present a detailed design of the final product(s) with 2-D drawings, 3-D solid models and part & assembly drawings.

• Produce a detailed cost analysis of the product(s) showing a bill of materials, cost of manufacturing, the total cost of product and the proposed unit price.

APPENDIX 8a: Business case used to complete bidding applications

MFC toy – "The Bio-battery"

PITCH:
We are looking to set up a spinout company for the development and commercialisation of Microbial Fuel Cell educational kits.

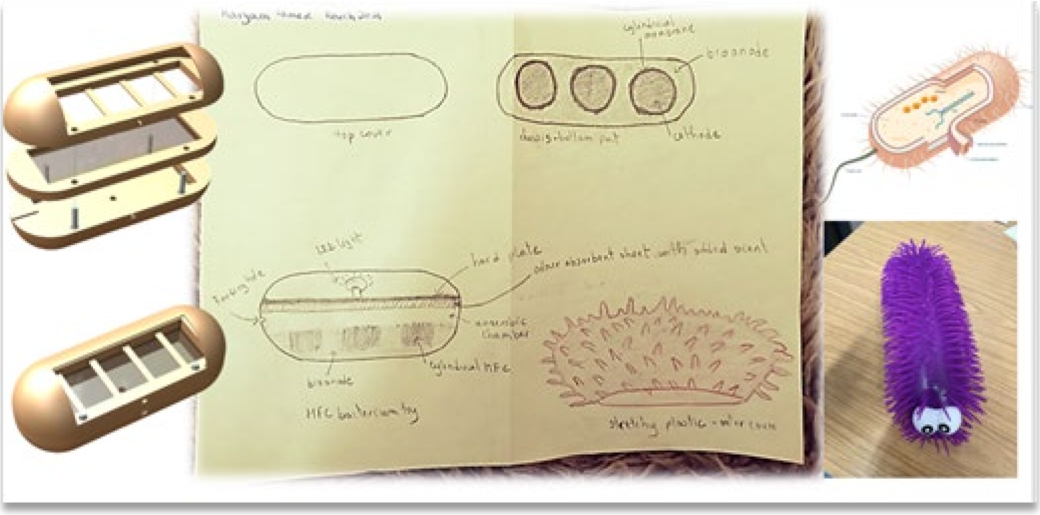
BUSINESS SUMMARY:
The bio-battery developed is an engaging STEM toy that uses Microbial Fuel Cells to generate energy. The toy kit is a great learning resource for schools and home-educators. It comes with an interactive App where learners can monitor electrons release and energy production from fuel cells, whilst engaging in fun MFC science games.

PROBLEM WORTH SOLVING:
Microbial fuel cell (MFC) is emerging as a sustainable approach to wastewater treatment which also generates electricity. Potential applications of MFCs are multiple (e.g. biosensors, energy, wastewater treatment) and with increasing public fascination about how the technology works, the need to educate and raise awareness becomes important. This is complemented by the fact that STEM education is now geared towards inquiry-based learning and the use of hands on activities that have relevant applications in today's society.

OUR SOLUTION:

MFC educational kits has been used in its most basic form in school outreach activities for the past seven years, with great interest from pupils and teachers.

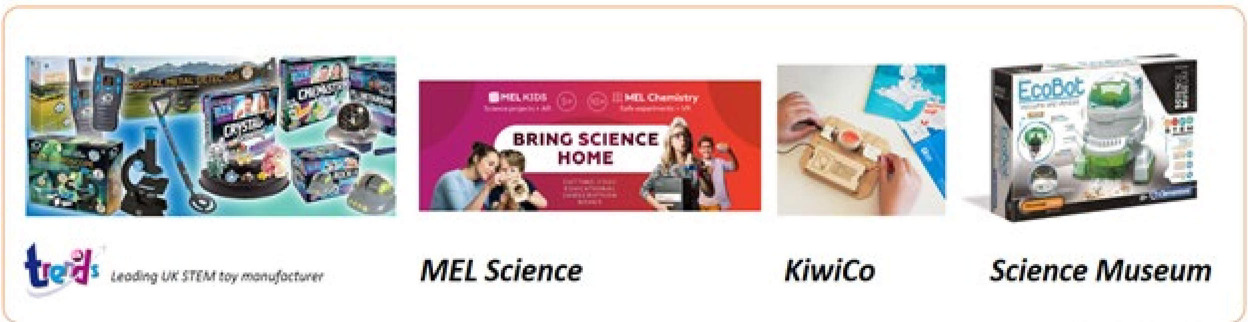
The updated kit has a refined design and interactive features, presenting good potential in the STEM education market. It is a bio-battery that is fed by muddy water and looked after by the pupils over the course of 3 weeks. Their pet-like toy is connected to an App that monitors the amount electrons released by the microbes (i.e. electricity generated) and shows fun engaging learning games about MFCs. Once the bio-battery is fully working, it begins to glow, then it can be used to power small electronic devices such as sensors and clocks. Several bio-battery can be mounted in series for more power.



The development of the toy stemed from a series of design sprint workshops and discussions with key stakeholders (design students, scientists, researchers, teachers, pupils, manufacturer, STEM education advocates such as Siemens Sttiftung and DETI). The kit offers learner a fun and engaging way to learn about MFCs and STEM subjects such as chemistry, physics and biology, whilst addressing main global challenges such as climate change and water crisis. By increasing awareness about MFCs, there are long term benefits for further advancement in the field of MFC from the younger generation. Other long term benefits include technology acceptance and adoption by the wider public, of innovative MFC product being developed.

COMPETITOR:

STRATEGIC BUSINESS PARTNERS:



COST:

Material and parts – cost estimation for one prototype

Parts	Material specification	Cost
Main parts		
Top cover	Plastic (transparent)	£1.00
Bottom cover	Plastic (sturdy)	£1.00
LED light		£4.00
Outer cover (bateria look)	Rubber (soft, stretchy)	£3.00
Microbial Fuel Cell	BBiC's Cylindrical MFC	£5.00
Intergrated digital voltmeter		£1.60
Dividing plate	Plastic	£1.00
Odour absorbent sheet	Sack filled with activated charcoal	£5.00
Possible add-ons		
App	For tablets and phones	
PH sensor	For soil	£7.00
Humidity and temperature gauge		£3.00
Packaging		
User manual	Printed booklet	£2.00
Packaging	Cardboard box	£3.00
Total		**£21.60**
Total with optional add-ons		***£36.60***

Further cost to consider: IP protection (registered design, trademarks –EU and internationally) and other associated cost of setting up and running the spinout company.

APPENDIX 8b: Engineering Intern's job description

ENGINEER INTERN:

Project Title: Design of a Microbial Fuel Cell educational kit for commercialisation
Supervisory team: Maryam Lamere, Jonathan Winfield, Ugnius Bajarunas
Project timeline: 1st June – 31st July (start date tbc)

Project Background:
In these uncertain times where both global sustainability and the pandemic are public concerns, the positivity around Microbial Fuel Cells can capture the imagination of an audience keen for good news. The PeePower as an example, is an innovative Microbial Fuel Cell (MFC) technology which uses liquid waste (such as urine, muddy water, grey water) to generate electricity, whilst performing wastewater treatment. Useful by-products such as fertilisers and disinfectants are also obtained from this process. Recent advancement in MFC research has also seen the development of the EcoBot II, an autonomous robot powered by muddy water. A mini Ecobot II and a Microbial Fuel Cell kit have been used for various educational purposes.
Indeed, Bristol BioEnergy Centre (BBiC) has been delivering MFC-based activities to primary and secondary school pupils around Bristol for over 5 years. The activity is always a success and a rewarding experience for all involved.
The activity provides the children with a hands-on experience over several weeks where they:

- Build a microbial fuel cell.
- Inoculate it, i.e. start-up the MFC by introducing 'electro-active bacteria' found in the school playground.
- Nurture the MFC over several weeks while monitoring its output. As the bacteria colonise the enclosed system the voltage increases, i.e. more power = happy bacteria.
- Interacting with an app to learn more about MFC, whilst monitoring outputs.
- The finale (normally 5 weeks later) showcases to the students that their MFCs can actually power something real.

The Microbial Fuel Cell educational kit currently used in outreach activities comprises a box with all the components necessary to build, feed and monitor a microbial fuel cell. These include MFC parts, voltmeter, syringe, tubing, resistor, cables and powdered nutrient for making bacterial feedstock. The children (normally aged 9-10) build the MFC, then collect mud (source of bacteria) from playground, mix with liquid nutrient and feed into the MFC. The MFC's are fed and voltage monitored by the children over few weeks. By week 5, the children connect all their MFC's together and use it to power a device (e.g. A digital weather station). The MFC parts need to be suitable for children to use and assemble. We have worked with key partners (Siemens Stiftung and DETI) to make these educational resources accessible to teachers and pupils around the world.

Project benefits:
A rewarding opportunity is given for the Engineer Intern to see their design turned into a commercial product. The Engineer Intern will have the opportunity to develop strongly desirable skills in engineering design, product development, team working, communication and other areas of the UK-SPEC competencies.
As a centre, we are inundated with requests from numerous schools to run activities highlighting the potential market demand there might be for such an educational kit. The development of this educational toy, will play a key role in the long term adoption of innovative Microbial Fuel Cell technologies (such as UWE's flagship PEEPOWER). School, Science Museums and the general public will have the opportunity to purchase the educational kits helping to reinforce renewable energy as a viable future solution. The commercialisation of this kit will play a long-term role in facilitating the adoption and diffusion of the PEEPOWER technology.

Project tasks:
The Microbial Fuel Cell kit was redesigned by a group of Masters Engineering students. The design produced by the Masters students (see figure 1) is novel but not yet at a stage where it can be transformed into a prototype. The students employed in this project will take the V1 design and develop it further towards commercialisation. They will work on the designs remotely, liaising with the UWE/BBiC team via MS Teams. With subsequent funding the designs will then be turned into working prototypes to test in the lab.

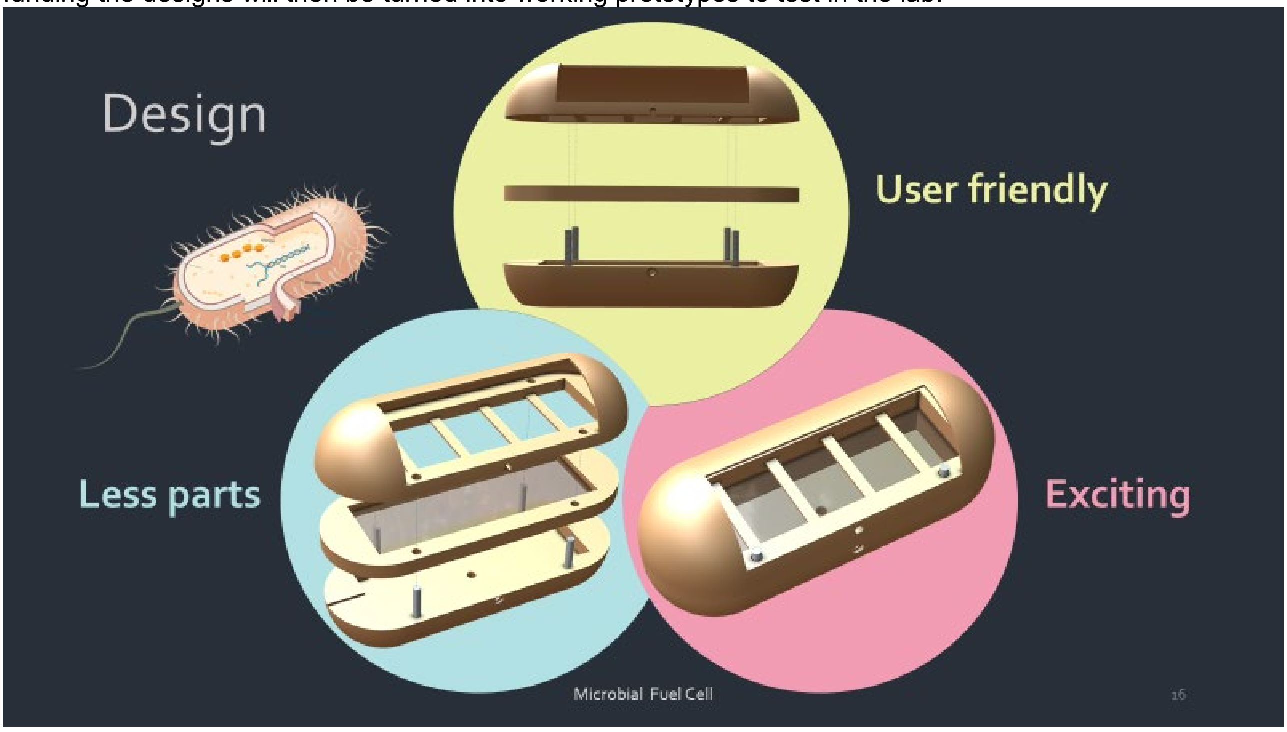


Figure 1: Bacteria-shaped MFC toy design

The main tasks of the project are as follows:

1. Incorporate multiple MFCs (approx.3) into each Bacterium-shaped module. The electrical and fluidic connections must be considered along with the feeding mechanism.
2. Develop the modules so that they can be interconnected with other units to generate higher outputs.
3. Explore the possibility of integrating the MFC toy with the EcoBot
4. Produce the following:
    a. A bill of materials for all the necessary parts of the toy
    b. A 3-D representation of the bacterium-shaped module along with incorporated MFC's
    c. Assembly drawings of the toy to be used during prototype manufacturing
    d. A brief instruction manual to go with the kit (if time permit)

Key design criteria to be considered are: Safety, aesthetic, ease of use, robustness, the wow factor! The toy needs to be safe, particularly in respect to the culturing of bacteria in a system that will be handled by children. This can also lead to unpleasant smells in the classroom especially in summer!
A human-centred design process is to be used in this project. A good understanding of the target users and their needs is thus key in this design task.

APPENDIX 9: NDA between BBiC and Renewable World

This Agreement is made on the date of the latest signature ("Effective Date")

Between:

1. **University of the West of England, Bristol** whose address is at Frenchay Campus, Coldharbour Lane, Bristol BS16 1QY ("**UWE**"); and

2. **Renewable World** whose address is Community Base, 113 Queens Road, Brighton, BN1 3XG, UK.

Collectively known as "the Parties" and individually as a "Party"

Background:

A. The Parties are discussing possible areas of collaboration in relation to the Purpose (as defined below) and, for the purposes of such discussion, the Parties have agreed to disclose to each other certain Confidential Information.

B. The Parties acknowledge that such use of Confidential Information **shall not include** commercial exploitation by either Party of the other Party's Confidential Information.

It is agreed as follows:

1. Definitions and interpretation

1. In this Agreement, unless the context otherwise requires, the following words have the following meanings:

"**this Agreement**"	this Agreement (including any schedule attached to it and any document in agreed form);
"**Confidential Information**"	any commercial or technical or scientific information including, without limitation, business, statistical, financial, marketing and personnel information, data, specifications, drawings, films, designs, samples, models, equipment, computer readable media and information of all kinds and in whatsoever form, tangible or intangible, which is disclosed to the other Party or if disclosed orally, is identified as confidential at the time of disclosure; and
"Discloser"	Means the Party disclosing Confidential Information to the other Recipient Party; and
"**the Purpose**"	The operation and maintenance of UWE's Microbial Fuel Cell Technologies.
"Permitted Recipients"	Means for UWE, Ioannis Ieropoulos and anyone working with or supervised by Ioannis Ieropoulos. For Renewable World, shall mean Jacqueline Connell and anyone working with or supervised by Jacqueline Connell; and
"Recipient"	Means the Party receiving the Discloser's Confidential Information.

2. Use and handling of the Confidential Information

In consideration of the mutual obligations entered into by the Parties to this Agreement it is agreed that:

1. Each Party shall exchange Confidential Information with the others through the Permitted Recipients only. No Recipient shall disclose any Confidential Information received from the Discloser to any third party - a Permitted Recipient may only share Confidential Information with those of the Recipient's employees or registered students who the

Permitted Recipients have authorised strictly on a need-to-know basis in order to effect the Purpose.

2. Each Recipient shall treat Confidential Information with the same degree of care and apply no lesser security measures than it affords to its own confidential information, which the Recipient warrants as providing adequate protection against unauthorised disclosure, copying or use.

3. The Recipient shall not make any use of the Confidential Information except for the Purpose and in particular (without limitation) will not use any of the Confidential Information for any commercial purposes including research sponsored by commercial entities. Any further use of the Confidential Information must be specifically authorised by the Discloser in writing.

4. Confidential Information may be disclosed if and to the extent:

   a. it is required by law or any regulatory or government authority to which the Recipient is subject wherever situated provided prior written notice of the disclosure is sent to the Discloser where reasonably practicable to do so to allow the Discloser the opportunity to obtain any appropriate protection from the relevant governmental or judicial entity;

   b. the Recipient considers it necessary to disclose the Confidential Information to its external examiners, professional advisers, auditors and bankers but only if it does so on terms protecting the Confidential Information;

   c. the Confidential Information has come into the public domain through no fault of the Recipient;

   d. the Confidential Information can be shown by satisfactory documented evidence provided to the Discloser that it was previously known to the Recipient or disclosed to them by a third party without any obligation of confidence attaching to it; or

   e. the Discloser has given its explicit consent in writing.

5. The obligations contained in this Clause 2 do not apply to any information which is developed independently of the Purpose by the Recipient.

6. The Recipient shall, at the request of the Discloser made at any time, return to the Discloser or as the Discloser may direct (or if the Discloser so agrees, destroy or completely remove) all the Confidential Information in the Recipient's possession or under its control and all documents and other material (including all electronically generated or stored data) containing or embodying the Confidential Information (or any part of it) together with all copies, analyses, memoranda or other notes made by the Recipient and which are in its possession custody or control that bear or incorporate any part of the Confidential Information.

7. If any Party elects at its sole discretion to transfer Confidential Information to the other Party electronically, the Recipient makes no warranty, nor is any to be implied that its IT systems are sufficiently secure to ensure that no unintended breach of confidence occurs in transmission, nor upon receipt, nor that its systems are free of a risk of hacking or other external interference, nor that any deletion of the Confidential Information will result in complete and immediate deletion of the same as a result of its own ‘back-up’ protocols for recovery of data. Confidential Information sent via electronic format is sent at the Discloser’s risk. Once received by the Permitted Recipient it will be maintained in accordance with the terms of this Agreement.

8. Any written materials, drawings, designs, other documentation, samples, models, data storage media, specimens, etc. which incorporate Confidential Information and with which one of the Parties has been entrusted by the other Party shall remain the property of the Discloser. All Parties, upon written request by another Party, undertake to return such materials to the other party without delay and to destroy any copies thereof except for one (1) record copy of the Confidential Information in written form which the Recipient may retain in its legal file solely for determining its obligations hereunder.

9. In the event of any representatives of the Recipient visiting any of the establishments of the Discloser or its subcontractors or meeting or discussing the Purpose with the Discloser or any agent of the Discloser, the Recipient further undertakes that any information which may come to the knowledge of the Recipient as a result of any such visit in addition to the Confidential Information shall be kept strictly confidential, and that any such information shall not be divulged to any third party and shall not be made use of in any way by the Recipient other than strictly, solely and directly as is required in relation to the Permitted Purpose.

3. Term

This Agreement relates to any disclosure of Confidential Information made during the period commencing on the Effective Date set forth in the heading of this Agreement and expiring Two Years after the Effective Date. The obligations of non-use and confidentiality on the Recipient under this Agreement will continue until a period of ten (10) years from the expiry date.

4. Notices

1. Any notice to a Party under this Agreement shall be in writing signed by or on behalf of the Party giving it and shall, unless delivered to a Party personally, be left at, or sent by prepaid first class post, prepaid recorded delivery, or facsimile followed by prepaid first class post, to the address of the Party as set out below or as otherwise notified in writing from time to time:

1. For UWE that address shall be:

Attention: Director of Commercial Services
University of the West of England, Bristol
Frenchay Campus, Coldharbour Lane, Bristol BS16 1QY
With a carbon copy to VCOExecsupport@UWE.ac.uk

Please quote reference Renewable World on all correspondence to UWE and note that email alone shall not constitute validly served legal notice.

2. For **Renewable World** that address shall be:

Attn: Programme Development and Partnerships Manager
[Renewable World,
Community Base, 113 Queens Road, Brighton, BN13XG
at the above address
With a carbon copy to jac.connell@renewable-world.org

2. Rights

1. The Recipient shall not obtain any rights to or licence of the Confidential Information of the Discloser save as expressly provided in this Agreement. Each Party retains ownership or control over its own intellectual property rights in the Confidential Information it divulges.

2. No obligations shall arise from this Agreement for the Parties to provide specific Confidential Information to each other, to use the Confidential Information so provided in a product, to warrant the accuracy, usability and/or completeness of the Confidential Information provided, and/or to grant a contracting party licences in and to intellectual property rights or copyrights beyond the right of use provided for in this Agreement.

3. Each Party retains full rights to disclose its own Confidential Information to any other third party of its choosing and no obligation of exclusivity is intended in respect of the Recipient regarding receipt of the Discloser's Confidential Information.

5. **Variation**

No purported variation of this Agreement shall be effective unless it is in writing and signed by or on behalf of each of the Parties by their authorised signatories.

6. **Waiver**

Any failure of a Party to enforce or to exercise, at any time or for any period of time, any term or any right arising pursuant to this Agreement does not constitute, and shall not be construed as, a waiver of such term or right and shall in no way affect that Party's right to enforce and exercise it.

7. Assignment

This Agreement shall be binding on and for the benefit of the successors in title of the Parties but shall not be assigned or sub-contracted by either Party without the prior written consent of the other.

8. Governing law and jurisdiction

1. This Agreement shall be governed, construed, and enforced in accordance with the laws of England and Wales, without regard to its conflict of laws rules.

2. The Parties shall submit all their disputes arising out of or in connection with this Agreement to the exclusive jurisdiction of the courts of England and Wales.

Signed by authorised signatories for the Parties:

Signed on behalf of **University of the West of England, Bristol**	Signed on behalf of **Renewable World**
Signed:	Signed:
Name:	Name: Jacqueline Connell
Position:	Position: Programme Development and Partnerships Manager
Date:	Date: 18/01/21

Page Break

Read and acknowledged by Permitted Recipients:

Party	Signature	Print Name	Date
UWE		Dr J Houlihan	
UWE		Prof I Ieropoulos	

Renewable World		[Jacqueline Connell]	18/01/21
Renewable World		[Benson Maroro]	18/01/21

APPENDIX 10: Paper submitted in peer reviewed journal "Technovation"

Framework for mapping Absorptive Capacity as enabler of effective Technology Transfer: Case study of the innovative PEEPOWER technology

Maryam Lamere, Basil Omar, Saad Mohammed, Ioannis Ieropoulos

Highlights:

- A '*techberg*' is used to comprehensively illustrate the concept of technology.
- Knowledge sharing and high Absorptive Capacity enable effective Tech Transfer.
- A timeline of evolving definitions of Absorptive Capacity from 1990 to 2017 is created.
- Good local partnerships is essential during international Tech Transfer.
- Managing expectations and protecting IP are key in the transfer of new technologies.

Abstract:

In its comprehensive sense, a technology goes beyond the hardware or system, to include associated skills and knowledge. Whilst this definition has been acknowledged across literature, there is a gap in practice reflected during Technology Transfer processes. The current paper aims to investigate measures that can be taken by Technology Providers and Recipients to effectively incorporate knowledge and skills sharing during Technology Transfer. Conceptual frameworks are developed and used to inform empirical research. The case study of the PEEPOWER technology is used to discuss the relevance of existing theoretical findings. The PEEPOWER technology is illustrated on a novel '*techberg*' principle, showing all elements of the technology beyond the hardware. An insight into the level of effectiveness of the PEEPOWER transfer to Kisoro, Nairobi and Durban is obtained through an NVivo analysis of interview responses, by looking at the extent of knowledge sharing and the Absorptive Capacity of the Technology Recipient. The main recommendations coming out of this study are to: (1) adopt a knowledge exchange approach as opposed to a unidirectional knowledge transfer from the Technology Provider to the Technology Recipient, (2) establish good relationship with local partners and develop a good understanding of the local context, (3) manage expectations about innovations and ensure IP protection during knowledge exchange.

Keywords:

International Technology Transfer, Absorptive Capacity, Knowledge Transfer, Capacity Building.

1. Introduction:

The term "technology" has been used to describe an artificially created product or process (Morris, 2014) that solves a problem. However, in a complete sense of the term, it goes beyond just the tangible hardware, to include associated skills, knowledge and expertise (Wahab et al., 2012; Bozeman, 2000; Tihanyi and Roath, 2002; Maskus, 2004; Li-Hua, 2007; Ajibo et al., 2019). Cleveland and Morris (2014) built on that holistic understanding of technology to define Tech Transfer as the movement of goods as well as knowledge, techniques and capital amongst parties.

Whilst this definition has been acknowledged across literature, there is limited discussion as to how exactly to ensure adequate knowledge and skills sharing during a Tech Transfer process. This gap in literature is also reflected in practice and in the case of international Tech Transfer, transfer agreements often put a focus on procurement or installation of a technology, with the Tech Recipient having to continuously rely on the Tech Provider for ongoing maintenance and repair (AfDB, 2012). Such challenge is amplified with the need for companies to protect their know-how and IP, and also in cases where the Technology Recipients have low Absorptive Capacity; it has also been implemented as a requirement for technology development by organisations such as the Bill & Melinda Gates Foundation, making provisions for Tech Recipient ownership when technology is at a more mature stage. The current paper is thus concerned with the question of: "What roles do Tech Transfer parties have to play to ensure adequate knowledge and skills sharing for effective technology transfer?" This will be addressed by investigating measures that can be taken by Technology Providers and recipients to effectively incorporate knowledge and skills sharing during a Technology Transfer process.

A model of technology transfer that takes full account of the comprehensive concept of a technology, as elaborated earlier, is presented in this paper. It expands on the work of Bozeman (2016) on Technology Transfer effectiveness and is complemented by a thorough review of literature on technology, Technology Transfer and Absorptive Capacity (in sections 2 and 3). From the literature review, the models mapping out Technology Transfer effectiveness against levels of Absorptive Capacity are developed. The proposed theoretical framework is then used to inform the empirical research. In order to consolidate theory with practice, a case study illustrating an application of the model, is presented in the paper as an empirical example. Findings from this case study show that high level of Absorptive Capacity from the Technology Recipient has direct impact on the effectiveness of a Technology Transfer. The approach used to collect and analysed empirical data is presented in section 4. Section 5 then presents empirical findings, comparing the transfer process of the PEEPOWER technology from the UK to Uganda, Kenya and South Africa. Recommendations are made, with potential value to institutions, companies and policy makers involved in Technology Transfer.

2. Understanding technology and Technology Transfer:

2.1 What is a technology?

Saad (2000) refers to these main elements as 'software' or know-why, 'brainware' (or know-what and know-why) and 'support net' as necessary for effective use and management of technology. Earlier definitions of technology have described it more as an information-set: "*information of both technical and commercial character*" (Li-Hua, 2009), "*a bundle of* *information, right and services*" (Contractorv and Sagafi-Nejad, 1981), "f*irm-specific information concerning (…) production processes and product design*" (Dean and LeMaster, 1995), or "*information necessary to achieve a certain production outcome*" (Maskus, 2004). Other reports have offered different perspectives on the definition of technology, e.g. that of an artificial, human-made product that uses scientific knowledge to solve a defined problem (Hawthorne, 1971, Pacey, 1983, Goulet, 1989; cited by Wahab et al., 2012). Karatsu (1990) refers to technology as "*human understanding of natural laws (…) to make things that perform certain functions*" and Miles (1995) defines it as "*a mean by which we apply our understanding of the natural word to solutions of practical problems".* A broad definition of technology is provided by Burgelman et al. (2008), as the *"theoretical and practical knowledge, skills and artefacts used to develop products and services."* It presents the concept of technology as intricately linked with knowledge; and this is supported by several literature reports (Teece, 1976, Sahal 1981, 1982, Hawkins and Gladwin, 1981, Natarajan and Tan, 1992, Levin, 1996, cited by Wahab et al., 2012; Bozeman, 2000; Tihanyi and Roath, 2002; Maskus, 2004; Ajibo et al., 2019). As summarised by Li-Hua (2007) technology is "*the product itself, and the knowledge, technique and organisation by which it is produced*". As such, a Technology Transfer process is incomplete without the transfer of knowledge and skills relating to how the technology works, how to make it and adapt it to the recipients' context, and how to organise, manage and sustain its production, distribution or sale.

Further work has gone into constructing taxonomies to help classify knowledge and skills associated with the concept of technology (Wahab et al., 2012; Mansfied, 1975; Zhoa, 1990; Bell, 1984). First, there is technical knowledge that comes in material forms, such as manuals, blueprints and books, or as embedded R&D knowledge within the product itself (Bell, 1984; Inkpen and Dinue, 1998). Then there is tacit technical knowledge that comes as embodied within skilled personnel. Madeuf (1984) and Hall and Johnson (1970) referred to this tacit knowledge as 'human embodied' or 'person embodied' technology. Non-technical knowledge and soft-skills needed for the use, production, sale of the technology have also been included within the concept of technology (Saad, 2000; Li-Hua, 2007; Wahab et al., 2012). Figure 1 illustrates the concept of technology based on this review, were the product, system or artefact only constitute the tip of the iceberg. Whilst underneath are associated knowledge and skills that form an even more important part of the technology - what can be called the *'techberg'*. The advantage of having such conceptual model is that it makes it easy to visualise why a technology is more than the physical product. As such, it can help tech providers and tech recipients to see beyond the tip of the '*techberg'* and pay close attention to other elements that form essential parts of the technology (additional knowledge and skills as elaborated in figure 1).

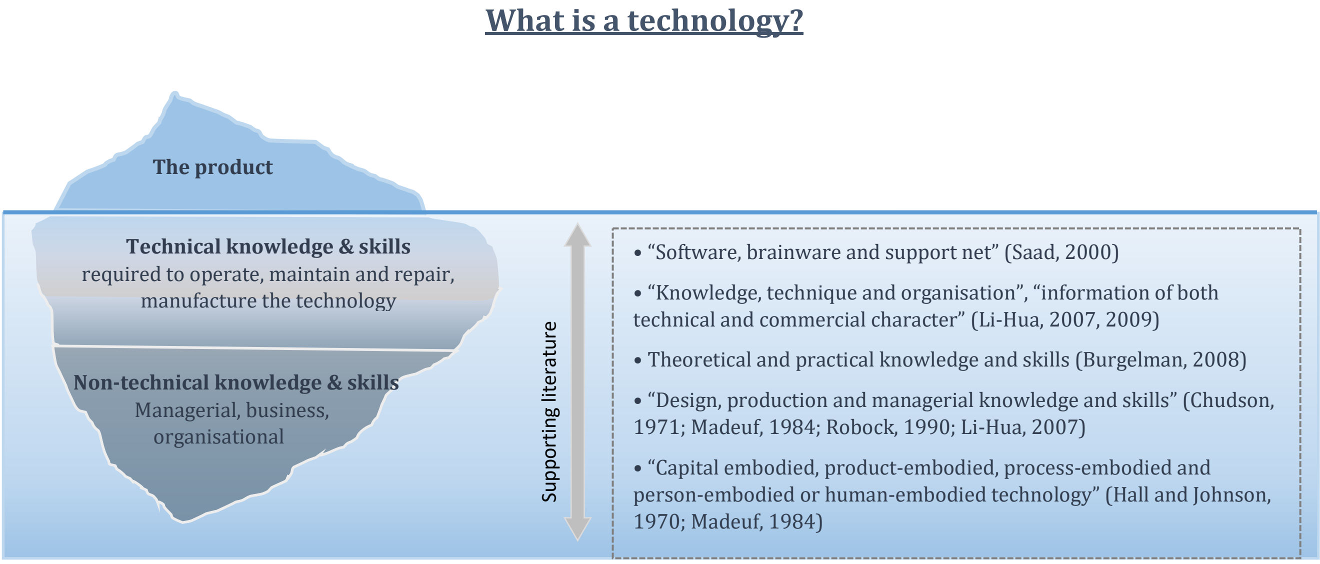


Figure 1: A '*techberg*' –Illustration of the concept of technology based on literature review
Source: Author.

2.2 What is effective Technology Transfer?

Technology transfer refers to the movement of a technology, along its lifecycle stages, or across geographical boundaries, sectors, or firms. Mansfield (1982) distinguishes the former as vertical Technology Transfer, which may go "*from basic research to applied research, then development and finally, production"*, or from market to R&D – frugal innovation (Weyrauch and Herstatt, 2017). The rest is then classified as horizontal Technology Transfer. Horizontal Tech Transfer takes place from a place, organisation or sector to another. This includes international Tech Transfer across national borders, regional Tech Transfer, inter-firm Tech Transfer, intra-firm Tech Transfer, cross-sector or cross-discipline Tech Transfer or a combination of the above (Mansfiel, 1982; Ramanathan, 2008; Ajibo et al., 2019).

Cleveland and Morris (2014) build on the holistic understanding of the concept of technology and define Technology Transfer as the movement of goods as well as knowledge, techniques and capital amongst parties. There are typically three main actors in this process: the Technology Provider, the Technology Recipient and the end users (Lopez and Maurico, 2018). Odekon (2015) also note that the process of Technology Transfer has to encompass the transfer of capacity and knowledge associated with the technological product, which goes *"beyond the mere sale or lease of goods"* (UNCTAD, 2012).

In practice, the process of Technology Transfer can be highly complex. This is because: (1) researchers, developers and users may hold different understandings of what a technology is (Wahab et al., 2012) and (2) it requires collaborations between individuals from different structural, cultural, disciplinary or organisational backgrounds (Gibson and Smilor, 1991; Sung and Gibson, 2005). Gibson and Smilor (1991) thus describe Technology Transfer as "*an interactive process, with a great deal of back-and-forth exchange among individuals over an extended period of time".* This associated level of complexity has been widely acknowledged in the literature (Zaltman et al., 1973, Kidder, 1981, Smith and Alexander, 1988, Agmon and von Glinow, 1981; cited by Wahab et al., 2012).

It then becomes challenging to agree on what constitutes an effective Technology Transfer. Is it gauged by the extent to which all elements of a technology have been transferred –i.e. the product as well as technical and non-technical knowledge and skills? Or in the case of international Technology Transfer, is it gauged by the outcome i.e., whether a technology ends up being adopted and used widely? Bozeman (2000) developed a conceptual framework for defining effective Technology Transfer, which is based on five dimensions: who is doing the transfer, how the transfer is done, what is being transferred, factors that influence the transfer and whom the technology is transferred to. The way these dimensions interact then determines the effectiveness of a Technology Transfer process, which according to Bozeman et al. (2016) is gauged by seven criteria: (1) the reception of a technology by the transferee, (2) the commercial impact of the Technology Transfer, (3) the impact on wider regional or national economy, (4) the impact on human capital, (5) resulting political benefits, (6) the effect of Technology Transfer on enhancing public values and (7) other opportunity costs resulting from the Technology Transfer activities. Bozeman's model (see figure 2) has been applied by researchers in various industries (Gunsel et al., 2019; Borge and Broring, 2017; Qiu et al., 2017, cited by Gunsel et. al; Hafeez et. al, 2020; Barros et al., 2020).

The current research builds on this comprehensive model and presents an in-depth study of the Scientific and Human Capital criterion for effective Tech Transfer. The role of Tech Transfer actors in the process and the object of transfer will be the main dimensions used to assess this effectiveness (see figure 2). Bozeman et al. (2016) point out to the lack of Tech Transfer research focusing on Scientific & Human Capital and Public Value as effectiveness factors. This research will be a complementary contribution in those areas of Bozeman's model.

The next section of the paper discusses how the recipient's ability to assimilate, transform and exploit transferred knowledge and skills, can either hinder or enable Tech Transfer. This ability is also known as Absorptive Capacity, and without a certain level of Absorptive Capacity to start with, the Tech Transfer process can only result in limited impact on scientific and technical human capital.

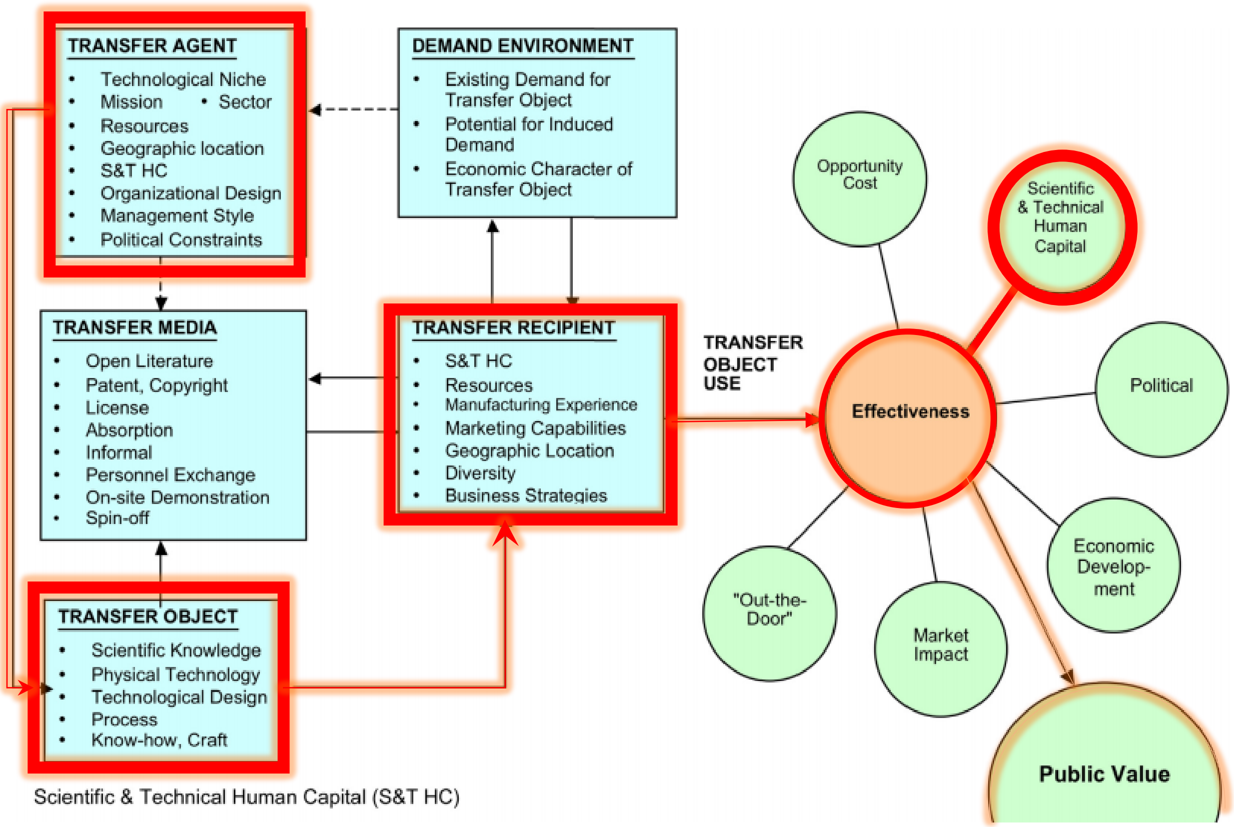


Figure 2: Bozeman's contingent effectiveness model of Tech Transfer with research focus highlighted in red (Bozeman et al., 2016)

3. Absorptive Capacity as an enabler of effective Technology Transfer:

The review of Tech Transfer literature showed that effective technology transfer goes beyond the transfer of tangible hardware or product. It should also integrate the transfer of knowledge and skills relating to how the technology works, how to make it, and how to organise and manage its production, distribution or sale. However, for a Technology Recipient to be able to absorb such inflow of knowledge, a prior level of knowledge base is required (OECD, 2012) as well as skilled personnel and adequate infrastructures. This requires consistent financial investment and appropriate organisational arrangements, which can be a challenge (African Development Bank, 2014).

This section thus seeks to explore measures that can be used to increase a Tech Recipients' Absorptive Capacity. Before that, a clear understanding of the concept of Absorptive Capacity is required.

3.1 Evolution of the concept of Absorptive Capacity:

The concept was originally developed in the early 1990's to provide a perspective on the acquisition of knowledge from external sources, learning and innovation within firms. Cohen and Levinthal (1990) showed that a firm's ability to value, assimilate and exploit external knowledge is fundamental to its innovative capacities; this ability strongly depends on the level of related prior knowledge within the firm; and is defined as its Absorptive Capacity. Several researchers build on that definition, extending it to other areas of organisational learning, notably for understanding of managerial IT use (Boynton et al., 1994), Technology Transfer (Mowery & Oxley, 1995; Keller, 1996) and transfer of best practices (Szulanski, 1996), research productivity within a firm (Cockburn & Henderson, 1998, cited by Zahra & George, 2002), open innovation (Zobel, 2017). Cohen & Levinthal (1990) also note the effect of increased Absorptive Capacity on the diffusion of innovation process[10].

The evolution of the construct of Absorptive Capacity then expanded over the years with numerous propositions for reconceptualisation. Building on Cohen and Levinthal's definition, Van den Bosch et al. (1999) adds that a firm's Absorptive Capacity should not only be gauged by its level of prior related knowledge. Rather, its organisation form (i.e. hierarchical structure) and combinative capabilities (i.e. ability to systematise, socialise and coordinate knowledge) should also be taken into account. An extensive review of literature around Absorptive Capacity carried by Zahra & George (2002) led to another reconceptualisation. The conceptual model proposed accentuated on the ability to acquire (which goes beyond valuing), to assimilate, transform and then apply or exploit new knowledge. They also made the distinction between realised Absorptive Capacity of a firm and potential absorptive capacity. Combining this new conceptual model with the original construct, Tsai et al. (2012) came to propose what was called the 3R's model which distinguished the Responsive absorptive capacity (sensing and acquisition), Reconfigured Absorptive Capacity (socialisation and transformation) and Realised Absorptive Capacity (assimilation and combination). Nonetheless Cohen and Levinthal's definition has remained the main paradigm. Figure 3 shows a timeline of the evolution of the construct since Cohen and Levinthal's original definition. Efforts have now shifted towards measuring or expanding on the different dimensions of absorptive capacities and linking it to other constructs (Zobel, 2017; Aghion & Jaravel, 2015; Chinho et al., 2002). Saad et al. (2017) further expands on the importance of awareness as an antecedent dimension of Absorptive Capacity. The authors show in an empirical study of 43 manufacturing SME's how awareness based on taking the first step to generate interest and motivation to value external knowledge significantly impacts its acquisition, assimilation, transformation and exploitation.

The work of Mowery and Oxley (1995) was amongst the earliest examples to apply the notion of Absorptive Capacity at a national level; with the aim to examine the role of national innovation systems on inward Technology Transfer. They defined a country's Absorptive Capacity as relating to the broad range of skills required to exploit the implicit components of a transferred technology, as well as the ability to modify imported technologies to fit the domestic context. This definition was further reinforced in various other reports, elaborating on the importance of developing skilled human capital and investing in R&D at national level (Kim & Dahlman, 1992; Keller, 1996; Liu & White, 1997; Luo, 1997; Veuglers, 1997; Glass & Saggi, 1998; cited by Zahra & George, 2002; Kim, 1998). It thus helps to understand how that

[10] There are five decision stages in the process of innovation diffusion: knowledge, persuasion, decision, implementation, confirmation. Increasing Absorptive Capacity (and thus knowledge) help with the diffusion of innovation (Cohen & Levinthal, 1990).

acquisition and assimilation of knowledge are key conditions for a successful Technology Transfer. Keller (1996) argued that while Tech Transfer mechanisms such as trade liberalisation were beneficial for the domestic economy, sustained growth in the long run required rapid upskilling of the labour force. Liu & White (1997) demonstrated through a five-year study of 145 Chinese firms from 29 manufacturing industries, that national innovation level is driven by a synergy between investment in foreign Tech Transfer and investment in developing skilled R&D personnel. Kim (1998) also pointed the necessity for firms in Newly Industrialising Countries, to go beyond assimilation of external knowledge for imitation to developing problem-solving skills that lead to innovation. This shows that good assimilation and adaptation of external knowledge should enable organisations and nations to re-innovate (Rothwell, 1992) or adapt that knowledge to the needs of a dynamic environment.

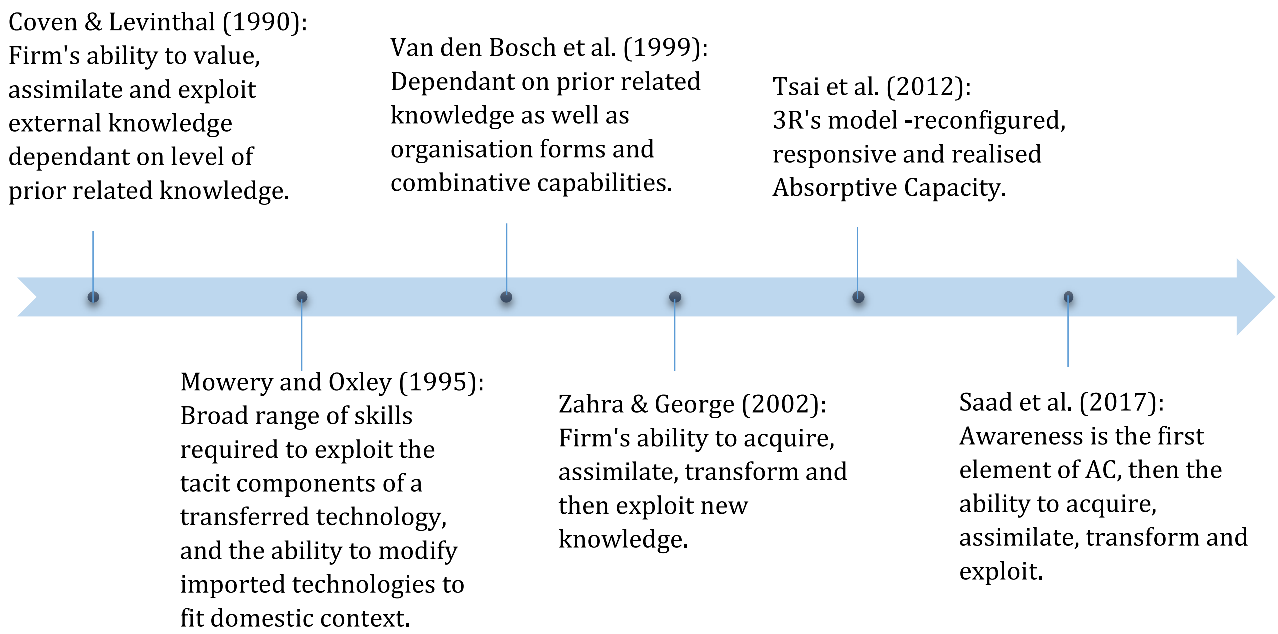


Figure 3: Timeline showing evolution of the concept of Absorptive Capacity.

3.2 Conceptual Framework for mapping Absorptive Capacity and Technology Transfer:

The following conceptual framework summarises the major points of learning from the current literature review. Firstly, the concept of technology, as illustrated in figure 1, has been described in its most comprehensive sense as going beyond the technological product (or the hardware) to include: the necessary knowledge and skills required to operate, maintain, repair or manufacture the technology, as well as managerial and business knowledge and skills required to sell, distribute or produce the technology. It then followed that Tech Transfer mechanisms that do not incorporate transfer of knowledge and skills raise issues such as lack of ability to maintain the technology and overreliance on the Technology Provider. It was also found that Technology Recipients do have a part to play in preparing an enabling environment for effective Tech Transfer. This would involve investing in initiatives that increase their

Absorptive Capacity at both firm level and national level. Table 1 shows that Tech Transfer is more effective when the transfer of the product or system is coupled with transfer of knowledge and skills, and when Technology Recipients have high levels of Absorptive Capacity. It is worth reiterating that the notion of effective Tech Transfer can in fact be quite broad, with several defining criteria (see figure 2). Nonetheless, as highlighted by Bozeman et al. (2016), there is a need for more focussed research that explores Tech Trnasfer effectiveness exclusively from the angle of Scientific and Human Capital (i.e. knowledge and skill levels).

Table 1: Mapping effective Technology Transfer (TT) and Absorptive Capacity (AC) – conceptual framework. *Source: Author*

<table>
<tr><td rowspan="5">Ineffective TT</td><td colspan="7">Object of transfer from Technology Provider</td><td rowspan="5">Effective TT</td></tr>
<tr><td colspan="2">The Product</td><td colspan="3">with technical knowledge & skills required to operate, maintain, repair and manufacture the technology</td><td colspan="2">and non-technical knowledge & skills (Managerial, business, organisational)</td></tr>
<tr><td colspan="7">Absorptive Capacity of Technology Recipient</td></tr>
<tr><td>AC</td><td colspan="2">Level 1
Awareness and value of external knowledge</td><td>Level 2
Assimilation of external knowledge</td><td colspan="2">Level 3
Transformation of external knowledge</td><td>Level 4
Exploitation of external knowledge</td></tr>
<tr><td>Effect on TT</td><td colspan="2">Creates need to acquire external knowledge</td><td>Facilitates ability to maintain and repair transferred technology</td><td colspan="2">Facilitates ability to modify and adapt technology</td><td>Creates ability to develop innovative technologies</td></tr>
</table>

4. Research approach:

A qualitative approach in the research to explore what is needed for an effective transfer of technology and knowledge in the PEEPOWER case study. By taking a qualitative approach, where small data samples were explored in depth and in detail, it allowed: (1) greater focus on meanings from participants answers and observations noted, (2) better understanding of challenges faced and recommendations made (as opposed to stressing on causality and fundamental laws), as pointed by O'Gorman and MacIntosh (2015). Data collection involved semi-structured interviews of staff members who took part in the PEEPOWER field trials in Kisoro, Nairobi and Durban; access to technical reports, minutes and presentations; field visits to the installation site in Durban; and participant observations as a working team member of the Bristol Bioenergy Centre for over 18 months. A total of 17 people were interviewed, which constituted the majority of all team members involved in the PEEPOWER Tech Transfer (80% of all employees). It included Project Managers, Researchers, Community Liaison Officers, Technicians and Engineers from the Bristol Bioenergy Centre in the UK and the WASH R&D

Centre at UKZN (South Africa). Ethical considerations were duly taken to get informed consent from participants, whilst ensuring anonymity. A summary of data sources used and their purpose is presented in table 2. The interview guide used during the semi-structured interviews is shown in table 3. The first part of the interview includes more open-ended questions with the aim of uncovering key challenges faced and key success factors for effective Tech Transfer. The second part of the interview was informed by the literature on technology and Absorptive Capacity.

The interview transcripts were analysed first using a deductive thematic approach, which is a top-down approach where a predetermined set of codes is used, then excerpts found from the analysed text to fit those codes. Interviewees' answers were thus grouped into identified patterns or main themes predefined from the interview questions, such as 'what went well during the trials?', 'what could have been done differently?' and 'what are the key recommendations for best practices in future field trials?' However, as other unexpected themes were seen to emerge from participants' answers, an induction coding approach was then used to complement the analysis. This was a bottom-up approach which consisted of exploring the interview transcripts and making note of important themes that were brought up by the participants yet not directly related to the interview questions. About one third of transcripts was initial coded manually (data from the Nairobi field trial). Although time consuming, it allowed the researcher to proofread, get familiar with the text, and then analyse it with rigour and reflection. The transcripts were then re-analysed with the data computer-assisted qualitative data analysis software NVivo, along with the remaining data from the Kisoro and Durban field trials.

Other primary data from participant observation during team meetings and field visits were recorded in the form of research diary and meeting minutes. These data gave the researcher a good understanding of the technology itself and how it works, it also gave an insight into the challenges faced and key success factors in some of the projects. As such, the main themes obtained from the interview analysis were then further complemented and validated during the 18-month participant observation period. These themes were then mapped out with the theoretical framework developed in the literature review.

A deductive thematic approach was carried out first, grouping interviewees' answers into main themes; then complemented by an inductive analysis which revealed other important themes that were not directly related to the interview questions. An overview of the data analysis process is given in the sub-sections below.

As purely a qualitative research using case study approach, it was important to ensure validity and robustness of data and findings. This was done through the adoption of triangulation throughout the research: (1) the critical review of different key concepts in the literature review used for development of the theoretical framework, (2) the use of different qualitative methods (collection of secondary and primary data) such as interview and participant observation, and (3) the adoption of deductive and inductive approaches in the analysis of interview data (see table 4).

Table 2: Summary of data sources.

Data sources	Amount	Purpose
Interviews	17 (total: 450min)	Understand challenges faced, success factors for effective Tech Transfer and level of Absorptive Capacity
Team meetings with technology developer (BBiC)	32 (total: 1920min)	Validate responses collected during interviews and acquire further understanding of the technology and extent of knowledge transfer
Meetings with BBiC's external partners	15 (total: 800min)	Implement/test recommendations drawn from findings
Emails	Over 200	Validate responses collected during interviews and acquire further understanding of the technology
Presentations, reports and posters	10	Validate responses collected during interviews and acquire further understanding of the technology
Press releases	Managing BBiC Twitter account in 2020/21	Acquire further understanding of the technology, challenges and opportunities

Table 3: Guide used for the semi-structured interviews.

Part 1: Self-evaluation and reflection	Objective
What went well in the project? What could have been done differently by your team? What external obstacles did your team face? E.g. social, cultural, political, economic. What recommendations would you give to someone willing to run a similar project in those regions?	Open-ended questions with the aim of uncovering key challenges faced and key success factors for effective Tech Transfer.
Part 2: Absorptive capacity	**Objective**
Did the project help local labour to understand how MFC technology works? Explain. Did the project help local labour learn how to maintain and repair the MFC system? Explain. Do you think some of the local labour now have the technical skills to modify, adapt or invent new ideas that can improve the MFC system?	Understand level of Absorptive Capacity as defined in the literature review and gauge extent of knowledge transfer.

Table 4: Triangulation of data and methods for research validity and robustness.
Literature review

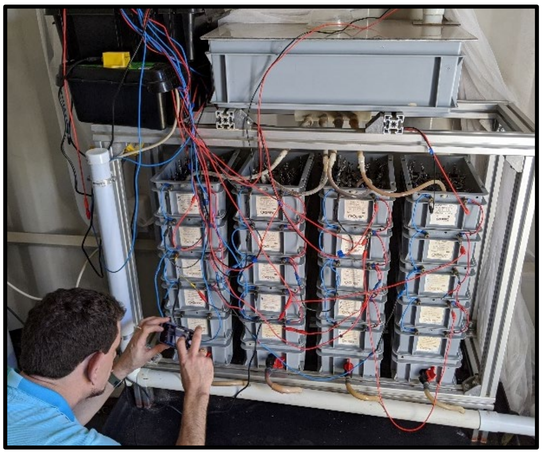
Theoretical framework based critical review of key concepts	Use of different qualitative methods	Use of different approaches in the analysis of interview data
• Definition of the concept of technology • Bozeman's model for effective Tech Transfer • Understanding Absorptive Capacity	• Primary data: transcripts of semi-structured interviews, minutes from participants observation used to validates interview data • Secondary data: Meeting minutes, emails, presentation, reports and posters, press release	• Deductive analysis • Inductive analysis • Manual coding • Computer aided coding using and data visualisation using NVivo

5. Case study findings: transfer of the PEEPOWER technology from the UK to Uganda, Kenya and South Africa:

5.1 Case study description:
The PEEPOWER is an innovative Microbial Fuel Cell technology (MFC) that uses wastewater, including urine to generate electricity, whilst also producing fertilisers and disinfectants (Ieropoulos et al., 2016. The technology was developed at the Bristol Bioenergy Centre and is now bridging the gap from R&D to commercialisation phase (University of the West of England, 2016). It has been trialled in various real-life settings and was installed at a girls School in Kisoro (Uganda) in 2017, in a secondary school in Nairobi (Kenya) in 2018, then in an urban community settlement in Durban (South Africa) in 2019 (You, 2020; University of the West of England, 2018; University of Kwazulu-Natal, 2020), see figure 4.

a. PEEPOWER lighting a boarding school toilet at night in Kisoro.

b. PEEPOWER maintenance at the Mathare school in Nairobi.



c. PEEPOWER connected to a community ablution block in Durban.

Figure 4: PEEPOWER installation and maintenance in Nairobi and Durban.

5.2 Empirical findings discussion and link to theoretical frameworks:

The main findings from the three field trials (Kisoro, Nairobi and Durban) are based on transcript analysis of interviews carried out with 80% of employees both from the Tech Provider and Tech Recipient teams. These findings were then triangulated and supplemented with technical reports, posters and presentations provided by BBiC and UKZN, as well as notes taken during regular team's meetings. The thematic analysis carried out using Nvivo generated 125 nodes, grouped into 23 themes; nine of those themes were most relevant to the subject of the current paper –effectiveness of the transfer and Absorptive Capacity. A summary of those nine themes is presented in Figure 5 and further elaborated below. The theoretical framework developed from the literature review are mapped against empirical findings from the case study in Figures 6 and 7.

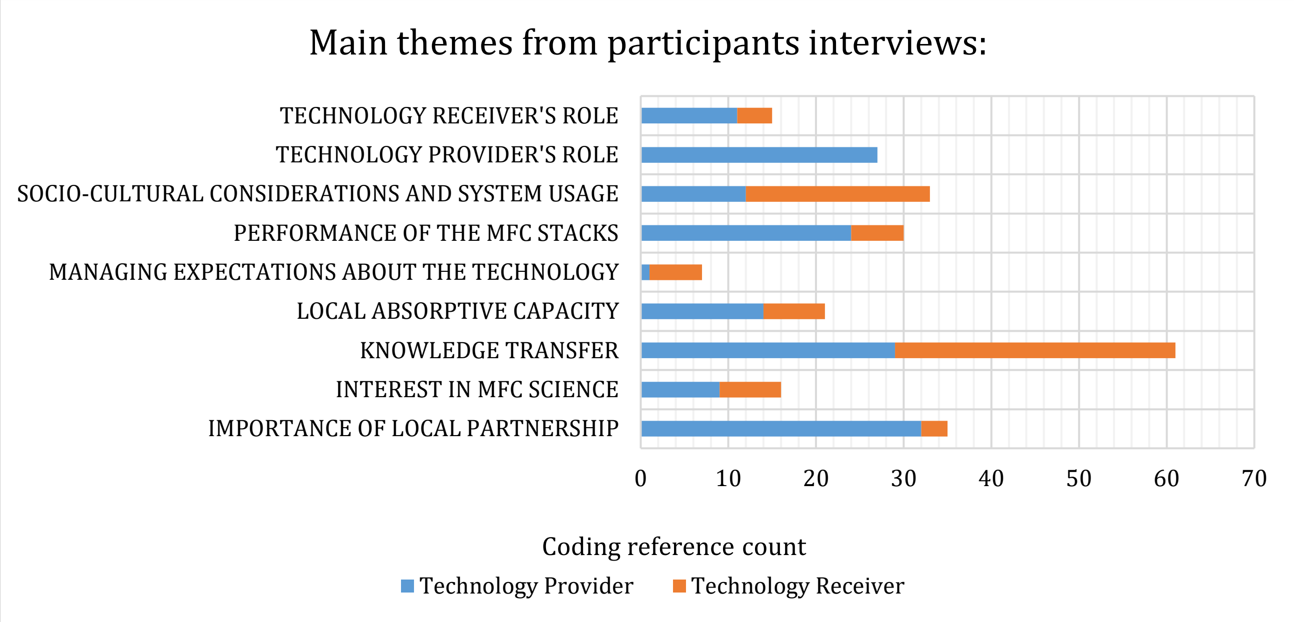


Figure 5: Thematic analysis of interview transcripts – presentation of main themes against coding reference count.

- **Roles of Tech Transfer parties:**

In all three locations, the purpose of the transfer was for a fixed term scientific trial, in a real-world setting. The Tech Provider was responsible for installing the system, carrying out need-driven maintenance visits and then decommissioning the system at the end of the trial. Maintenance tasks were carried out in a timely manner with the help of local technicians or unskilled local personnel provided by the technology recipient. Those maintenance visits were said to be valuable learning experiences for the Tech Provider who was able to make continuous improvement on the system from lessons learnt during each field trial. In Kisoro and Nairobi, the PEEPOWER team did not have the opportunity to liaise with local technicians to carry out continuous maintenance tasks on the system, which was a real obstacle in the effective transfer of the technology. Durban was the exception, where a skilled maintenance engineer was provided by the Tech Recipient. The engineer was able to effectively monitor and maintain the system during the whole of the trial. Partnership was established in Durban with the WASH R&D Centre (formerly known as Pollution Research Group – PRG) at the University of KwaZulu Natal and Khanyisa Projects, who carried out further experimental work in their laboratory facilities, provided the maintenance engineer and managed the relationship with the local community.

- **Importance of local partnership during international Tech Transfer:**

This was a key factor for the successful implementation of the PEEPOWER project in all three locations. Local partners in Durban facilitated access to the community and coordinated the entire project implementation; a good relationship was established with the Tech Provider who was "*impressed with the quality of support*" received. Access to communities in Nairobi and Kisoro and logistics were also facilitated by collaborating with partners already working in the locality. However, the major obstacle with these two cases was the lack of available local technicians to maintain the system. The technology provider relied on schoolteachers on site to occasionally check the system and give updates. All the interviewees who worked on the

Nairobi project commented on the difficulty faced from not having a local technician to maintain the system in their absence.

- **Socio-cultural considerations during the PEEPOWER transfer:**

With regards to Tech Recipient and Tech Provider collaboration, there are local socio-political hierarchies to be made aware of when establishing local partnerships, so this needs to be done by approaching the right people. It is also good to be aware of potential language (geographical and technical) barriers that may exist. Personnel from the Tech Provider team commented on the culture they experienced when visiting a slum environment for the first time. They also commented on how they had to be mindful of local social customs and etiquettes especially when interacting with people. A member of staff from the Tech Recipient team recommended having a diverse team, which may facilitate communication and interactions between personnel. These are considered non-technical knowledge and soft-skills that are nonetheless needed (Saad, 2000; Li-Hua, 2007; Wahab et al., 2012).

With technology users, there were reported difficulties with using urine diversion plates that were added to the toilets when the PEEPOWER system was installed. Furthermore, waste other than urine and in some cases solid material, was poured/thrown down the urinals, causing blockages in the system. There were also unexplained reasons for improper toilet usage. Posters and workshops had to be used to elaborate on correct toilet practice needed for the system to operate. In doing so, it is essential to acknowledge local community practices and sensitivity around sanitation discussions. One also needs to understand the level of changes or disruption in users' habits that the new technology may bring. With the PEEPOWER system, this is particularly important, as the system relies on correct use of the toilet in order to continuously generate electricity. Following the workshops with the local community, it was said that the PEEPOWER may have been an incentive for men to start using public toilets. Another point highlighted by the interviewees was the ethical considerations that come with measuring urine flow rates in schools toilets. Though these data were needed for monitoring the system and adjusting settings, an alternative measurement (power output) had to be taken instead, which was then converted to meaningful data.

- **Managing expectations:**

There was high expectation of the system from the local community. A lack of explanation of the system's capacity and limitations at the onset of installation caused unrealistic expectations of what the system could achieve. It is therefore important to be clear about what the system can or cannot do. The Microbial Fuel Cell system was highly robust and could operate in extreme conditions, however struvite build-up often occurred after periods of non-use, which implies no-draining either, causing blockages which affected its performance. The system also relied on frequent usage of toilets in order to produce enough electricity. The wiring electronic system was said to be very complex and was affected by corrosion due to the high humidity level in its working environment. With these technical challenges, the lights could not switch on at times, thus affecting user perceptions and trust in the technology.

- **Interest in MFC science:**

Staff, visitors, users, students were all fascinated by the idea of producing electricity from urine. There was much interest in the science of Microbial Fuel Cells as shown in the following quotes from participants: *"the fact that you can get that (electricity) from urine, to me despite being an engineer, it still kind of shocks me"* (Tech Recipient); *"as a technologist, I am fascinated by it"* (Tech Recipient)*; "something I never thought would ever happen in my lifetime"* (Tech Recipient); *"the teachers were actually interested and were asking us lots of questions"* (Tech Provider)*; "getting lots of interest from the girls from more of an academic point of view (…) they're really interested in the science"* (Tech Provider). The Tech Recipient and Tech Provider took this opportunity to organise educational workshops at the schools. They recommended running public engagement workshops at the beginning of the project (pre-installation of the system) and even developing educational kits and textbooks for schools on the science of Microbial Fuel Cells. This is in fact not only increased the level of Absorptive Capacity of the population in the field of MFC but also constituted a key factor in facilitating the diffusion of innovation.

- **PEEPOWER representation on a '*techberg':***

Having acquired a good understanding of the PEEPOWER, it was clear that effectively transferring this technology will have to go beyond the simple transfer and installation of the system as emphasised in the literature (Wahab et al., 2012; Bozeman, 2000; Tihanyi and Roath, 2002; Maskus, 2004; Li-Hua, 2007; Ajibo et al., 2019). The main elements of the PEEPOWER technology based on the earlier comprehensive definition were presented on the '*techberg'* (see figure 6) comprising at its summit, the product, the tangible PEEPOWER hardware. Then, additional components that ought to be transferred along with the system have been considered: a list of technical knowledge and skills required to operate, maintain, and manufacture the PEEPOWER and a list of non-technical knowledge skills to be considered for a successful transfer (e.g. effective communication with multidisciplinary stakeholders, socio-cultural consideration of users' practices). Another observation that came out of this mapping was that knowledge and skill transfer does not only take place from the Technology Provider to the Technology Recipient. The idea of knowledge exchange between partners may seem more beneficial. For instance, in the case of the PEEPOWER knowledge of local materials and spare parts, local manufacturing methods, users needs and local market were all transferred from the local Technology Recipient to the Technology Provider.

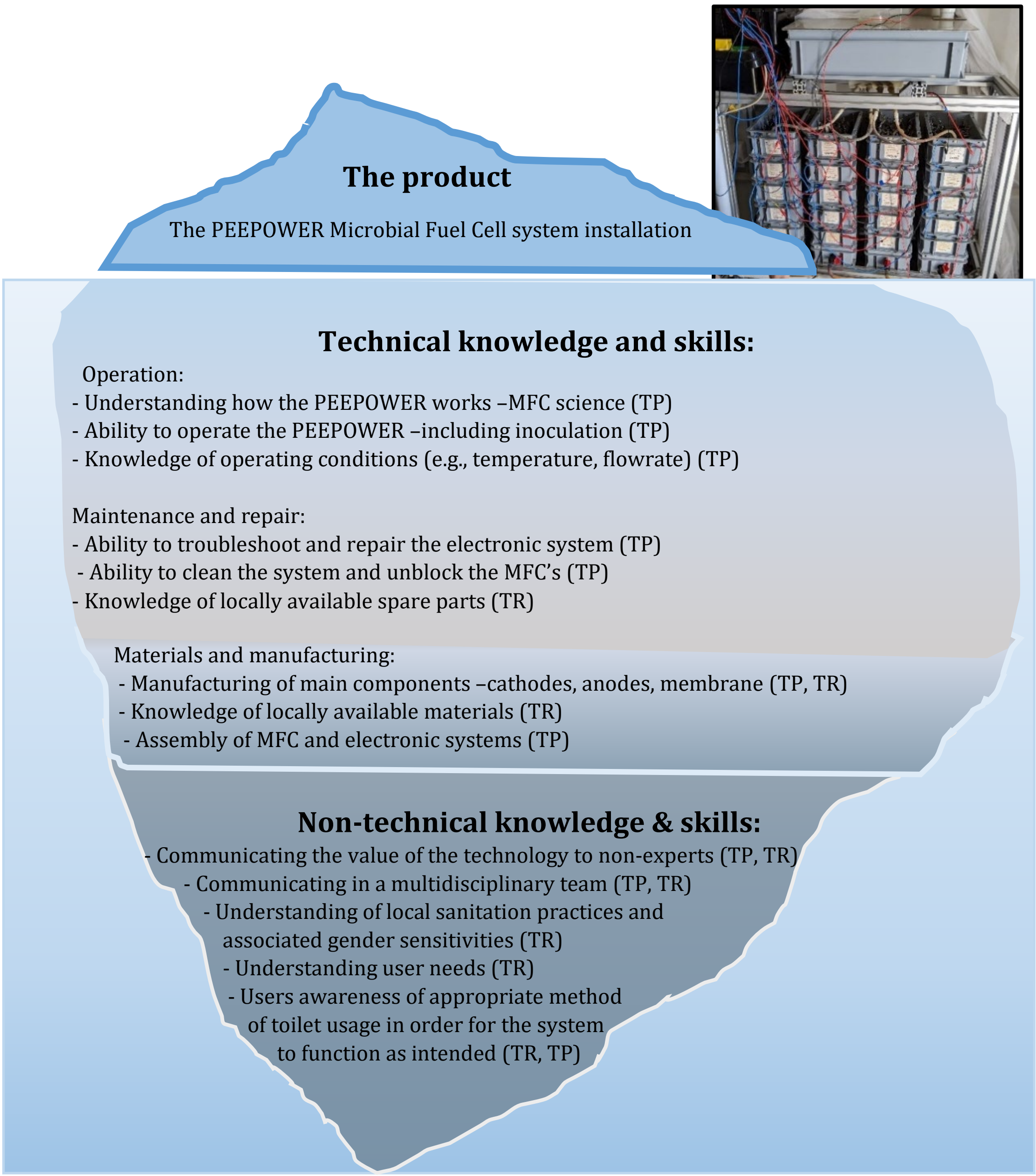


Figure 6: PEEPOWER technology represented on a '*techberg*' –TP and TR denote transfer from the Tech Provider and the Tech Recipient respectively.

- **Local Absorptive Capacity:**

Interest in the PEEPOWER technology grew as users, the general public and staff members were fascinated by the idea of producing electricity from urine. In Kisoro, the local labour involved in the installation acquired a basic understanding of how the system works. In Nairobi, there was no local labour or technician involved, it was therefore difficult to comment on the level of Absorptive Capacity in this case. The highest level of Absorptive Capacity of all the three locations was found in the partnership established in Durban, which was by far the better organised one, with very good understanding of how the system works, access to the necessary facilities to independently carry out most maintenance and repair work and even adapt the system to the local environment. This made exchanges with the technology provider a lot easier. What is important to note here is that this assessment of local Absorptive Capacity within the context of the PEEPOWER field trials, to a certain extent, focusses mainly on the skills, understanding and capabilities of individuals working with the technology and the availability of adequate facilities within partner organisations. As such, it cannot be generalised to represent absorptive capacities at national level or even regional level (in Durban, Nairobi and Kisoro).

- **Knowledge transfer, knowledge exchange and the need for IP protection**:

This was the most discussed theme, given that the interview questions were set to capture the extent of knowledge transfer between the Technology Provider and the Technology Recipient. In Durban, extensive support was provided to the local maintenance engineer responsible for the PEEPOWER system. Knowledge transfer took place in the form of meetings, presentations and one-to-one discussions before system installation, during the project and post-decommissioning. One of the recommendations made, was to use the 'little but often' approach when it comes to knowledge transfer and training as opposed to only relying on intensive days of workshops and presentations. Communication between Tech Provider and Tech Recipient was said to be timely and effective throughout the project duration. Senior management personnel from the Tech Recipient team expressed the need to understand the long-term vision of the innovative PEEPOWER technology and for clearer communication about the power capacity of the system and its technology readiness level. Durban had a transdisciplinary platform in place which facilitated collaboration between the Tech Provider, the Tech Recipient and the municipality.

In Nairobi and Kisoro, knowledge transfer was very limited due to lack of availability of local technicians. The Tech Provider however recognised the potential for local manufacturing of key ceramic component of the systems, as ceramic materials were locally available at lower cost. There was also a recognition of the value of community knowledge, especially in helping the Tech Provider understand the local context and identify user needs. It became apparent that when it comes to knowledge sharing during international Tech Transfer, there may need to be a shift from unidirectional knowledge transfer where knowledge is only expected to be transferred from the Tech Provider to the Tech Recipient. There is instead a need to emphasise more on the importance of knowledge exchange between Tech Provider and Tech Recipient, which can also give an empowering sense of ownership of the technology to the Tech Recipient. Further recommendations were made by interviewees regarding the need for (1) IP protection of the technology before knowledge transfer/exchange, (2) more involvement of maintenance technicians during installation, (3) creation of a user manual or maintenance guide for local technicians and (4) exchange visits between universities. These suggestions were in line with recommendations in the literature for the transfer of technical knowledge (Bell, 1984; Inkpen and Dinue, 1998) and tacit technical knowledge (Madeuf, 1984; Hall and Johnson, 1970).

- **Mapping out Technology Transfer effectiveness**

Based on the conceptual framework, mapping out Absorptive Capacity and Technology Transfer (See table 1), a funnel diagram depicting levels of effectiveness of transfer was drawn as shown in Figure 7. This diagram allows a simple visualisation of the Tech Transfer effectiveness model with a focus on levels of skills and knowledge transferred. Another important element is added to the model: the role of Tech Transfer Offices in facilitating effective technology transfer. Indeed, the Tech Provider and Tech Recipient could be both willing to engage in exchange of knowledge and skills. However the case of the PEEPOWER technology has shown that achieving successful transfer, would be very difficult without adequate and timely support from Tech Transfer Offices (for example, in completing legal agreements, ensuring IP protection or just providing legal advice). A more elaborated list of what is considered non-technical knowledge and skills to be transferred is shown. These skills include social and cultural knowledge relating to the context –as was seen in the case of the PEEPOWER. Indeed, with the PEEPOWER, knowledge of local sanitation practices was a major factor to be taken into consideration by the Tech Provider, in order to be able to develop an appropriate technology that meets its users' needs.

There is scope for further development of the framework. For instance, the partitioning of the diagram in sections and the position of markers is not a proportional measure of level effectiveness, but it should be seen as a simplified, visual representation of the framework. The markers (K), (N) and (D) on the diagram are thus simple indications of the extent of Tech Transfer and knowledge sharing in Kisoro, Durban and Nairobi and the levels of Absorptive Capacity of the technology recipient with respect to the PEEPOWER –as per Coven & Levinthal's (1990) definition. As pointed previously, Tech Providers also have a lot to learn from Tech Recipients, such as socio-cultural challenges and the understanding of the local market and local materials. However, the model presented, mainly focusses on the elements transferred by the Tech Provider. Nevertheless, the point remains that Tech Providers and Tech Recipients should consider effective Tech Transfer as a process involving knowledge exchange with mutual learning from partners, as opposed to a one-way knowledge transfer process.

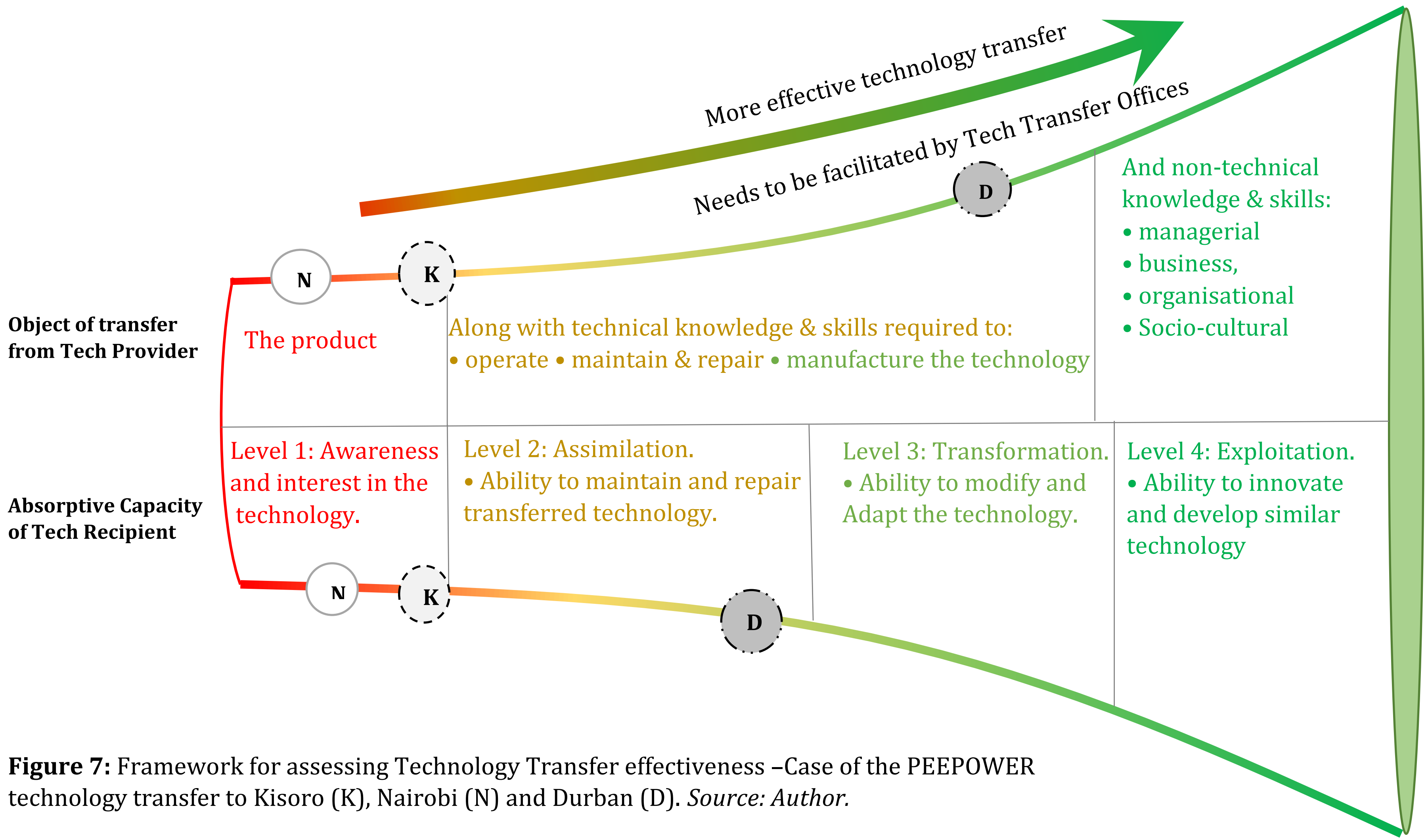


Figure 7: Framework for assessing Technology Transfer effectiveness –Case of the PEEPOWER technology transfer to Kisoro (K), Nairobi (N) and Durban (D). *Source: Author.*

6. Concluding remarks:

In order to enable effective Technology Transfer, both the Technology Provider and the Technology Recipient have roles to play in ensuring adequate knowledge exchange throughout the process. This begins with both parties understanding the concept of technology in its comprehensive sense and the term '*techberg*' was used to represent the fact that the physical product or artefact is only an element of what the technology is; beyond that, there are additional knowledge and skill sets required to maintain, operate and manufacture the technology. This knowledge and skill set can be technical or non-technical (e.g. managerial skills, socio-cultural knowledge needed to be able to adapt the technology to the context).

For the Technology Provider, acquiring a good understanding of the local socio-cultural context, being aware of locally available materials and spare parts, of the local environmental conditions that could affect operation and maintenance, are all key factors to be considered; which is facilitated by working closely with local partners. In the case of PEEPOWER, some effective methods of knowledge and skills transfer recommended for the Technology Provider were: the use of the 'little but often' approach during trainings and seminars so as not to overwhelm the recipient with new information, involving local technicians during installation and maintenance tasks, having exchange visits between the parties for a more experiential learning, having post-installation recap meetings and engaging in public awareness activities all whilst managing expectations about what the transferred technology can and cannot achieve. The Technology Recipient has a key role to play in preparing an enabling environment to acquire the transferred technology, the higher their Absorptive Capacity, the easier the transfer of knowledge and skills. Ensuring adequate IP protection is also key during the knowledge exchange process; which is why timely adequate support from Technology Transfer Offices is needed.

Areas of contribution and implication of findings:

The main areas of contribution of this paper have been the conceptual framework developed; notably the '*techberg*', the timeline of the evolution of the concept of Absorptive Capacity, the proposed framework for assessing Technology Transfer effectiveness and the lessons learnt from the PEEPOWER case study.

Recommendation for further research:

It is to be noted whilst the model presented does not serve the purpose of measuring Tech Transfer effectiveness, it can certainly help gauge and visualise how well knowledge transfer is being incorporated and received. One main limitation of the model is the fact that it does not account for knowledge exchange between parties, but only focusses on knowledge transfer from the Technology Provider to the Technology Recipient. Furthermore, whilst the models developed were tested with the innovative PEEPOWER during an international Tech Transfer, implementation with different technologies and different types of Tech Transfer would determine how practical the tools are and whether it needs to be refined and adapted to each case. This would be an area of further research.