Fuel Cell Technology to extend Remote Pilot Aerial Systems (RPAS) in the City of Cape Town

Thematic Area: Infrastructure, New Technologies and Sustainability

---

Prepared by:
Tabassum Zalgaonkir, Matthew Kapp, Adrian Parsons

Department of Chemistry – South African Institute for Advanced Materials Chemistry (SAIAMC)
Faculty of Natural Sciences
University of the Western Cape
Robert Sobukwe Road, Bellville
Ext 9315

Prepared for:
City of Cape Town

June 2017

Key words: Unmanned Aerial Vehicles, Remotely Piloted Aircraft, fuel cells, City of Cape Town

ABSTRACT

The technology of Unmanned Aerial Vehicles (UAVs) or Remotely Piloted Aerial Systems (RPAS), originally deployed in military and defence, is now emerging in the commercial space. Apart from military applications, civilian applications such as surveillance, weather monitoring, aerial mapping, infrastructure management farming, agriculture, horticulture, utility services, forestry, wildlife monitoring, aerial survey and others uses are being adopted.

Propulsion systems for these aircraft currently include electric propulsion, batteries, solar as well as internal combustion engines. Battery powered electrical propulsion systems are common for smaller UAVs but lack the range of larger UAVs that are typically powered by internal combustion engines. Due to high electrical energy requirements for longer flight times of smaller UAVs, fuel cells as an alternative propulsion systems are currently being introduced offering longer endurance, improved efficiency, zero carbon emissions as well as low noise and thermal signatures. The aim of this research is to determine whether the City of Cape Town can benefit from the combination of RPAS and fuel cell technology in these smaller UAVs, typically weighing less than 20kg with payloads less than 5kg. This is done by researching different types of small UAVs available and how fuel cell technology extends the capabilities of the different aircraft configurations. Together with an overview of applications as identified by the City of Cape Town and the relevant key performance requirements, potential cost savings can be identified.

This report shows that fleet operating costs and capital expenditure on the fleet could potentially be reduced by way of two example studies representing typical applications in the CCT future UAV fleet. Both RPAS/UAVs and fuel cells are an advanced, emerging technology that the Western Cape can benefit from and includes other benefits such as local skills development, training and acquisition of advanced technical know-how in the region was well as local industry development.

A special thanks to the City of Cape Town / CHEC funding program for supporting this research which in turn was used to assist an MSc. Engineering Candidate who worked as the research assistant on the project. The student's thesis will include results developed for this report. Through HySA System Fuel Cell Vehicle Program, we were able to employ an engineering graduate on a short fixed term contract to also support this project. This demonstrates our ability and approach to co-funding research projects related to fuel cell technology. The engineering graduate, who had been unemployed at the time with little experience, was able to gain employment with a top technology consulting firm shortly thereafter.

ABBREVIATIONS AND ACRONYMS

CCT – City of Cape Town

GCS – Ground Control Systems

UAV – Unmanned Aerial Vehicle

LIDAR – Light Detection and Ranging

RPA – Remotely Piloted Aircraft

RPAS – Remotely Piloted Aerial System, used interchangeably with UAV

ICE – Internal Combustion Engine

PEM - Proton Exchange Membrane

VTOL – Vertical Take-off and Landing

UAS – Unmanned Aerial System

MTBF – Mean Time between Failures

OPEX – Operating Expenditure

CAPEX – Capital Expenditure

Quad – Quadcoptor: a variant of a Multi-Rotor type but limited to 4 vertical propellers

Table of Contents

1. INTRODUCTION AND AIMS / QUESTIONS

1.1. BACKGROUND

Unmanned Aerial Vehicles (UAVs) are aircrafts with no pilot on board. It can either be remotely piloted (RPA), by a pilot at a ground control station or flown autonomously where the flight is pre-programmed [1]. UAVs can save costs by replacing the need of a helicopter and pilot, amongst many other advantages. Over the years, UAVs has been used widely in military applications. As a result of technological advancements, UAVs are also being used in civilian applications such as monitoring, surveillance, mapping and other remote sensing applications [2] [3] [4].

Current UAV propulsion systems are based on different types of internal combustion engines fed by fossil fuels. For micro, short range UAVs, pure electrical propulsion is also used. However, due to range limitations encountered with battery only energy system, alternative hybrid propulsion systems using fuel cells are being introduced [5]. In addition to increased endurance, using fuel cells as propulsion systems yields many more advantages including low thermal and noise signatures and zero carbon emissions at point of use.

The City of Cape Town has funded a research proposed by HySA Systems, which aims to evaluate the benefits of integrating fuel cell technology in RPAS applications for their future UAV fleet the city will soon operate. This paper researches some of the applications suited to RPAS as well as the feasibility of integrating fuel cell technology within RPAS for some of the applications identified by the City of Cape Town.

1.2. OBJECTIVES OF THE PROJECT

1.2.1. Objectives

The objective is to determine if the City of Cape Town can benefit from combining fuel cell and RPAS technology within their future fleet of UAVs. Questions to be answered include but not limited to:

- Which RPAS applications in the City of Cape Town require extended flight times, extended range as well as quiet and vibration free remote sensing capabilities?
- What are the benefits of using fuel cell technology in RPAS applications?
- What are the limitations and challenges of using fuel cell technology in RPAS?
- What are the life cycle costs of fuel cell versus conventional technology RPAS systems?

Research output detailing the specific applications that could benefit from fuel cell technology integrated in RPAS in the form of this report.

1.2.2. Motivation

The City of Cape is commencing with a request for information and procurement of advanced remotely piloted aerial system technology (RPAS) within a two year time frame. To support the city in this process, the project research will focus on and provide valuable data on:

- The benefits of fuel cells in RPAS applications which have the potential to extend the usefulness and capabilities of the RPAS technology. To date, this technology combination has mostly been applied to military applications but can benefit civilian applications in terms of extended flight times, range and improved remote monitoring capabilities.

- Providing additional information to the relevant department to increase the awareness and possibilities of alternative power sources that can be used in RPAS (and other mobility's) with zero carbon emissions at point of use.

- Both RPAS and fuel cells are an advanced emerging technology that the Western Cape can benefit from including the skills development, training, and acquisition of advanced technical know-how in the region.

1.3. SCOPE AND LIMITATIONS

This research is entirely research based. It is restricted to Remotely Piloted Aerial Systems and does not deal with any other type of UAVS. The duration of the research is within a one year time frame and focuses primarily on the benefits related to UAVs using fuel cell propulsion technology with respect to increased range and flight times over battery powered UAVs. The size and weight of UAVs focused on this report typically weigh less than 20kg and payload capacities of less than 5kg.

1.4. PLAN OF DEVELOPMENT

- Section 2: Deals with the approach taken for the research as well as the method used.

- Section 3: Focuses on UAV technology.

- Section 4: Looks at fuel cell technology.

- Section 5: Reviews the integration of fuel cell technology within RPAS as well as a life cycle cost of fuel cells vs conventional battery powered RPA technology

- Section 6: Design and Simulation of small scale multi-rotor UAV with subsequent comparison of battery range versus fuel cell range analysis.

- Section 7: Discussion and summary of results found.

- Section 8: Proposal and recommendations for next steps.

2. RESEARCH APPROACH AND METHODS

The following research areas and specifics needed to be investigated and addressed in this report:

- Research on different types of UAVs where the focus was on Remotely Piloted Aerial Systems (RPAS),

- Different types of UAVs, specifically with regards to aircraft frame configuration (multi-rotor, fixed wing or hybrid configuration) and restricted to UAVs typically weighing less than 20kg.

- Fuel cells and the application in UAVs: Propulsion systems comparison (battery versus hydrogen fuel cell technology) focusing on range and flight time extension and how this may impact operating and/or capital costs.

- From the information obtained from the City of Cape Town, identification of key requirements for the various UAV applications and related mission requirements.

- Verification of research data used in the form of a theoretical design and simulation of a fuel cell powered UAV system: This component of the research study adds support and improved credibility on data collected that is then used to conduct the comparative analysis and draw certain conclusions on the benefits of integrating fuel cell technology into UAVs

- Provide an indication where fuel cell technology could be used as propulsion systems through examples / applications types of the technology which potentially reduces operating fleet setup costs.

- Further recommendations based on discussions and conclusions drawn.

The structured approach taken was to first complete a research of what technology is already available in the commercial space and quantify the technical performance improvements achieved by integrating fuel cell technology into UAVs. This could then be evaluated within the context of various RPAS applications the CCT intends to implement.

Over 70 applications and uses of RPAS technology are identified by the City of Cape Town. A systematic approach was adopted for the high level evaluation of the major applications that could be supported by RPAS technology. Key performance criteria were listed to determine the UAV type best suited for each application case. Once this was established, the most suitable UAV type applicable to each case could be better identified. Thereafter, subsequent analysis of the benefits gained by utilizing fuel cell technology in each aircraft type was conducted to quantify the benefits in terms of extended range and flight times per UAV type.

Lastly, by way of a comparative study of two simple example applications, certain cost benefits could be demonstrated:

The inspection of 20 000km of power lines quantifies and illustrates operating cost differences between battery powered and fuel cell powered UAV systems. Sensitivity analysis tables were used to allow for uncertainty in missions of expected personal costs which highlight the impact on operating costs by varying the labour rate. Additionally, the cost of hydrogen fuel was similarly considered due to varying costs as to how it is ultimately sourced: Both these variables influence which technology is preferable under various application conditions and requirements.

A ‘grid like’ implementation of UAVs for the purpose of monitoring and response to emergency situations was considered as the second application example. Again, fuel cell technology compared to battery operated UAVs was further analysed, in this case in terms of capital setup costs demonstrating the difference in fleet costs and how this could potentially be reduced if one utilizes fuel cell technology as a propulsion system for UAVs.

Further, by approximating a fleet consisting of various UAV types that range in suitability for diverse application requirements that the fleet is expected to service, an approach to optimising the fleet structure of the fuel cell UAV types with respect to maximising the benefits gained is illustrated.

Lastly, as a final component of this research, the data researched and obtained from the internet from the ‘desktop research approach’ needed to be verified since this data collected was predominantly based on company claims on performance enhancements expected from integrating fuel cell technology in UAVs and the systems they sell. Since this data was directly used to quantify cost reductions, to eliminate potential bias from this industry data, we conducted our own theoretical analysis, design and simulation using MATLAB to confirm some of these claims thereby increasing confidence in our results derived from this data. This component of the research was supported by an engineering MSc student in exchange for a student fee support in the form of a R45000 bursary that was paid from the CHEC funding received. His results will be further formulated as part of his Thesis.

Additional benefits of this research included employment (short fixed term contract) for a junior undergraduate engineer who was at the time unemployed. She subsequently was offered employment at Accenture shortly after completing this research. Her salary was paid from HySA Systems own funding as part of our philosophy to match / co-fund research and demonstrator projects related to and incorporating fuel cell technology respectively.

3. REMOTELY PILOTED AERIAL SYSTEMS

This section aims to define and clarify the components or subsystems typical of a remotely piloted aerial fleet.

3.1. What is RPAS?

Remotely Piloted Aerial/Aircraft system, is an unmanned aircraft (UAV) which is piloted from a remote pilot station [6]. It is capable of flight either autonomously or pre-programmed. It includes the sub-systems such as control station and pilot which forms part of the full system.

3.2. RPA System components

The system is made up of different sub-systems which forms part of the total system [7] [8].

3.2.1. Aircraft

Remotely Piloted - See Section 3.3

3.2.2. Ground Control Station

The ground control station or GCS is the land (or sea) based control centre of the operation. The facilities for human control of the unmanned vehicles and the interface between the operator and machine are provided here.

GCS can vary in physical size and can be as small as a hand-held transmitter or as large as a self-contained facility with multiple workstations. The GCS usually consists of a pilot station for the pilot-in-command that operates the aircraft as well as a sensor station for communications and payload operations.

3.2.3. Payload

In order for UAVs to accomplish a mission, it requires a payload. Depending on the operational task, the payload can range from a simple sub-system containing a camera/video system or more sophisticated sub-systems such as a combination of different types of sensors. Examples of sensors include: electro-optical cameras, infrared (IR) cameras, radars, light detection and Ranging (LIDAR), thermal as well as hyper spectral imaging.

3.2.4. Communication - Data links

In order for command and control information to be send and received, data links are required. The tasks of the data links are:

- Uplink- transmission of commands from the GCS to the aircraft, as well as
- downlink – transmission of data from aircraft to GCS

The operational tasks required from the system can either be Line-of-Sight (LOS), which refers to operation via direct radio waves or Beyond Line of Sight (BLOS) where operations are done via satellites or relay communications.

3.2.5. Human Element

A human is required for the operation of the aerial aircraft. A pilot is needed as well as a ground crew depending on how complex the system is. The pilot in command is responsible for the safe operation of the aircraft.

3.2.6. Launch, Recovery and Retrieval

Launch equipment is required for aircrafts which does not have vertical flight capability, nor access to a suitable runway. This is usually achieved with the use of a ramp, accelerated by a trolley and propelled by a system of rubber bungees until the aircraft has reached airspeed enough to remain airborne.

Recovery equipment would also be needed for aircraft with no vertical flight capability. This is usually in the form of a parachute which is installed in the aircraft and deployed over a land strip at a suitable altitude.

Retrieval equipment would be needed in order to transport the aircraft back to its launcher, unless it is lightweight enough to be man-portable.

3.3. Types of Remotely Piloted Aircraft

3.3.1. Fixed wing

Fixed-wing aircrafts has one or more rigid wings used to create lift, with propellers or engines to power the design. They usually only move forward, but tail control allows it to change its heading [9].

The main advantage of a fixed wing RPA is that it consists of a simple structure which provides a less complicated maintenance and repair process. The simpler structure also ensures more efficient aerodynamics that provides longer flight durations at higher speeds thus enabling larger survey areas. A fixed wing aircraft can also carry greater payloads for longer distances on requiring less power and energy.

One disadvantage is that a fixed wing aircraft requires a runway or a launcher for take-off and landing. Also, air moving over the aircraft’s wings is required to generate lift, they must stay in a constant forward motion and thus is unable to stay stationary or hover [10].

Applications for fixed wing aircrafts include surveillance, aerial surveying, geo-referenced imagery, aerial mapping as well as applications requiring high speeds and long distances.

3.3.2. Multi-rotor

Also called rotary wing aircraft, it relies on spinning blades which are centred by a rotor to keep the machine in flight [9]. Multi rotors comes in wide range of setups consisting of a minimum of one main rotor (helicopter), 3 rotors (tricopter), 4 rotors (quadcopter), 6 rotor (hexacopter), 8 rotors (octocopter) as well as more unusual setups like 12 and 16 rotors.

The biggest advantages of a rotary wing aircraft is the ability for it to take off and land vertically which allows for operation in smaller vicinities and the ability to hover for improved monitoring and inspection of stationary objects and static structures.

On the other hand, the disadvantage is that a multi rotor aircraft involves greater mechanical and electronic complexity which would require more complicated repair and maintenance processes. Also, the speed is lower as well as the flight range shorter, hence the user would require additional flights which is time consuming and costly [10].

Rotary aircrafts are best suited for maintaining visual on a single object for extended times. This includes applications such as facility inspections, pipeline inspection, power line inspection as well as railroad and bridge inspections.

3.3.3. Hybrid

A Hybrid UAV is also known as Vertical Take-off and Landing (VTOL) aircraft. It can vertically take off and lands like a rotary wing aircraft. Additionally, in forward flight the main lift is generated by the airstream flowing over its wings which makes it more efficient than a rotary wing aircraft [11]. A hybrid combines the vertical take-off and landing (VTOL) capabilities of a rotary aircraft and the efficiency, speed, and range of a normal fixed-wing aircraft. [12].

Advantages includes reduced operational footprint as no runway is required. Initial system cost is generally more than a simple fixed wing or multi-rotor, however lower fuel and energy requirements compared to multi-rotor and simpler launch procedures of the system potentially reduce operational costs of these type of UAVs.

4. FUEL CELL TECHNOLOGY

This section provides a short overview of fuel cell technology and the various types of fuel cells available today.

4.1. What are fuel cells?

A fuel cell is a device which generates electricity by a chemical reaction. Chemical potential energy is converted to electrical energy by the fuel cell. Hydrogen and oxygen is combined to produce electricity, heat and water Fuel cells uses an external supply of chemical energy and can run indefinitely, as long as it is supplied with a source of hydrogen as well as oxygen [13] [14].

4.2. How does a fuel cell work?

Every fuel cell has two electrodes, the anode (positive) and the cathode (negative). At these electrodes, the reactions producing electricity takes place. In addition to this, a fuel cell has an electrolyte, which carries electrically charged particles from one electrode to the other, and a catalyst, which speeds the reactions at the electrodes.

Hydrogen atom enters the fuel cell at the anode where a chemical reaction strips them of their electrons (ionized) and carries a positive electrical charge. The negatively charged electrons provide the current. Oxygen enters the fuel cell at the cathode and combines with the electrons which have travelled through the electrolyte. Whether combination occurs at the anode or cathode, together the hydrogen and oxygen forms water, which is drained from the cell. As long as the fuel cell is supplied with hydrogen and oxygen, it will produce electricity.

It is to be noted that a single fuel cell generates a small amount of DC electricity. Practically, many fuel cells are assembled into a fuel cell stack, where the principle of operation remains the same albeit with higher voltages and thus higher power output performance [15].

4.3. Classification of fuel cells

Fuel cell types are generally classified according to the nature of the electrolyte they use. Each type requires particular materials and fuels and is suitable for different applications. The different characteristics of each type of fuel cells determine applications it is best suited for. Usually high temperature fuel cells are not considered appropriate for UAVs due to large size and weight, start time and systems required to manage the dissipated heat [5]. Nevertheless, attempts are being made to miniaturize UAVs using a combination of fuel cells along with other technology, and different types which could be used is summarized below [5] [14] [16] [17]:

4.3.1. PEMFC

The proton exchange membrane fuel cell (PEMFC) uses a water-based, acidic polymer membrane as its electrolyte, with platinum-based electrodes. The use of the polymeric electrolyte provides high current densities. PEMFC cells operate at relatively low temperatures (below 100 degrees Celsius) and can tailor electrical output to meet dynamic power requirements. They have a quick start up, a high specific energy density and a low specific power density. Due to the relatively low temperatures and the use of precious metal-based electrodes, these cells must operate on pure hydrogen.

PEMFC cells have been successfully demonstrated in light duty vehicles, heavy duty vehicles e.g. buses and trucks as well as trams and trains. Materials handling vehicles have shown early commercial viability as well as some for stationary applications. They offer potential advantages related to increased flight time and range extension for low manoeuvrability and high endurance UAVs – typically used in surveillance applications. In addition to this, efficiency, environmental benefit, low noise and thermal signature can potentially offer additional benefits.

4.3.2. DMFC

The direct methanol fuel cell (DMFC) is a class of PEMFC. It uses a polymer membrane as an electrolyte. However, the platinum-ruthenium catalyst on the DMFC anode is able to draw the hydrogen from liquid methanol, eliminating the need for a fuel reformer. Therefore pure methanol is used. It has about half the efficiency (higher heat losses) and power density of PEMFCs, but higher energy density (greater endurance) and simplicity. In addition to this, the storage system is lighter than that of hydrogen, logistics are simpler and methanol can be obtained from biomass (e.g. wood distillation) which can be considered as a renewable fuel.

DMFCs operate in the temperature range from 60ºC to 130ºC and tend to be used in applications with modest power requirements, such as mobile electronic devices or chargers and portable power packs. It already has uses in terrestrial applications and can also be applied in very light, low manoeuvrability UAVs such as helium airships.

4.3.3. SOFC

SOFCs use a solid ceramic electrolyte, such as zirconium oxide stabilised with yttrium oxide, instead of a liquid or membrane. They work at very high temperatures, the highest of all the fuel cell types at around 800ºC to 1,000°C. They can have efficiencies of over 60% when converting fuel to electricity; if the heat they produced is also harnessed; their overall efficiency in converting fuel to energy can be over 80%. SOFCs are used extensively in large and small stationary power generation. They are expected to be used for generating electricity and heat within industry, and potentially providing auxiliary power in vehicles.

4.3.4. AFC

Alkaline fuel cells (AFCs) were one of the first fuel cell technologies to be developed and were originally used by NASA in the space programme to produce both electricity and water aboard spacecraft. AFCs use an alkaline electrolyte such as potassium hydroxide in water and are generally fuelled with pure hydrogen. The first AFCs operated at between 100ºC and 250ºC but typical operating temperatures are now around 70ºC. The use of AFCs are limited due to only pure hydrogen can be used as fuel. Air needs to be cleaned from CO_2 which limits the application for terrestrial applications.

4.3.5. MCFC

Molten carbonate fuel cells (MCFCs) use a molten carbonate salt suspended in a porous ceramic matrix as the electrolyte. Salts commonly used include lithium carbonate, potassium carbonate and sodium carbonate. They are heated to high temperatures such as 650 ºC, which does arise in problems. The cells then take time to reach operating temperature which makes it unsuitable for transport applications and due to the corrosive nature of it, MCFCs are unsuitable for home power generation. However, MCFCs are used in large stationary power generation and attractive for use in large-scale industrial processes and electricity generation turbines due to their high power generating efficiencies.

4.3.6. PAFC

Phosphoric acid fuel cells (PAFCs) consist of an anode and a cathode made of a finely dispersed platinum catalyst on carbon and a silicon carbide structure that holds the phosphoric acid electrolyte. The operating temperature is around 200 ºC. Typical applications are in the industrial and commercial combined heat and power.

5. INTEGRATION OF FUEL CELL TECHNOLOGY IN RPAS / UAVs

5.1. What are the benefits of using fuel cell technology in RPAS?

The main characteristics of hydrogen fuel cells are their high energy density, clean emissions at point of use, high efficiency, modularity, reversibility (this property is exploited in RFC Systems) and low noise as well as low operating temperatures (60-70 degrees Celsius).

These characteristics relate to various advantages in several applications. In UAVs, higher energy density provides greater endurance in terms of increased flight time and longer range of the aircraft. Reliability is better than ICE engines due to few moving parts and simpler automation due to the all electrical configuration. Fuel cells can continually produce power as long as fuel is been supplied as opposed to batteries which require charging. Fuel cells can rapidly change their power output, however, for demanding manoeuvres including take-off and climbing, the addition of a small battery in a serial configuration is commonly used.

Aside from the large energy storage advantages carried on-board, due to direct energy conversion (no combustion), negligible noise and vibration leads to far quieter operation when compared to ICE powered UAVs. Further, zero emissions at point of use and low thermal signature can offer advantages where stealth and sensitive instruments / sensors on-board are involved.
When considering large UAVs, water, as well as heat and low oxygen-containing exhaust air emitted as a side product of the fuel cell that could have other applications to compensate the weight disadvantages such as water supply for other subsystems, de-icing, or in-erting of a fossil fuel tank in hybrid configurations.

Considering these benefits, fuel cell powered UAVs are slowly becoming available in the commercial space. Initially, this has been limited to the development of fuel cell powered fixed wing aircraft, however, more recently, multi-rotor systems are beginning to be developed and we are now starting to the emergence of hybrid fixed wing / multi-rotor UAVs, although these systems are mostly in the development phase.

5.2. Fuel Cell Powered UAV Type – Fixed Wing

Integrating fuel cell technology into fixed wing UAVs is far more common than multi-rotor systems. Here the performance increases in terms of flight time and range capability are where substantial gains are achieved. Furthermore, relatively smaller fuel cell systems are required as the power needed to maintain cruise speed is typically 1/3 of that for take-off and climb power requirements. The comparison of battery powered versus fuel cell powered UAV performance in terms of range and flight time is illustrated by means of the Ion Tiger as a case study:

The 'Ion Tiger' was a project undertaken by the Naval Research Laboratory (NRL) together with a fuel cell manufacturer called Protonex (the company was subsequently bought out by Ballard Systems), a larger fuel cell manufacturer in Canada. The Ion Tiger UAV demonstrates the endurance advantages offered by hydrogen powered fuel cell systems integrated into fixed wing UAVs. It is a 16-kilogram system with a 3-meter wingspan designed around a composite hydrogen tank (pressure of tank equals 300 bar). It has the capability to carry a 2.2-kilogram payload. When fuel was stored on-board the vehicle as compressed gaseous hydrogen, the Ion Tiger platform demonstrated 26 hours of flight. For comparison, an equivalent weight of batteries would provide an endurance of approximately 4 hours. This equates to a range increase of 650% or 6.5:1 when compared to battery powered systems.

A second configuration or second phase of the project, the Ion Tiger was outfitted with a liquid hydrogen storage subsystem and demonstrated 48 hours of flight time, nearly double that of using compressed hydrogen gas at 300bar. When compared directly to the equivalent battery version UAV, an increase in flight endurance by a factor of 1200% was achieved with this particular fixed wing UAV. Further details regarding this project have been published in papers entitled, “Hydrogen Fuel Cell Propulsion for Long Endurance Small UAVs” and “Projecting the Impact of Aircraft Design Decision on the Performance of a Fuel Cell Power and Energy System in Unmanned Aircraft Systems”. [39]

UAV platforms traditionally powered by small internal combustion engines (ICEs) typically have payloads greater than 5kg and therefore do not fall into the scope of this study – however, since ICE propulsion systems have certain advantages they offer over those powered by batteries, it may be worth a brief discussion in the case of fixed wing UAV types: Given the high energy density of liquid hydrocarbons, ICE powered UAVs, like fuel cell powered systems have very good endurance versus battery-powered vehicles and compete with the advantages offered by fuel cell powered systems in this regard. However, small engines have several deficiencies relating to reliability and predictability. In operation, small engines are noisy and polluting with a high thermal signature, making them less suitable for applications where stealth, low vibration and low thermal signature is required, such as environmental monitoring, conservation and infrared imaging applications. The small engines have a narrow band of fuel efficient operation and poor load following leading to operating efficiencies as low as 10%. Additionally, a secondary electrical system is also required e.g. battery with an electric alternator to supply the electrical loads on the UAV system. The complexity and high number of moving parts can not compete with the reliability of more simple propulsion systems such as batteries or fuel cells. Considering this, fuel cells offer the longer ranges similar to iCE powered UAvs, however, without the reliability, noise and vibration problems as well as the need to add a secondary electrically based power system on-board.

For fixed wing UAV types, fuel cells offer excellent range and require smaller fuel cell systems when compared to multi-rotor systems. However, integrating fuel cell systems still show impressive benefits across all UAV types in terms of range extension.

5.3. Commercial Fuel Cell Powered UAV Type – Multi-Rotor

Two commercial multi-rotor UAVs companies offer fuel cell systems on the market to date (EnergyOR and MMC). Each company offers two models which all offer increased flight times / extended range when compared to conventional battery technology used in multi-rotor UAV types.

Company MMC: The Hydrone 1550 is produced and sold by the Chinese company MMC. This fuel cell powered multi-rotor UAV is the smaller of the two systems offered by MMC and can fly for a period of 2,5 hours without a payload. The cost of the drone is in the region of R200 000 excluding VAT and import duties. With a payload of 1kg, the UAV has a range of 57km and a cruising speed of 8m/s..

The larger model, the HyDrone 1800 which has a 1.8kW fuel stack is claimed to have a flight time of 4.5 hours endurance without a payload. MMC's HPS-1800 hydrogen fuel cell's weight vs. output power against a lithium battery can be analysed. The weight of the HPS-1800 is 9.2kg, and its power output is 1800W. The potential energy storage in the hydrogen tank is 4500Wh. This equates to an energy density equal to ~490Wh/kg, more than twice that of the LiPo battery. Both flight times and range are improved on the smaller model and an 80km range or greater is expected.

The fuel cell systems are both rated to last 1000 hours of operation time and fall in the range of 1kW – 1.8kW. The rated 1000 operating hours compare favourably to conventional batteries which have a lifetime of typically 80 to 100 cycles delivering one order of magnitude less operating life time before requiring replacement.

Figure 5-1: HyDrone 1550 (MMC)

Company EnergyOR: EnergyOR likewise offers both a small and larger system, the Quad400 which achieves a 2 hour flight time with a payload of 400g and the larger system, the Quad1000 can fly for over 2 hours with a 1kg payload. They claim 4x longer flight time than any battery powered systems The range is stated as 80km and again, the company claims this is 3x the range that any equivalent battery powered multi-rotor UAV achieves.

Figure 5-2: H2 Quad 1000 (EnergyOR)

It is also worth noting that a Russian fuel cell powered multi-rotor (the NELK Octocopter) recorded a flight time of 3 hours 10 minutes in April 2016– this test was done in winter, outdoors with gusty winds while streaming video i.e. under real life conditions. The NELK demonstrates a further advantage of fuel cell technology over batteries – the ability to perform under very cold conditions. Batteries performance and range can reduce up to 50% under near zero temperatures. EnergyOR however hold the longest record for longest flight time recorded and have demonstrated multi-rotor flight time of 3 hours 43 minutes under ‘perfect conditions’ [40]. Both these record setting flight times are simply not achievable with battery technology due to the extra weight of the batteries needed to store equivalent amounts of energy.

5.4. Fuel Cell Powered UAV Type – Hybrid Fixed Wing with VTOL

Combining a multi-rotor with a fixed wing UAV provides a middle ground solution to the multi-rotor and the fixed wing only UAV options. It is a relatively new type of UAV emerging and indeed, our research study indicates that no commercial system with a fuel cell integrated has been released to date.

The Volanti from Sydney-based Carbonix is one such aircraft with carbon composite frame and a 2.7-m (9-ft) wingspan. The UAV uses a multi-rotor system for vertical take-off and landing (VTOL) and an additional ‘push-prop motor’ for forward motion. It comes in 2 configurations, a battery powered option and a hybrid gasoline and electric powered option.

The UAV transitions to horizontal flight as a ‘push-prop fixed-wing UAV’ once it has taken off and gained sufficient altitude in the air. It has a capability to stay air borne for over two hours on electric power or seven with the hybrid gasoline version. The company Carbonix hopes it will fill the industrial-grade niche in between hobby and military UAV market segments.

The electric version has a claimed flight time of two hours with a 2kg payload. The gasoline version claims up to 7 hours. The disadvantage of this hybrid is however, the large power requirements during VTOL as the system has to lift the extra weight of the gasoline motor and added weight of the wings when compared to a simpler multi-rotor UAV. This essentially results in a large amount of electrical energy needed just for take-off in the electrical version and virtually no electrical energy left for hovering the gasoline version other than for take-off and landing manoeuvres.

Figure 5-3: Volanti Hybrid (Electric / Gasoline) Fixed Wing VTOL Aircraft

A similar fixed wing VTOL system is the ALTi Transition. It is powered by a 20cc Gasoline Engine push motor as well using 4x electric motors for vertical take-off and landing. The ALTi is developed and manufactured in South Africa. It shares an equivalent frame design as the Volanti. The Alti Transition likewise suffers from the increased weight disadvantage due to the configuration including both electric and internal combustion engine motors. The payload is rated at 1kg. The UAV has a proven endurance of 6 hours. This again illustrates the energy density of hydrocarbon based fuels which in this case extends the flight time by a factor of 3x over the battery powered system, similar to the range increase benefits achieved by fuel cells on a multi-rotor platform. Both the Volanti and Alti Transition are similar aircraft and the frame is designed and manufactured by the same company Carbonix).

Figure 5-4: ALTi Transition (Electric / Gasoline) Fixed Wing VTOL UAV

If we consider the case of a fuel cell propulsion system for this type of UAV, certainly the energy intensive requirements during take-off and landing still apply. However, in this case the, fuel cell system can supply both the VTOL as well as forward propulsion motors while achieving extended range.

Comparing to pure battery powered hybrid UAVs versions, range improvements can be expected to fall somewhere between the multi-rotor and fixed wing. The ICE powered hybrid UAV shows substantial gains in range as well, however, it appears the fuel cell system will still have the advantage due to the weight savings encountered by avoiding the required dual ICE and electrical propulsion systems i.e. it can be designed as a 100% electrical architecture with an electric motor driving the forward prop as well. As mentioned previously, no fuel cell powered hybrid fixed wing VTOL UAV is available on the market yet, however, EnergyOR are working on such a system and have released a ‘teaser video’ on it, calling it the H1 Tron. The company claims an 8 hour flight time endurance which tops both the battery powered Carbonix UAV as well as the ICE powered / electrical lift ALTi UAS System. The range increase seems quite feasible at 400% (4:1) of the battery powered systems and better than ICE powered versions due to propulsion system synergies

The fuel cell powered H1 Tron utilizes an ‘all electric’ propulsion system and further shares the forward and vertical propulsion motors saving on overall weight. At this stage, it is too early to confirm the range performance increases between the fuel cell UAV and the ICE or battery UAV as no real data has been independently reviewed other than pre-launch performance claims. However, considering the massive range extension benefits obtained on multi-rotors and fixed wing UAVs as well as the ability to adopt an ‘all electric’ architecture, the range extension is expected to be in line with EnergyOR’s released figures offering 4x the range over battery powered systems and 25% increase in endurance of a hybride ICE / electric versions.

Figure 5-5: H1 Tron – Fuel Cell Electric Hybrid Fixed wing VTOL

5.5. What are the life cycle costs of fuel cell versus conventional technology RPAS systems

Sections 5.2, 5.3 and 5.4 show expected range increase of fuel cell powered systems over battery powered systems to vary between the different types of UAVs available. For the multi-rotor system, an increase of 300% or 3:1 ration can be expected when compared to battery powered systems. The fixed wing offers considerably more and assuming only compressed hydrogen gas is used, a range extension of 650% or 6.5:1 can be expected. The hybrid fixed wing VTOL system, although not yet commercially available is imminent. With this UAV type we can expect a range increase of 400% or 4:1 ratio.

Using this data collected, a simple cost feasibility study can be conducted to show the potential cost savings of operating a fleet of hydrogen powered UAVs. The worst case scenario is the multi-rotor UAV type which offers the least gain in performance of only 300% range increase over battery powered systems. It is this type of UAV we will analyse by means of an example for feasibility demonstration which, if proves valid, will hold for the worse case and therefore results with other types can be extrapolated:

Example 1: A sensitivity analysis was conducted comparing the operating costs of a fuel cell powered versus a battery powered multi-rotor UAV under the following premises and assumptions:

- 20 000km of power lines needs to be inspected for encroaching trees or vegetation.
- A fuel cell powered UAV option with range 80km is available.
- A battery powered UAV option with range 27km is available.
- The project needs to be completed in 125 days and therefore requires 160km of power line inspection per day.
- For visual inspection of this kind, a 20km/h speed is opted for throughout the inspection.

- A 30% labour cost penalty for the battery powered UAV is given to account for the fact that the operator will need to launch and retrieve the UAV 3x more often the fuel cell powered UAV because of range limitations related to battery powered systems.

- This increased effort also assumes to cover the required battery swops and additional travel required to access the power line twice between normal pickup points A and B (See Figure 5-5-1 below)

- The sensitivity analysis varies the cost of labour from R200/h to R600/h. This variation accommodates for various specialty technologists and/or could further allow for two workers at reduced rates depending on the general mission requirements.

- The other variable used for sensitivity analysis is the cost of Hydrogen which, depending how it is sourced, can vary from R150 / kg to nearly R900/ kg. Hydrogen can be sourced in many different ways from onsite production sources to simply having it delivered in hydrogen compressed gas cylinders

- Fuel cell life operating hours equals 1000 hours, while battery life cycles equal 80 (these are currently typical values achieved for applications specific to UAV multi-rotors).

- Further, after 1000 hours operation (required for completion of this project, the fuel cell UAV will need a fuel cell stack refurbishment at a cost of R130k while 9.4 sets of LiPO batteries will be replaced at estimated cost of R93k relating to the battery powered UAV.

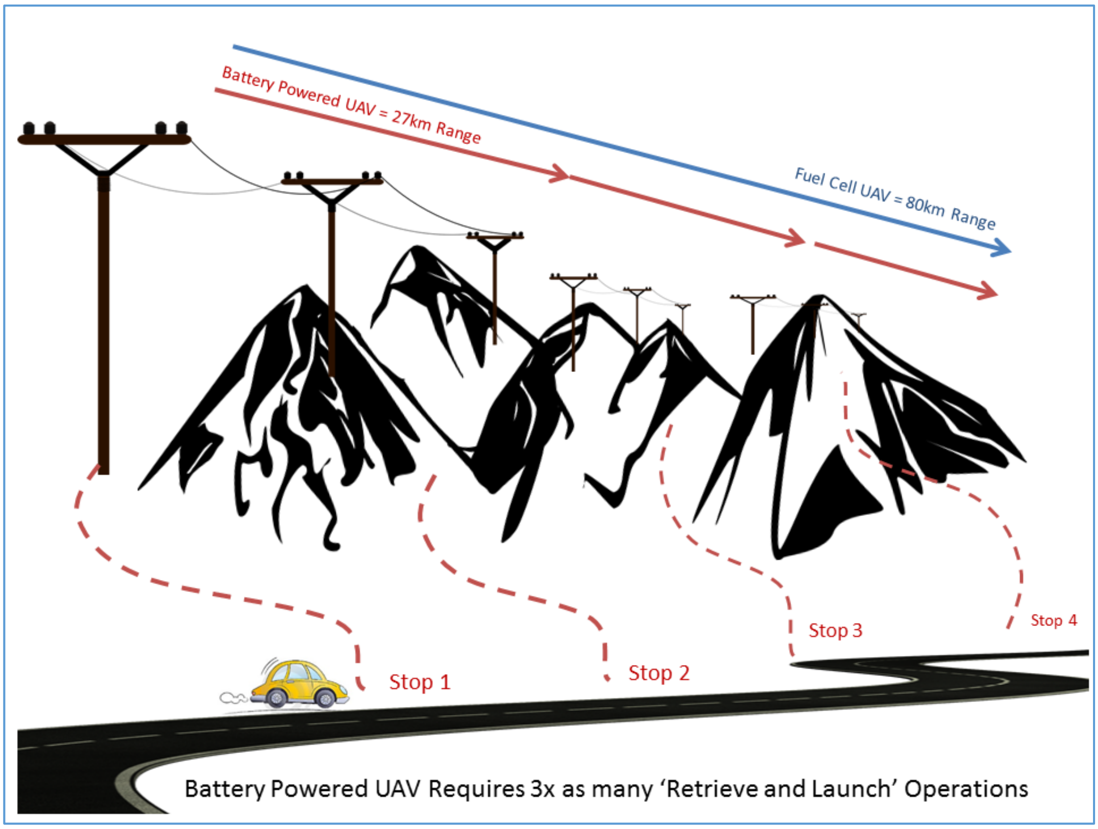
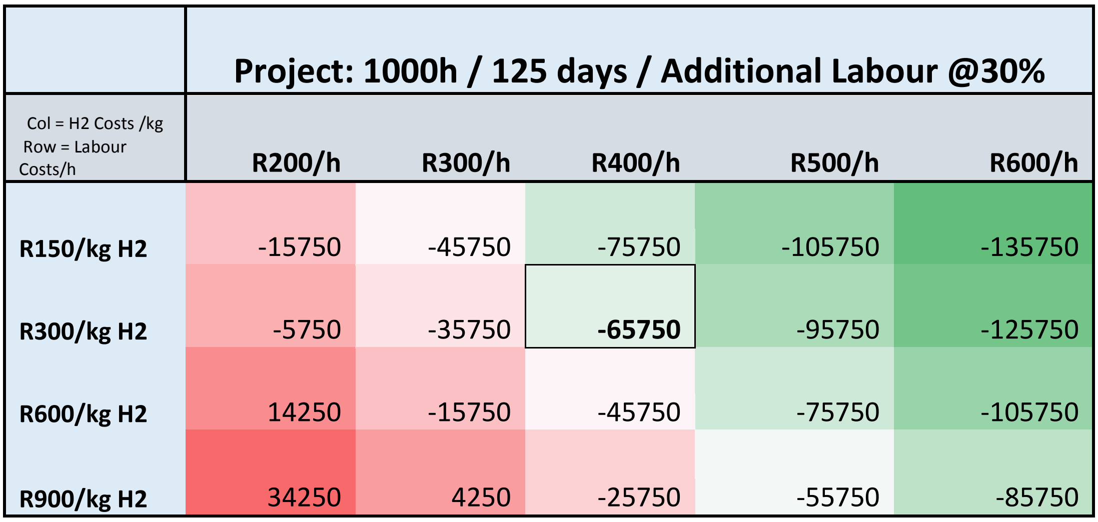


Figure 5-5-1: Illustrating Range Limitation of Battery Powered UAVs (Multi-rotor)

In reference to **Table 5-5-1** below, if we assume a labour cost of R400/ h and a cost of Hydrogen @R300/kg, the operating costs (OPEX) over the project will be R65000 less for the fuel cell powered UAV multi-rotor. If one compares the cost delta of a fuel cell powered UAV, one can expect to pay the additional capital expenditure (CAPEX) required for the fuel cell system in less than 2 years if similar projects are undertaken over a continuous 2 year period. If we look at the scenario of two personal required, each at a rate of R300/h and consider the low end of the scale for hydrogen sourcing costs at R150/kg, the payoff period is less than a year. Additionally, after the CAPEX is paid within the first year or two, the OPEX cost savings remain thereafter. This could potentially range from R65000 – R135000 per equivalent project depending on which scenario is more relevant for a particular application or mission using a multi-rotor UAV. This example demonstrates the worst case, and much higher savings will be achieved in favour of fuel cell technology when considering fixed wing or hybrid UAVs.



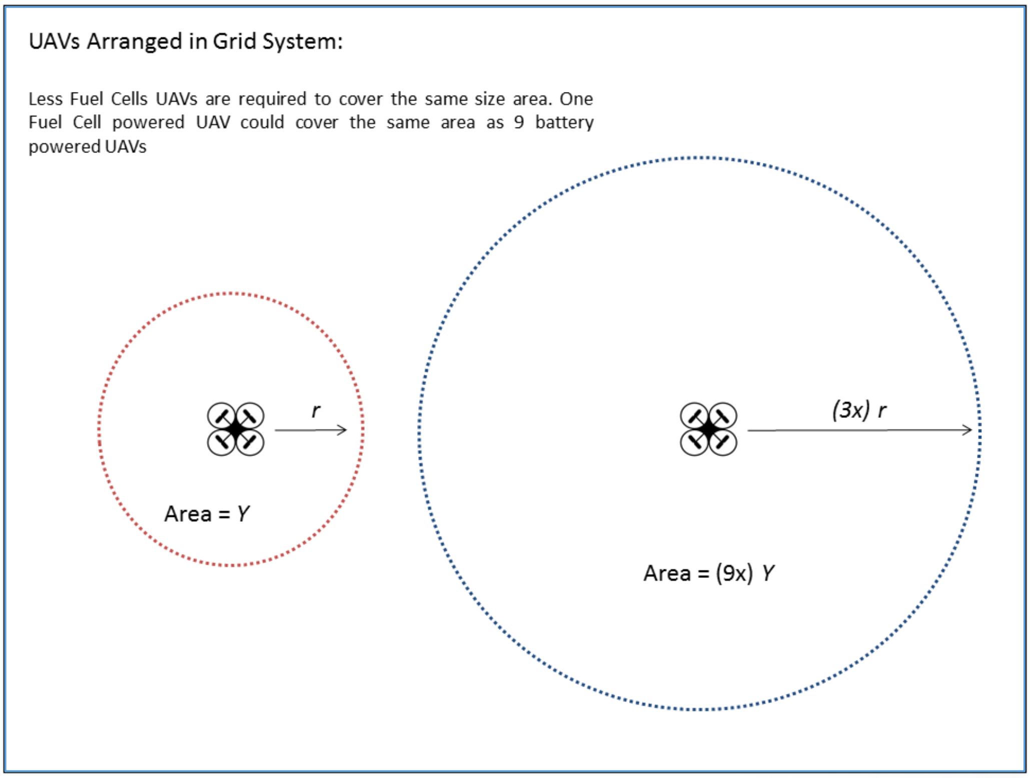
	Project: 1000h / 125 days / Additional Labour @30%				
Col = H2 Costs /kg Row = Labour Costs/h	**R200/h**	**R300/h**	**R400/h**	**R500/h**	**R600/h**
R150/kg H2	-15750	-45750	-75750	-105750	-135750
R300/kg H2	-5750	-35750	**-65750**	-95750	-125750
R600/kg H2	14250	-15750	-45750	-75750	-105750
R900/kg H2	34250	4250	-25750	-55750	-85750

Table 5-5-1: Sensitivity Table for Operating Costs (Fuel Cell versus Battery powered Multi-rotor)

Example 2: Rapid Response and Monitoring Multi-rotor UAV Grid System

As discussed with CCT, the intention to implement a fleet of multi-rotor UAVs for rapid response in case of emergencies can also been considered. In this scenario, a fleet of multi-rotor UAVs will be positioned in a ‘grid like’ configuration for rapid response in the area of coverage. The area of coverage is not specified, however, it is not required to illustrate the potential savings in this case: If we take into account the multi-rotor UAV, we have shown that in this case, a fuel cell powered UAVs have 300% the range of battery powered ones. This equates to a significantly smaller fleet of fuel cell UAVs required to cover an equivalent are using battery powered systems. A range of 3:1 increase equates to a nine fold increase in area coverage. This means, a UAV fleet nine times smaller in size is needed: This is due to the circle of coverage for each fuel cell powered UAV being 9x larger than battery powered systems i.e. 3x the radius squared. Please refer to **Figure 5-5-2**.

If we estimate a cost of R150k for a commercial grade battery powered UAV, the cost to cover the area of one fuel cell powered UAV will be R1,35 million. This is R930k more than the cost of one single fuel cell powered UAV (estimated at R420k). The savings escalate quickly as the amount of area coverage increases. Although in this example we have not included the maintenance and operating costs, it is clear securing and maintaining 9x as many grid stations with multi-rotors will amount to far higher OPEX costs using battery powered UAVs when compared to fuel cell powered systems.



UAVs Arranged in Grid System:

Less Fuel Cells UAVs are required to cover the same size area. One Fuel Cell powered UAV could cover the same area as 9 battery powered UAVs

Figure 5-5-2: Illustrating Range and Area Coverage for Multi-rotor UAVs

5.6. Refuelling Strategies

Proton Exchange Membrane (PEM) Fuel cell systems consume hydrogen fuel. These type of fuel cells require high grade, low contamination Hydrogen. This can be produced in large "central production" plants and transported to the point of end-use and stored until the fuel is required. Liquid hydrogen is the most cost effective form of hydrogen to transport in large quantities. Hydrogen may also be produced in smaller "distributed production" facilities, very near or at the point of end-use.

Hydrogen fuel required to operate the UAV could be generated on-site and on-demand using available water and a portable electrolyzer driven by a ground-based generator. Various means for storing the hydrogen fuel on-board the UAV have been evaluated. Compressed hydrogen storage systems have been demonstrated in many fuel cell vehicles and are readily available commercially at low production volumes. Storage of hydrogen as a gas typically requires high pressure carbon-composite tanks (350–700 bar tank pressure). Liquid hydrogen storage is more complex and special handling and materials are required to contain and keep the fuel cool, preventing waste from "boil-off."

An alternative way to store hydrogen for smaller UAV platforms is based on chemical hydride cartridges. In general, a chemical hydride can store hydrogen at low pressure with minimal weight added from the container that can further be dispersed as the fuel cell consumes the hydrogen. Typically these systems run at low pressures, so the weight savings of not adding a compressed hydrogen storage tank is achieved. One such chemical hydride is Sodium Borohydride, which has a large hydrogen content, is readily available and cost effective. The chemical hydride is stored in a water based solution that is non-flammable.

There is a large variation in hydrogen fuel costs depending on how it is sourced and used and can vary from R150 /kg to R900 /kg Hydrogen. The energy content of 1kg H2 is approximately equivalent to 3-4 times that of 1l gasoline.

5.7. What are the limitations and challenges of using fuel cell technology in RPAS?

Some of the current limitations of PEM hydrogen fuel cell technology include:

- **high costs**: it is not yet a mature technology and uses expensive materials like platinum, used as a catalyst in the fuel cell stack.
- **sensitivity to fuel contamination**, requiring expensive filtering systems,
- the need for qualified maintenance personnel,
- **challengers related to storage of hydrogen fuel**,
- **Availability of hydrogen**: H_2, one of the fuels used in fuel cells, is not naturally abundant; it must be obtained through water electrolysis or hydrocarbons reforming, defining it as an energy carrier rather than an energy source; there is also currently no distribution infrastructure,

Although fuel cell powered UAVs could cost up to several times more than that of their battery counterparts, the saving in CAPEX and OPEX can be immense as demonstrated in the two preceding examples.

6. RESULTS

Due to the favourable results arising from the two examples demonstrated in section 5, it was considered important to validate the manufacturer's claims in the form of our own simulation of fuel cell powered multi-rotors to further provide supportive data regarding the conclusions we made on the range extension and performance expected. Therefore, after completing a literature study and internet research of commercially available fuel cell powered UAVs, we undertook our own theoretical study to evaluate the claims made by the companies that are developing fuel cell technology propulsion systems for small UAVs.

Essentially, this was needed to improve confidence in the life cycle cost calculations we performed based on the range benefits offered by fuel cell propulsion systems, namely, that they offer up to three times the range (as a minimum when on multi-rotor UAVs) or better compared to battery equivalent UAVs with equivalent payloads. It must be emphasized that far greater range improvements for fixed wing and hybrid configurations based on the Ion Tiger case study which easily showed gains of up to 12x the range of battery technology are possible. We again conducted the study on multi-rotors as this was considered the worst case when looking at endurance increases when applying fuel cell technology. The fixed wing and UAV types which have far higher range increases has a well-established data base and have been proven across many fixed wing UAVs. The need for a theoretical study is therefore not required for this type of UAV.

We also used the theoretical study to see if smaller UAVs with payloads of less than 200 grams would also benefit from fuel cell technology. This was done by applying a smaller 500W fuel cell as compared to the literature studies which highlighted 1000 to 1800W. This would further provide confidence to the feasibility study by way of extending the validity to small UAVs that just need a small camera on-board for monitoring purposes only. This ensures we cover a larger portion of the City of Cape Town's future UAV fleet.

6.1. Theoretical Study on Fuel Cell Range Extension of UAV (Multi-Rotor 500W)

Comparing range of battery and fuel cell powered quadcopter:

6.1.1 Method

An analysis was done to compare the expected range of a quadcopter (quad) using two different power supply systems. The one power supply system is a Lithium-Polymer (LiPo) battery, the standard technology used on most (if not all) modern quads. The other power supply system is a hydrogen fuel cell – LiPo hybrid system (here on referred to as a fuel cell system). This analysis was done using an engineering software computing and simulation system (MATLAB). The analysis was done on an existing quad (shown in figure 6-1).

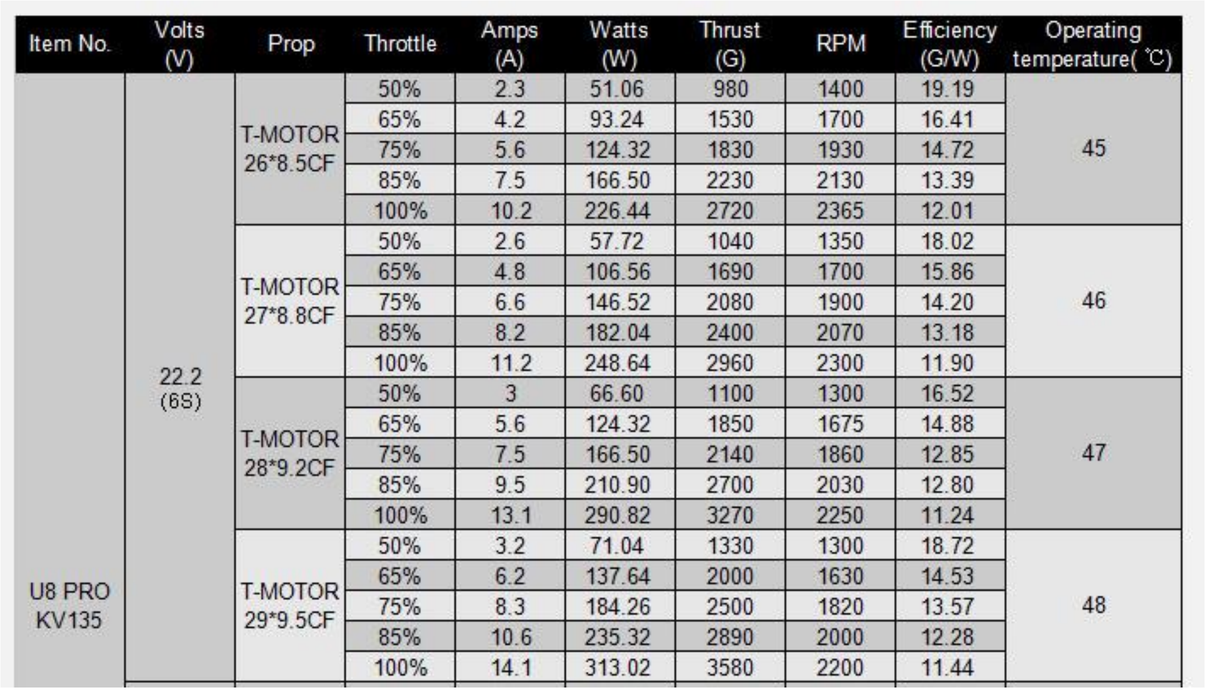
Figure 6-1: Quadcopter used for study

Information for the analysis was gathered including the mass of the components of the quadcopter as well as from the following sources:

- LiPo battery used in the quadcopter (shown in Figure 6-2)

Figure 6-2: LiPo battery

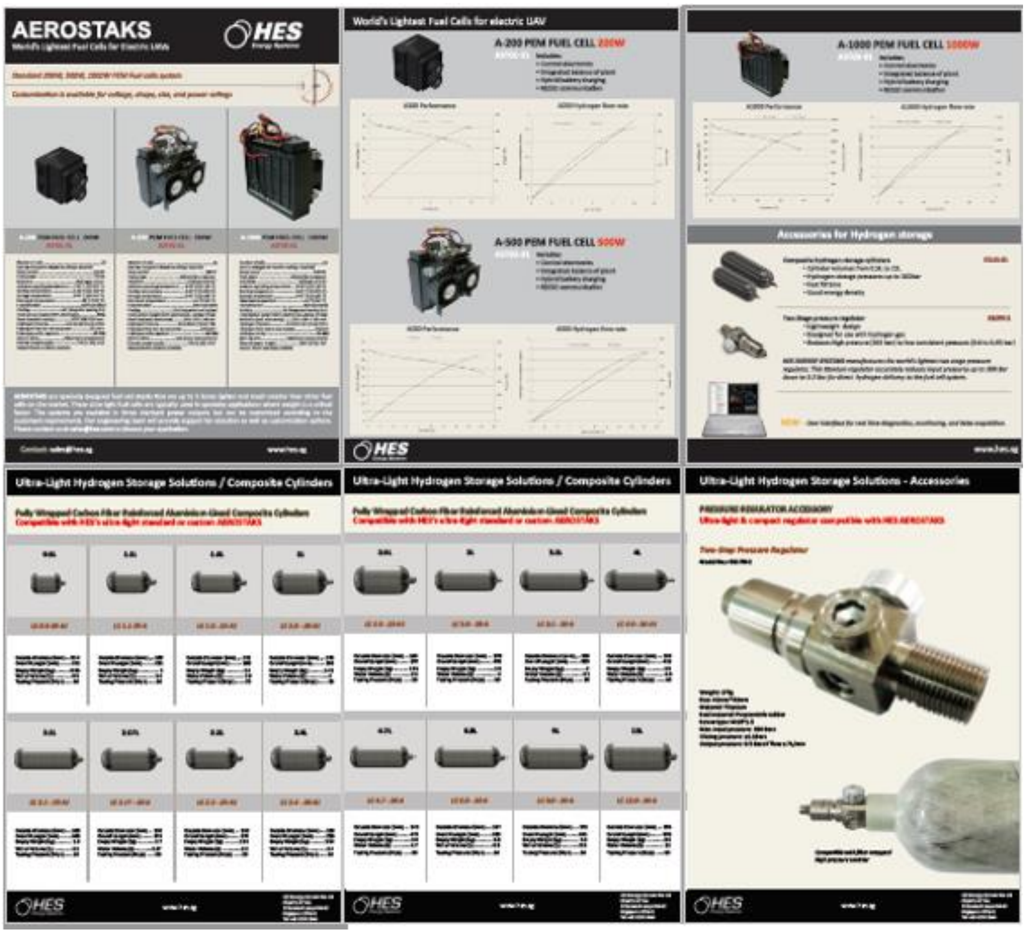
- Manufacturer data of the motor-propeller system used on the quadcopter [29]. The data sheet is shown in Figure 6-3.



Item No.	Volts (V)	Prop	Throttle	Amps (A)	Watts (W)	Thrust (G)	RPM	Efficiency (G/W)	Operating temperature(℃)
U8 PRO KV135	22.2 (6S)	T-MOTOR 26*8.5CF	50%	2.3	51.06	980	1400	19.19	45
			65%	4.2	93.24	1530	1700	16.41	
			75%	5.6	124.32	1830	1930	14.72	
			85%	7.5	166.50	2230	2130	13.39	
			100%	10.2	226.44	2720	2365	12.01	
		T-MOTOR 27*8.8CF	50%	2.6	57.72	1040	1350	18.02	46
			65%	4.8	106.56	1690	1700	15.86	
			75%	6.6	146.52	2080	1900	14.20	
			85%	8.2	182.04	2400	2070	13.18	
			100%	11.2	248.64	2960	2300	11.90	
		T-MOTOR 28*9.2CF	50%	3	66.60	1100	1300	16.52	47
			65%	5.6	124.32	1850	1675	14.88	
			75%	7.5	166.50	2140	1860	12.85	
			85%	9.5	210.90	2700	2030	12.80	
			100%	13.1	290.82	3270	2250	11.24	
		T-MOTOR 29*9.5CF	50%	3.2	71.04	1330	1300	18.72	48
			65%	6.2	137.64	2000	1630	14.53	
			75%	8.3	184.26	2500	1820	13.57	
			85%	10.6	235.32	2890	2000	12.28	
			100%	14.1	313.02	3580	2200	11.44	

Figure 6-3: Datasheet of motor-propeller system used on quadcopter

- Manufacturer data of a possible fuel cell system supplier [30], [31]. An overview of this data is shown in Figure 6-4.



AEROSTAKS

HES

World's Lightest Fuel Cells for electric UAV

A-200 PEM FUEL CELL 200W

A-1000 PEM FUEL CELL 1000W

A-500 PEM FUEL CELL 500W

Accessories for Hydrogen storage

Ultra-Light Hydrogen Storage Solutions / Composite Cylinders

Ultra-Light Hydrogen Storage Solutions / Composite Cylinders

Ultra-Light Hydrogen Storage Solutions - Accessories

Figure 6-4: Manufacturer datasheets of hydrogen fuel cell system components

6.1.2 Assumptions

It was assumed that the mission profile of the quadcopter was to take video footage, and fly along a continuous line. This would be the case for analysing power lines, coastal environment, etc. It was assumed that a GoPro HERO4 Black with housing is the payload (weighing 152g) [32]. It was assumed that there is no wind. It was assumed that the quadcopter flies forward at a constant speed of 15 km/h.

6.2.3 Insight to be gained from analysis

For the battery-powered system, there is one design variable, the size of the battery. For the fuel cell system, there are two design variables, the size of the fuel cell and the size of the storage tank. The object of this analysis was to see what the effect of increasing the mass of the power supply systems would have on the range. This would help gain valuable insight into the relationship between the mass of the quadcopter and its performance.

On the one hand, one would like to make the power supply system as large as possible, as this should result in a long range. The downside of this is that the quadcopter would be quite lethargic in its response, and the components would be driven to the edge, reducing their lifespan. On the other hand, one would like the power supply system to be as small as possible. This would allow the quadcopter to be quite agile, and the components to not be stressed that much, increasing the lifespan of the quadcopter.

To help with this analysis, the following design variable was created:

$$thrust\ factor = \frac{Allowable\ total\ mass\ of\ quadcopter\ [kg]}{Maximum\ thrust\ of\ quadcopter\ [kg]}$$

As a rule of thumb, the thrust factor should be around 0.5, i.e. the quadcopter should hover at half the maximum thrust [33]. This allows a good compromise between range and agility.
The thrust factor was varied, and the resulting range of the different power supply systems was calculated. The result is shown in Figure 5-5.

6.1.4 Results

The thrust factor was varied, and the resulting range of the different power supply systems was calculated. The result is shown in Figures 6-5 and 6-6, and Table 6-1.

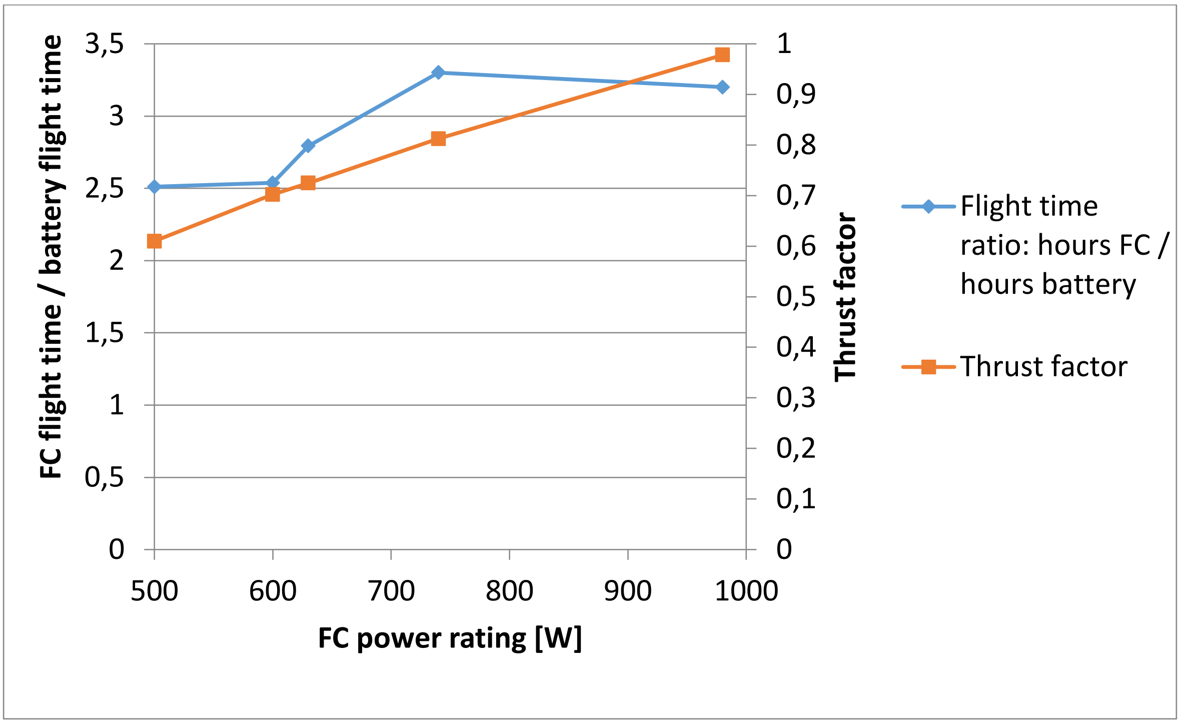


Figure 6-4: flight time ratio and thrust factor vs power rating

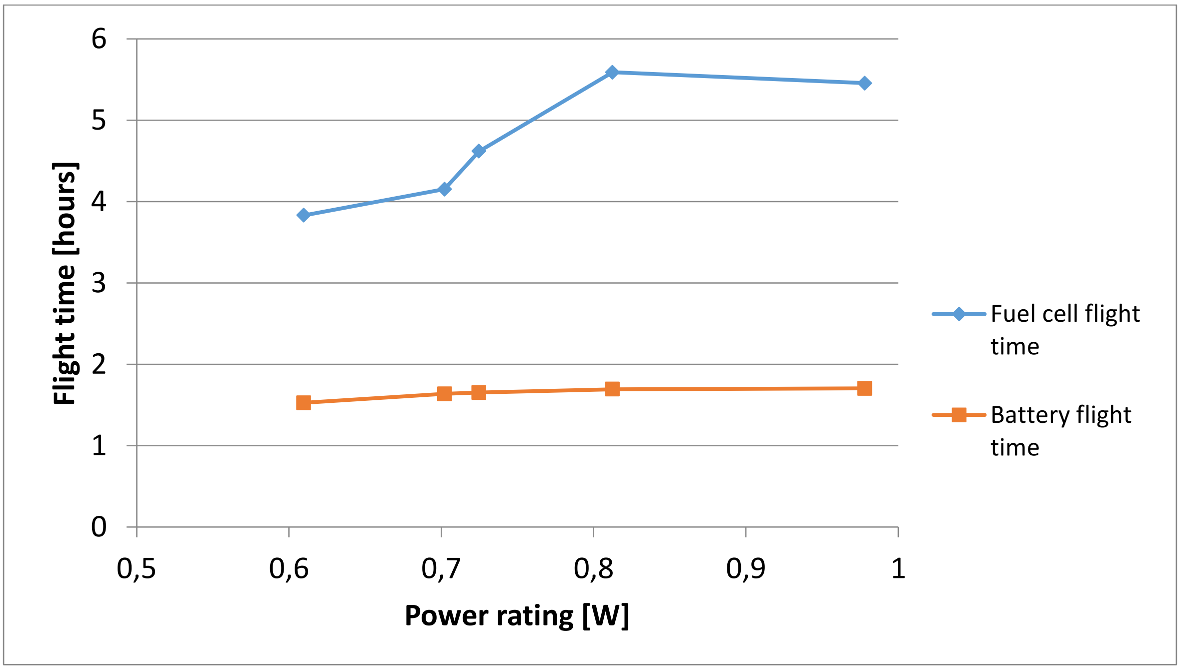


Figure 5-6: Flight times for different power sources vs thrust factor

Cell power rating	tank volume	Thrust factor	Fuel cell flight time	Battery flight time	Flight time ratio
W	litres		hours	hours	hours fc / hours battery
500	3	0.6098	3.8321	1.5261	2.511
600	4	0.7022	4.1514	1.6363	2.537
630	4.7	0.7248	4.6181	1.6533	2.7932
740	6.8	0.8125	5.59	1.6934	3.3011
980	9	0.9781	5.4544	1.7042	3.2005

Figure 6-6: Data from comparison of different power sources

With the current size of the LiPo battery (Figure 6-2), the thrust factor is around 0.5. As can be seen by the bottom line, if one were to increase the mass of the battery, the range wouldn't change much. As can be seen by the top line, if the mass of the fuel cell system is increased, the range increases quite significantly.

A thrust factor of 0.6 is only slightly higher than the recommended value of 0.5, so the agility should still be acceptable. At this value, the fuel cell system achieves a range of about 3 hours or 45km compared to the range of battery system of about 1.5 hours or 22.5km. This means that the fuel cell system has about 2 times longer range than the battery system, with a reasonable amount of agility. To obtain this result for a thrust factor of 0.6, the battery size should be increase from its current mass of 2.376 kg to 3.505 kg. For a fuel cell system, a 500 W fuel cell with a 3l storage tank should be selected.

The quadcopter used was designed to be used with batteries. The intention is to replace the batteries with a fuel cell system. Fuel cell powered quadcopters currently available on the market were designed from the ground up to be powered by fuel cells. This analysis will, therefore, not yield as good results as the commercially available fuel cell - powered quadcopters. It was then suggested to use different motors for the quadcopter in this analysis. This would result in but better results for fuel cell propulsion: The different specs on the motor, and its weight, were taken into account. A 1kW fuel cell was used in the simulation. The results are shown in Figure 6-7.

The fuel cell system can be improved further with the installation of larger fuel cells as well as opting for increased hydrogen storage capacity - flight times and mission range of over 3x of that compared to a battery powered systems are feasible as already demonstrated with the EnergyOR quadcopters: The quadcopter analysed was designed to be used with batteries. At a thrust factor of 0.58, the fuel cell range is 3.7 hours with a 4.7 times longer flight time than a battery powered system. This allows good agility with a long flight time.

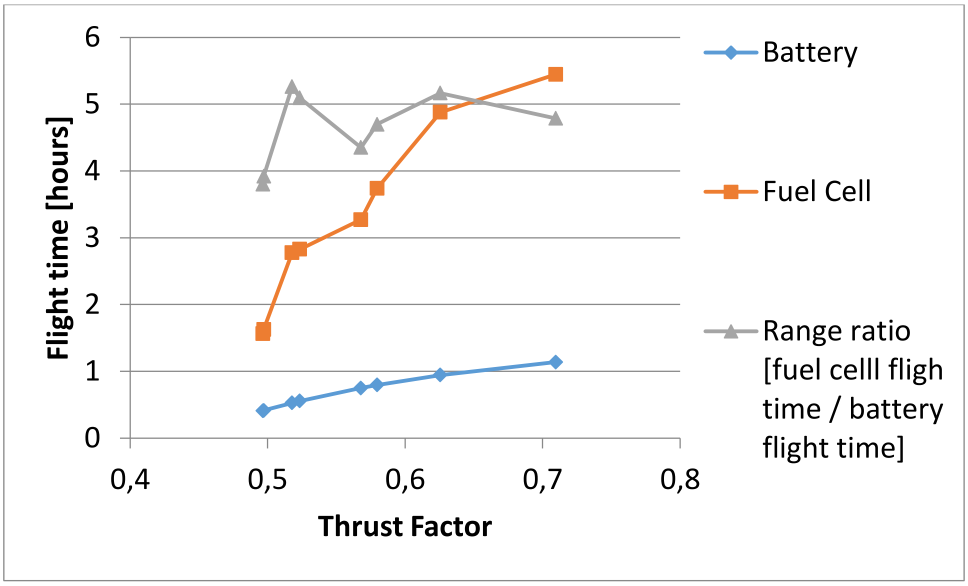


Figure 6- 7: Results of quadcopter with stronger motors

5.2.6 Accuracy of results

Improvements need to be made to the accuracy of the simulation. The relationship between thrust required by the propellers and the forward flight speed used in this simulation is quite theoretical. Tests were done with the quadcopter to obtain experimental results. However, this data hasn't been implemented in the simulation yet. The effect of wind wasn't included in the simulation. There is usually wind in Cape Town. The forward flight speed was quite slow. It might be desirable to fly a quadcopter faster than 15 km/h.

However, these shortfalls should affect both curves equally. If the simulation is improved to fix the above-mentioned shortfalls, the range of the fuel cell system should still be significantly higher than the range of the battery system. The main thing to be gained from the results is that the range of a battery system tapers off with increasing power supply mass, whereas the range of a fuel cell system doesn't.

The results in Figure 6-5 provide further support to what is currently on offer in terms of fuel cell powered quadcopters. The capability of fuel cell technology to extend the range of UAVs up to 300% has been shown both from a theoretical / simulation study as well as applying performance figures reported from a commercial fuel cell UAV development company EnergyOR. The techno-economic feasibility study is therefore further supported by reliable data collected / simulated and demonstrates the reduction of operating cost as well as capital investment costs under the two scenarios provided for UAV fleet operations.

6.2. Types of UAV's for Applications Identified by City of Cape Town

Table 6-2 shows a breakdown of UAV types recommended based on research data collected with key performance criteria considered most relevant to each application (see **Appendix A1** for specific application performance criteria listed).

Table KEY:

i. Patrolling and monitoring of vulnerable sewer routes;
ii. Patrolling and monitoring water and sanitation servitudes in terms of
iii. Assisting in the identification of smoke exits during smoke machine investigations into detecting sewer/storm water interconnections;
iv. Mapping of stolen drain covers on sewer routes;
v. Monitoring pipeline routes in remote and difficult areas to access to detect possible leaks
vi. Patrolling of cable routes using thermal and optical cameras to determine if people are living there, digging, planting structures such a tents, theft etc;
vii. Viewing of high points such as on metal lattice structures;
viii. Response to substation premise or asset tag alarm activation (instead of
ix. Conduct HV underground cable route and HV overhead line patrols to detect illegal/unauthorized activities;
x. Conduct HV OH line inspections;
xi. Detection of HV OH line servitude and cable installation encroachment
xii. Creation of geo-referenced images and mosaics and mapping in 3D.
xiii. Wastewater outfall monitoring;
xiv. River mouth estuary sandbar analysis;
xv. Origin / Destination surveys of private or public transport vehicles;
xvi. Queue length surveys and congestion analysis;
xvii. Turning movement surveys at intersections and traffic impact
xviii. Boarding and alighting surveys at BRT and rail Stations and public transport stops;
xix. Public Transport Interchange operations surveys;
xx. Pedestrian surveys including pedestrian crossings and desire lines;
xxi. General x,y,z (3D) topographical surveys – pipe routes, overland flow
xxii. Data gathering for disaster mitigation
xxiii. Damage assessments;
xxiv. Data gathering for reconstruction and rehabilitation projects

Application **(see 'Table Key' below for application decription)**	UAV Types		
	Multi-rotor	Fixed wing	Hybrid
i.	✓		
ii.		✓	
iii.	✓		
iv.		✓	
v.	✓		
vi.		✓	✓
vii.		✓	
viii.	✓	✓	
ix.	✓		✓
x.	✓		✓
xi.		✓	
xii.		✓	✓
xiii.		✓	
xiv.		✓	
xv.		✓	
xvi.		✓	✓
xvii.		✓	

xviii.	✓		
xix.		✓	
xx.	✓		
xxi.	✓	✓	
xxii.	✓		✓
xxiii.	✓		✓
xxiv.		✓	
Total (24)	**11 [2;4]**	**15 [2;3]**	**7 [4;3]**

Table 6-2: Suggested UAV Fleet Type for CCT's Major Applications

NOTE: From Table 6-2 we can estimate the expected fleet breakdown based on the assumption that all applications have an equivalent demand in terms of UAV operating hours (the validity of this assumption needs to be verified in pilot trials representing fleet operations) but anyway serve to illustrate a first approach to estimating and optimising the fleet structure:

If we assume no hybrid UAVs are adopted in the fleet, we would then expect similar numbers of fixed wing and multi-rotor UAVs i.e. between 9-11 multi-rotors and 13-15 fixed wings depending what we decide on the overlapping applications / UAV types. In the case of our power line inspection study, it would make sense to opt for more fixed wing UAVs that offer much better range enhancement with the integrated fuel cell systems. There is also the benefit of smaller, less expensive fuel cell systems that cost less and further use less fuel consumption in a fixed wing configuration. More specifically a ratio of 9:15 multi-rotors to fixed wing UAVs selected would improve the results of the case study even further. We could improve the results even further by including hybrid UAVs and replacing a further 4 multi-rotors with the hybrid UAVs configuration which show an expected range extension by a factor of 4:1, this is 30% better than the multi-rotor systems.

The average savings from the original business study could then be calculated by applying a range extension benefit equal to the weighted average of all three types of UAVs: For the multi-rotor we can expect 3:1 range increase, for a fixed wing (compressed hydrogen only) a value of 6.5:1 and the hybrid UAV, an expected range extension of 4:1

The fleet would then comprise of:

- 5 multi-rotors
- 15 fixed wing
- 4 hybrid fixed wing

This equates to a value of greater than 500% range extension for group average of range performance extension for the entire fleet, significantly higher than the 300% range extension expected from fuel cell powered multi-rotor UAVs. This figure boosts the productivity and business case considerably if the fleet were to be deployed in similar project scenarios. To support the case even further, we could now justify and estimate a labour penalty of 40% for the battery operated fleet giving us a payback of over R100 000 with a similar project implemented and nearly halving the payback period for the original case study at R400/hour and R300/kg Hydrogen cost variables.

.

	Project: 1000h / 125 days / Additional Labour @40%				
Col = H2 Costs /kg Row = Labour Costs/h	**R200/h**	**R300/h**	**R400/h**	**R500/h**	**R600/h**
R150/kg H2	-35750	-75750	-115750	-155750	-195750
R300/kg H2	-25750	-65750	-105750	-145750	-185750
R600/kg H2	-5750	-45750	-85750	-125750	-165750
R900/kg H2	14250	-25750	-65750	-105750	-145750

Table 6-3: Sensitivity Table for Operating Costs (Fuel Cell versus Battery powered FLEET)

7. CONCLUSIONS

It has been shown the multi-rotor UAVs using fuel cell propulsion can fly up to four times longer and three times further than battery powered UAVs. ICE powered multi-rotors are not commercially available and so the only option to increase flight times with this type of aircraft is using fuel cell technology. For fixed wing and hybrid VTOL UAVs, the range extension and flight times are even greater than that of multi-rotor systems. It has also been shown that using fuel cell technology in fixed wing and hybrid fixed wing UAV types result in even greater range extension as that seeing in multi-rotor fuel cell powered systems up to 650% more than that of battery powered systems in the case of fixed wing configurations. Based on these findings, we can make the following concluding remarks:

Fuel cell based propulsion systems for UAVs show strong potential for reducing operating costs when compared to battery operated UAVs under specific project scenarios and implementation strategies. All types of UAVs powered by fuel cells show potential savings related to operating cost reductions.

Additionally, when creating a grid-like setup of UAVs for the purpose of monitoring and responding within a defined area, the capital expenditure can be massively reduced by using fuel technology powers systems that have a capability to cover an area by a factor of nine time or greater compared to battery powered systems.

The cost reductions can be increased by selecting appropriate UAV types to make up larger fleets intended to service a multitude of applications. Fixed wing and hybrid fixed wing UAVs should be used wherever possible rather than multi-rotor UAVs applications for project requiring repeated runs (launch, fly, and retrieve operational cycles) in order to cover long distances e.g. power line, water pipe and other infrastructure monitoring and inspection services.

Aside from the expected operating cost savings under these scenarios, fuel cell powered UAVs simply offer better solutions in cases where battery powered UAVs cannot be operated due to insufficient flight times or range performance e.g. inspection of infrastructure across inaccessible terrain that exceeds the range of the UAV. This similarly applies to security monitoring scenarios which require the UAV to be airborne for long periods e.g. pursuit and maintaining visuals on fleeing suspects.

8. RECOMMENDATIONS FOR FOLLOW-UP ACTION

Various cost saving opportunities have been analysed and presented in this report with regards to operating UAV fleets to service various activities and applications identified by the CCT. Due to the potential and significant benefits, it is proposed that a demonstrator project could further add valuable insights and contribute with data captured from real life testing and piloting the use of a fuel cell powered UAV. It is therefore proposed that a joint project be initiated and co-funded between the CCT and HySA Systems to be operated and trialled as part of the CCT UAV / RPAS fleet.

It is expected that the future CCT UAV fleet will comprise of several different types of UAVs that are intended to service a multitude of applications. Once the CCT has gained some experience with operating a conventional fleet, the constraints and limitations of the incumbent battery technology will become apparent thus identifying specific applications required for fuel cell technology to overcome these barriers. With some foresight and collaboration, a project demonstrator could be initiated in the early phase of the roll out to ensure timely introduction of future systems. Local UAV development skills and emerging fuel cell technology are currently been developed in the Western Cape – this presents an opportunity to develop a 100% local solution for the pilot project to be demonstrated together with the CCT.

REFERENCES

[1] "The UAV," [Online]. Available: http://www.theuav.com/. [Accessed October 2016].

[2] S. G. Gupta, M. M. Ghonge and D. P. Jawandhiya, "Review of Unmanned Aircraft System (UAS)," *IJARCET,* vol. 2, no. 4, pp. 1646-1657, 2013.

[3] esc Aerospace, "UAV/RPAS Applications," esc Aerospace, 1999. [Online]. Available: http://www.esc-aerospace.com/?page_id=3065. [Accessed October 2016].

[4] Unmanned Aerial Vehicle Systems Association, "Unmanned Aircraft Systems," Buckle Consulting, 2016. [Online]. Available: https://www.uavs.org/uas. [Accessed November 2016].

[5] O. Gonzalez-Espasandin, T. J. Leo and E. Navarro-Arevalo, "Fuel Cells: A Real Option for Unmanned Aerial Vehicles Propulsion," *The Scientific World Journal,* vol. 2014, no. 497642, pp. 1-12, 2014.

[6] South African Civil Aviation Authority, "Remotely Piloted Aircraft Systems," Computek, 2016. [Online]. Available: http://www.caa.co.za/Pages/RPAS/Remotely%20Piloted%20Aircraft%20Systems.aspx. [Accessed October 2016].

[7] R. Austin, Unmanned Aircraft Systems, Wiltshire: John Wiley and Sons Ltd, 2010.

[8] R. Barnhart, S. Hottman, D. Marshall and E. Shappee, Introduction to Unmanned Aircraft Systems, Danvers: CRC Press, 2012.

[9] M. Abid, T. Austin, D. Fox and S. Hussain, "Drones, UAVs and RPAs," Worcester Polytechnic Institute, Massachusetts, 2014.

[10] N. King, "Applications," QUEST UAV, 30 April 2015. [Online]. Available: http://www.questuav.com/news/fixed-wing-versus-rotary-wing-for-uav-mapping-applications. [Accessed October 2016].

[11] PX4, "Fixed Wing Vertical Takeoff and Landing Aircraft (VTOL)," PX4, 2015. [Online]. Available: https://pixhawk.org/platforms/vtol/start. [Accessed November 2016].

[12] Latitude Engineering, “Hybrid Quadrotor Technology,” Latitude Engineering, 2016. [Online]. Available: https://latitudeengineering.com/products/hq/. [Accessed November 2016].

[13] Renewable Energy World, “Hydrogen Energy,” Renewable Energy World, 1999. [Online]. Available: http://www.renewableenergyworld.com/hydrogen/tech.html. [Accessed November 2016].

[14] Fuel Cell Today, “About Fuel Cells,” Johnson Matthey plc, January 2014. [Online]. Available: http://www.fuelcelltoday.com/about-fuel-cells. [Accessed October 2016].

[15] Smithsonian Institution, “Fuel Cell Basics,” Smithsonian Institution, 2008. [Online]. Available: http://americanhistory.si.edu/fuelcells/basics.htm#q2. [Accessed October 2016].

[16] H. Chen, T. Cong, W. Yang, C. Tan, Y. Li and Y. Ding, “Progress in Natural Science,” *Prgress in electrical energy storage system: A critical review,* pp. 291-312, 2 July 2008.

[17] Nedstack R&D, “Fuel Cell Types,” Nedstack, 2016. [Online]. Available: http://www.nedstack.com/technology/fuel-cell-types. [Accessed December 2016].

[18] Georgia Tech Research Institute, “Flying on Hydrogen: Georgia Tech Researchers Use Fuel Cells to Power Unmanned Aerial Vehicles,” Georgia Institute of Technology, 28 August 2006. [Online]. Available: https://gtri.gatech.edu/casestudy/flying-hydrogen. [Accessed November 2016].

[19] J. Krawczyk, A. Mazur, T. Sasin and A. Stoklosa, “Fuel cells as alternative power for unmanned aircraft systems,” *Transactions of the Institute of Aviation,* vol. 4, no. 237, pp. 49-62, 2014.

[20] National Academy of Sciences, Uninhabited Air Vehicles: Enabling Science for Military Systems, Washington DC: National Academy Press, 2000.

[21] City of Cape Town, “Water and Sanitation Department,” City of Cape Town, 2016. [Online]. Available: http://www.capetown.gov.za/Departments/Water%20and%20Sanitation%20Department. [Accessed November 2016].

[22] City of Cape Town, “Electricity Department,” City of Cape Town, 2016. [Online]. Available: http://www.capetown.gov.za/Departments/Electricity%20Department. [Accessed November 2016].

[23] City of Cape Town, “Transport for Cape Town Directorate,” City of Cape Town, 2016. [Online]. Available: http://www.capetown.gov.za/Departments/Transport%20for%20Cape%20Town%20(TCT)%20Directorate. [Accessed November 2016].

[24] Transport for Cape Town, “Departments,” Transport for Cape Town, 2016. [Online]. Available: http://www.tct.gov.za/en/structure/. [Accessed November 2016].

[25] City of Cape Town, “Disaster Risk and Management Centre,” City of Cape Town, 2016. [Online]. Available: http://www.capetown.gov.za/Departments/Disaster%20Risk%20Management%20Centre. [Accessed November 2016].

[26] N. King, “UAV Sensors,” QuestUAV Ltd, 19 June 2015. [Online]. Available: http://www.questuav.com/news/uav-sensors. [Accessed October 2016].

[27] TDWorld.com, “Unmanned Aerial Vehicle Inspects Powerlines,” 10 October 2014. [Online]. Available: http://tdworld.com/projects-progress/unmanned-aerial-vehicle-inspects-powerlines. [Accessed October 2016].

[28] AORPA, “UAV/UAS/RPAS Information,” AORPA, 2013. [Online]. Available: http://www.aorpa.com.au/approvals. [Accessed October 2016].

[29] T-motor, “U8 Pro”, T-motor, 2013. [Online]. Available: http://www.rctigermotor.com/html/2013/Efficiency-Type_1219/176.html. [Accessed May 2017].

[30] HES, “Standard 200W, 500W, 1000W PEM fuel cells system”, HES. [Online]. Available: https://media.wix.com/ugd/047f54_8483372175ef4e1aa43edbe62aaae68e.pdf. [Accessed May 2017].

[31] HES, “Ultra-Light Hydrogen Storage Solutions / Composite Cylinders”, HES. [Online]. Available: https://media.wix.com/ugd/047f54_e193a26906cc49b69056e2059930b850.pdf. [Accessed May 2017].

[32] GoPro, “GoPro Support Hub”, 2015. [Online]. Available: https://community.gopro.com/t5/Cameras/What-is-the-weight-of-the-different-cameras/td-p/2668. [Accessed May 2017].

[33] OscarLiang.com, “Mini quad motor guide”, Oscar Liang, 2016. [Online]. Available: https://oscarliang.com/quadcopter-motor-propeller/. [Accessed May 2017].

[34] DIY Drones, “My 97minute:06second record quadcopter flight”, Ian, 2013. [Online]. Available: http://diydrones.com/profiles/blogs/my-97minute-06second-record-quadcopter-flight. [Accessed May 2017].

[35] EnergyOr, “H2QUAD 400”, EnergyOr, 2017. [Online]. Available: http://www.energyor.com/products/detail/h2quad-400. [Accessed May 2017].

[36] Infrastructurene.ws, “Here’s how much water SA loses through water leaks”, Riante Naidoo, 2017. [Online]. Available: http://www.infrastructurene.ws/2017/03/06/heres-how-much-water-sa-loses-through-water-leaks/#. [Accessed May 2017].

[37] B. Shakmak, A. Al-Habaibeh, “Detection of Water Leakage in Buried Pipes Using Infrared Technology”

[38] Utility Magazine, “Aerial drones: the future of asset inspection”, Utility Magazine, 2015. [Online]. Available: http://www.utilitymagazine.com.au/aerial-drones-the-future-of-asset-inspection/. [Accessed May 2017].

[39] (a) https://www.nrl.navy.mil/lasr/content/hydrogen-fuel-cell-propulsion-long-endurance-small-uavs
(b) http://papers.sae.org/2012-01-2178/

[40] Fuel Cell Works "Russian Powered UAV Sets Flight Time Record"
https://fuelcellsworks.com/news/russian-fuel-cell-powered-uav-sets-flight-time-record

9. APPENDIX A1

9.1. Water and Sanitation Department

The City of Cape Town's Water and Sanitation department provides the residents with clean water as well as treats wastewater. Each year the maintenance team provides about 8500 new water connections and responds to 3200 pipe bursts. Water infrastructures are serviced, which is valued at R58 billion includes [21]:

- 3 major dams (Wemmerhoek, Steenbras Upper and Lower) and 8 smaller dams;
- 12 water treatment works;
- 25 bulk reservoirs;
- 400 pump stations;
- 23 wastewater treatment facilities;
- 3 marine outfalls;
- 38 maintenance depots; and
- 20 000 km of pipes in the water and sewer reticulation network.

9.1.1. Positively Impact Infrastructure (Water & Sanitation):

Examples include improved capability for:

xxv. Patrolling and monitoring of vulnerable sewer routes;

Low altitudes
Monitoring- sensor measuring depth and velocity (flow rate)
Sensors- RGB camera, thermal
Aerial surveying
Vibration-free
Extended times (to monitor)
Key performance requirements:
Total Energy
Maximum power required
Cruise power requirements
Total payload
Other requirements

xxvi. Patrolling and monitoring water and sanitation servitudes in terms of encroachment;

high altitude
large distances
long flight times
LIDAR, thermal sensors
Key performance requirements:
Total Energy
Maximum power required
Cruise power requirements
Total payload
Other requirements

xxvii. Assisting in the identification of smoke exits during smoke machine investigations into detecting sewer/storm water interconnections;

Low altitude
Sensor-LIDAR
Key performance requirements:
Total Energy
Maximum power required
Cruise power requirements
Total payload
Other requirements

xxviii. Mapping of stolen drain covers on sewer routes;

Low altitude
Sensor-thermal
Extended flight times
Key performance requirements:
Total Energy
Maximum power required
Cruise power requirements
Total payload
Other requirements

xxix. Monitoring pipeline routes in remote and difficult areas to access to detect possible leaks

Low altitude
Quiet
Vibration-free
Sensors- thermal
Key performance requirements:
Total Energy
Maximum power required
Cruise power requirements
Total payload
Other requirements

9.2. Electricity

Along with distributing electricity to customers in Cape Town, the Electricity Department also constructs and maintains the equipment that transforms the power supply for the customers' needs. Included in this department is branches of [22]:

- Enterprise Asset management which is responsible for maintenance of service standards,
- Electricity Supply which includes managing of the network operation and supply of energy to the end customer and regulate switching instructions for maintenance crews on planned and unplanned maintenance functions.
- Infrastructure Management which is responsible for all aspects of the wires business that makes up the distribution network of the department.
- Electricity Retail Management which is responsible for customer services.

9.2.1. Positively Impact Infrastructure (Electricity):

Examples include improved capability for:

xxx. Patrolling of cable routes using thermal and optical cameras to determine if people are living there, digging, planting structures such a tents, theft etc;
Thermal/optical cameras,
Sensors
Laser scanner (remote sensing)
Aerial survey
Long distances- extended
Key performance requirements:
Total Energy
Maximum power required
Cruise power requirements
Total payload
Other requirements

xxxi. Viewing of high points such as on metal lattice structures;
Aerial surveying
High altitudes
Large areas
RGB Camera
Key performance requirements:
Total Energy
Maximum power required
Cruise power requirements
Total payload
Other requirements

xxxii. Response to substation premise or asset tag alarm activation (instead of sending response vehicle)
Aerial spotting
Low/high altitudes
Extended flight times possible
RGB Camera
Key performance requirements:
Total Energy
Maximum power required
Cruise power requirements
Total payload
Other requirements

xxxiii. Conduct HV underground cable route and HV overhead line patrols to detect illegal/unauthorised activities;
Aerial surveying
Low altitude
Quiet/vibration-free
Thermal sensor
Key performance requirements:
Total Energy
Maximum power required
Cruise power requirements
Total payload
Other requirements

xxxiv. Conduct HV OH line inspections;

Low altitude
Infrared camera
Vibration-free
Extended flight times
Key performance requirements:
Total Energy
Maximum power required
Cruise power requirements
Total payload
Other requirements

xxxv. Detection of HV OH line servitude and cable installation encroachment

High altitude
Vibration-free
Sensor- infrared
Key performance requirements:
Total Energy
Maximum power required
Cruise power requirements
Total payload
Other requirements

9.3. Transport

The Transport for Cape Town (TCT) directorate is responsible for planning, costing, contracting, regulating, monitoring, evaluating, communicating, managing, and maintaining the City's transport infrastructure, systems, operations, facilities, and network [23]. Included in this is 9 functional departments which are [24]:

- Performance and Coordination: coordinates, monitors and manages TCT'S operational mandate.
- Planning: Ensures long term planning and policy development.
- Contract Operations: Responsible for operational management of contracts.
- Financial Management: Includes management of the budget, revenue management and generation and management of grants.
- Infrastructure: includes design and construction of new public transport infrastructure as well as design, construction, project management and upgrading of road and storm water infrastructure and sea walls, as well as the rehabilitation and upgrading of concrete roads.
- Asset Management and Maintenance: Rehabilitation of all 10 000kms of the City's roads, storm water, pavements and non-motorised transport infrastructure.
- Network Management: Includes public transport law enforcement, traffic signalling and variable messaging signs.
- Regulations: Consolidation of regulatory functions and includes industry transition and transformation.

9.3.1. Positively Impact Transport:

Examples include improved capability for:

xxxvi. Creation of geo-referenced images and mosaics and mapping in 3D. Capture of point clouds of proposed routes and construction progress of development of the IRT;

High altitude
LIDAR, multispectral imaging
Global Navigation Satellite Systems
Key performance requirements:
Total Energy
Maximum power required
Cruise power requirements
Total payload
Other requirements

xxxvii. Wastewater outfall monitoring;

3 marine outfalls; 23 wastewater treatment facilities;

Aerial spotting
High altitude
Thermal sensing
Key performance requirements:
Total Energy
Maximum power required
Cruise power requirements
Total payload
Other requirements

xxxviii. River mouth estuary sandbar analysis;

High altitude
Extended flight times
Sensor-LIDAR, hyperspectral

xxxix. Origin / Destination surveys of private or public transport vehicles;

High altitude
Extended flight times
Noise-free
Sensor- RGB Camera

xl. Queue length surveys and congestion analysis;

High altitude
Extended flight times
Quiet
Sensor- thermal imaging

xli. Turning movement surveys at intersections and traffic impact assessment;

High altitude
Sensors-RGB Camera
Extended times

xlii. Boarding and alighting surveys at BRT and rail Stations and public transport stops;
Low altitude
Noise free
Vibration-free
Sensors- RGB Camera

xliii. Public Transport Interchange operations surveys;
High altitude
RGB Camera

xliv. Pedestrian surveys including pedestrian crossings and desire lines;
Low altitude
Noise-free
Sensor- RGB Camera

xlv. General x,y,z (3D) topographical surveys – pipe routes, overland flow paths, beach profiles, erosion, river meandering etc (some LiDAR systems have limited water penetration capabilities)

High altitudes
Sensors- LIDAR, hyperspectral imaging, thermal
Global Navigation Satellite Systems

9.4. Disaster risk management

The aim of the Disaster Risk Management Centre (DRMC) is to identify, prevent or reduce the occurrence of disasters and to soften the impact of those hazards that cannot be prevented. The DRMC also facilitates the coordination, integration and efficiency of multiple emergency services and other essential services to ensure that these organisations work together, both pro-actively through risk reduction, planning and preparedness; and re-actively through response, relief, recovery and rehabilitation [25].

9.4.1. Disaster Risk Management:

Examples include improved capability for:

xlvi. Data gathering for disaster mitigation
Low altitudes
Extended flight times
Large distances possible
Noise-free
Vibration-free
Sensors-thermal, infrared

xlvii. Damage assessments;
Low altitude

Extended flight times
Large areas
Sensors-thermal, RGB Cameras, infrared

xlviii. Data gathering for reconstruction and rehabilitation projects
High altitude
Vibration free
Sensors-thermal, LIDAR