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Supervised Project Report
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A feasibility assessment of emergent technology for use in Antarctica.

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Abstract/executive summary (ca. 200 words):

Both the Antarctic Treaty 1959, and Madrid Protocol 1991, set as one of their leading principles "The protection of the environment". As such operations in Antarctica, and the operators behind them, should constantly be seeking more efficient and renewable ways of achieving processes. COMNAP recently undertook the ARC project which sought out to find challenges in regards to future scientific endeavours. This project will look at these challenges, and highlight potential emergent technology that may help to confront these challenges, as well as better achieve the purpose of environmental protection, under the Antarctic Treaty.

Aim:

The aim of this report is to acknowledge those technologies, which show promise in future implementation in Antarctica. By using the Antarctic Roadmap Challenges (ARC) project, led by COMNAP (Council of Managers of National Antarctic Programs) as a guideline for what technologies are needed most, this report seeks to expand on how emergent technology may help to lessen both the carbon footprint and logistical feat, that scientific endeavour in Antarctica currently requires.

Introduction:

The Antarctic Treaty 1959, and Madrid Protocol 1991 both, as one of their fundamental principles, seek out to inhibit (to the greatest degree), the amount of environmental degradation that Antarctica is subjected to by an anthropogenic presence. For example Article 3 “Environmental Principles” Section 1, states, in part, “The protection of the Antarctic environment and dependent and associated ecosystems and the intrinsic value of Antarctica, including its wilderness and aesthetic values….shall be fundamental considerations in the planning and conduct of all activities in the Antarctic Treaty area” (Madrid Protocol, 1991).

Unfortunately, it is unlikely that Antarctica will ever again be isolated from human occupation, at least not in the imminent future. Therefore in order to act in accordance with the guiding principles set by these international agreements, an ever fluctuating balance must be sought out between scientific engagement and reducing environmental impact. As such, emerging technologies should have their feasibility assessed for integration into Antarctic endeavours.

The Antarctic Roadmap Challenges (ARC) project, led by COMNAP (Council of Managers of National Antarctic Programs) surveyed a wide community of Antarctic entities to identify ‘high priority’ research questions. This was undertaken so that a clear ‘roadmap’ towards future scientific investigation could be established, as well as the challenges that are inhibiting this science from being practicable. In collaborating with SCAR (Scientific Committee on Antarctic Research) Horizon Scan, COMNAP recognised seven major challenges related to the established roadmap, of which COMNAP focussed on three. Challenge 1: Technology, Challenge 2: Extraordinary logistics requirements (Access) and Challenge 3: Infrastructure (COMNAP, 2016).

The focus of this report will be Challenge 1: Technology. More specifically it will look at energy storage and production, as well as Unmanned Aerial Vehicles (UAV’s). The other two challenges outlined by COMNAP will not be the focus of this report, though the technology outlined in this report will affect each of these challenges in multiple ways, which will be addressed.

Energy:

Background:

Energy, both storage and production, is a key issue in Antarctica. There has been a continual shift to try and make energy production as efficient, and environmentally-friendly as possible, from a number of claimant states. For example, in the 1960s-1970s, McMurdo Station was powered by a medium sized, portable, nuclear reactor. This was installed as a way of reducing large quantities of fuel oil needed to maintain operations, thereby reducing the use of fossil fuels.

During its 10 year lifespan, the nuclear power plant station produced over 78 million kilowatt hours of electricity, whilst also generating 13 million gallons of fresh water by utilising the excess steam in a desalination plant. Though the power plant heavily reduced the fuel needed for operations, it was riddled with logistical problems (e.g. the need for specialist operators), as well as environmental effects (high levels of Tritium in drinking water and radiation exposure), ultimately leading to its decommission in 1972 (Reid, T. 2014). Since this costly experiment, McMurdo (and Scott's Base) have ran on diesel-electric generators (as well as being supplemented by the Ross Island Wind Energy (RIWE) grid.

Currently Scott's Base uses an estimated annual 200,000 litres of AN8 (kerosene based fuel) for use in both vehicles and the boilers which heat the base. There are three main generators within Scott's Base which are fuelled by AN8, these generators contribute to the RIWE grid shared between Antarctica New Zealand and USAP (which is certified under the Certified Emission Measurement and Reduction Scheme (CEMARS), installed to monitor and control fuel consumption at Scott's Base). (Antarctica NZ, 2018).

Another example of renewable energy being tapped into in the Antarctic is Rothera (UK'S largest research base). Rothera has fitted 36 solar panels, providing 15kW of energy (saving 1000 litres of fuel annually), whilst also implanting a "switch-off" mentality within the base to decrease electrical usage (British Antarctic Survey, 2015).

Though, as outlined above, the gradual shift from fossil fuels to renewable source (wind and solar), has been occurring at permanent bases within the Antarctic. Field camps still rely on portable generators (AN8), in order to produce heat and energy out in the field. This creates a unique area for improvement in energy production, and storage, for small-scale operations.

A large amount of energy, in terms of field work in the Antarctic, is also needed for transportation (solely fossil fuels), and for cooking (LPG). Most research gear is powered through battery technology, which is inefficient but could potentially be improved by emergent battery technology (Wagner, M. 2010).

Emergent technologies

Integrated renewable systems & Micro Smart Grid:

Though perhaps not emergent technology, the integration of renewable technology seen at the Princess Elisabeth Antarctic station (Belgium) is the leading example of energy production in Antarctica and the first of its kind. With a “zero-emission” status, Princess Elizabeth station utilises nine wind turbines, both photovoltaic and thermal solar panels, battery rooms (lead-acid) and two back-up generators. Future changes include the addition of hydrogen fuel cells as an additional intermediary back-up. Though the integrated, renewable system, is already impressive, it is the emergent technology of an integrated, renewable “Micro Smart Grid” which allows it to achieve its “zero emission” status and is a technology network that should be implemented by all bases guided by the Madrid Protocol guidelines (International Polar Foundation, 2018)

The integrated micro smart grid is a system based on energy prioritization. The system manages energy demand by monitoring available resources (as renewable sources are not constant), prioritizing demand and then allocating energy to end users. Excess energy is stored in the lead acid batteries, for times of low energy production. Whilst all the technology applied at the Princess Elizabeth Station have been present for some time, they had never been integrated into a standalone network. The micro smart grid, managed by a “programmable logic controller”, reaches an installed energy ten times greater than that of the energy production, making the stations micro smart grid three times more efficient than any existing network. Furthermore, as the based is remote controlled, resulting from the integrated satellite ground system, the station is permanently linked to Belgium. This allows scientists to send scientific data worldwide in real time. Beyond this scientific advantage, this real time uplink allows the base to be controlled remotely, ensuring the micro smart grids ultimate efficiency (International Polar Foundation, 2018).

Micro smart grids increase reliability, reduces cost (as a local network), has the potential to generate revenue (through excess energy storage) and most importantly significantly reduce emissions, if powered by renewable means (GEI, 2017). Though micro smart grids fall under the technology challenge outlined by COMNAP, they are also relevant to, and should be integrated into Challenge 3: infrastructure, as this technology relies on a specifically designed base structure in order to effectively operate.

Limitations:

- Though integrated renewable systems coupled with micro smart grids, will reduce cost in the long run. It requires a large-scale redevelopment of any existent, non-compatible, station. This would require a large initial cost that would likely require outside entities to invest.

- The larger the station, the more operational cost and necessary energy storage. Energy storage currently relies on lead-acid battery rooms which are themselves problematic.

- Energy storage devices. As diesel and renewable are intermittent means for electricity production (except for Princess Elizabeth), fluctuations from unstable micro-sources and non-linear loads will execute considerable impacts on normal operations of micro grids. (This is where battery technology provides a solution).

- Other issues identified include: power imbalances', stability issues, inverter capabilities, protection issues.

Feasibility:

The use of integrated renewable energy sources, coupled with a micro smart grid, has already been achieved by the Belgian base, Princess Elizabeth. This technology is much easier to implement if it is modelled for in the design phase. Though there is an ability to implement these systems to current base networks, it is much more costly. Therefore, the real feasibility of these systems lies within incorporating them into the proposal phase for future established Antarctic bases.

Solar power:

Not only can large solar power technology help to power permanent bases, but adapted small-scale solar technology can be implemented to achieve renewably sourced energy out in the field. Though the technology is by no means new, emerging adaptions have made it both smaller-scale and more efficient (as well as cost effective).

For example, a solar photovoltaic (PV) power system was designed, built and installed at a remote field camp at Lake Hoare in the Dry Valleys. This provided a six-person field team with electrical power for computers, printers, lab equipment, lighting and a small microwave (NASA, 1993). This case study shows that solar panels effectively work at small-scales in the Antarctic environment.

Though the above case study is not a new technology, it illustrates the role of solar sourced power as a renewable alternative. The emerging technology that may help to replace crystalline silicon photovoltaic systems (crystalline silicon PV make up 90% of global PV solar cells) is that of the Perovskite solar cell (PSC's). Perovskite includes a perovskite structured compound, most commonly Tin halide-based material, as the light harvesting layer. The materials needed to produce this layer are both cheaper and simpler to manufacture than the more utilised silicon photovoltaic versions. Solar cell efficiencies of devices using this material have increased from 3.8% in 2009 to 22.7% in 2017, showing incredibly promising results for this technology. With an even greater potential for higher efficiency and lower cost, PSC's have become a promising alternative to silicon photovoltaic cells (Ossila, 2018).

The major concern with PSC's comes from their potential instability due to environmental conditions. The major concern for PSC's comes from moisture, as the organic component of the absorber material makes the device vulnerable in humid climate. In Antarctica, this issue may not be a problem due to the dry climate, though the cold temperature may produce new problems. The other issue is that of toxicity as an environmental and health risk, stemming from Lead being the alternative 'light-harvesting' compound. These toxicity risks can largely be reduced by using the tin halide-based material, though it must be noted that small amounts of toxic materials are still present in this formation, as they are with the currently deployed silicon PV solar cells (Manser, J. S. 2016).

Solar power will largely reduce the environmental footprint caused by fossil fuels, down in Antarctica, in accordance with the Madrid Protocol. Solar energy are perhaps the most important technologies under development, helping confront each of the challenges set by COMNAP in their ARC project. As it is projected to aid in both future technology and infrastructure, as well by supplementing logistical needs (e.g. auxiliary energy on traverses)

Limitations:

- Potential stability issues via environmental degradation.
- Currently the technology is yielding ambiguous efficiency values from current-voltage scans. With the origins of this hysteretic behaviour is presently unknown.
- Winter months inhibited insolation.
- (Low) Potential for toxic material to impact on environment and health.

Feasibility:

The PSC has the potential to improve small and large scale solar capabilities down in the Antarctic. The technology is both more efficient, cheaper and simpler to produce, making it more economically viable and less environmentally impacting (as long as the Tin halide-based material, is not swapped for its Lead counterpart). The major concern of this type of technology is that it is relatively untested, and therefore could be unreliable (Zhang, J. 2017). In order for this emerging technology to be a feasible replacement to the current silicon based solar cells, more testing would need to be implemented, especially in regards to its ambiguous efficiency values, but also in respect to its stability against environmental degradation (specifically in the Antarctic climate).

Battery Technology:

Battery technology not only has the ability to improve the renewable status of permanent bases through energy storage (as seen with the lead-acid battery rooms aforementioned). They can also contribute to scientific engagement, through improving the service life of field instruments (such as monitoring devices) and communication devices (such as the two-way receivers taken into the field).

Currently the most effective batteries are that which can be recharged (to minimise waste), with the most commonly used battery being the Lithium-Ion battery (LIB). LIB is the most popular type of rechargeable battery for portable electronics, due to its high energy density and low self-discharge. LIB batteries do suffer from some design flaws, for instance these batteries contain a flammable electrolyte, this electrolyte can combust if the battery cell isn't charged in the proper manner. As a result, LIB requires a greater range of test conditions, as well as additional 'battery specific' tests (Battery University, 2018).

Recent publications have highlighted the need for materials which are strategic, and have the potential of becoming scarce, to be recycled. Lithium falls into this category; yet currently very little Lithium is being re-used. It is forecasted that there will be a shortage of Lithium, because of demand for electric vehicles (and other products), by 2021-23 (Sonoc, A. 2014).

As such, other emergent battery technology should be looked at, to safeguard against the potential lack of supply. One promising alternative, is that of Sodium-ion batteries (SIB). Though sodium-ion batteries have been around for quite some time, it is emerging adaptations that have seen this battery become very dynamic and high performing. These adaptations include the study of new cathodes and anodes which have shown promise in faster operating rates, and greater sustainability (e.g. if organic materials are used). There has also been interest in the use of oxygen (O_2) as a high-energy density, high voltage cathode. Though this research is still awhile off commercialization, they are worth looking into as future alternatives to LIB (Nayak, P. K. 2017). Perhaps the greatest asset the SIB has is that sodium is an extremely abundant element (costing 80% less than its LIB alternative), making it far more economical ($150 per tonne for Sodium and $15,000 per tonne for Lithium) and posing no problem regarding scarcity (Slav, I. 2017).

Although Sodium-ion batteries will unlikely surpass the performance of LIB, continual research has brought it closer in terms of performance and light weight. SIB is also far more abundant, more economic and safer (with no volatile electrolyte). Making SIB a promising future alternative in the wake of potentially scarce LIB (Nayak, P. K. 2017).

Limitations:

- Negative electrode choices are limited, as graphite only stores sodium under special conditions and silicon seems to be largely inactive (though development is showing promising breakthroughs).
- Not as powerful as Lithium Ion.
- Switching lithium to sodium in electrochemical cells can create unexpected reactions.
- Weight problems (though this is being further and further reduced).

Feasibility:

Though Sodium ion batteries are not yet as powerful as their commonly used Lithium ion alternative, they are the best alternative due to their similar chemical makeup and large abundance (no supply constraints). They are also far cheaper and, as such, less environmentally impacting (especially when compounded with organic material). Though in terms of feasibility, it is unlikely that SIB will be implemented over LIB, as long as it underperforms in both charging and performance (as it currently does).

Unmanned Aerial Vehicles (UAV):

Background:

As Unmanned Aerial Vehicles (UAV) technology becomes both more sophisticated and economic, it is likely that applications will continue to be found for, and replaced by, UAV's. This has the potential to mark a paradigm shift in terms of how science is undertaken not only Antarctica, but across the world. The use of UAV's also has the potential to aid in the undertaking of the ARC project, in a diverse range of ways.

Currently UAV vehicles are being utilised between two main groups, the first is by groups of tourists on large tourism vessels, and the second is by groups of scientists conducting research. The specific UAV being piloted can have a diverse range of characteristics in terms of size, sophistication and make-up (as well as either being rotary or fixed-wing configuration as shown in Figure 1). Considering the technologies relatively new emergence, there is still little knowledge on the environmental implications of the use of these drones, especially in the Antarctic environment.

One such impact that has been alluded to is the potential for drones to mimic the behaviour of the Skua bird (a predator which stalks penguin nests), and how this may affect the level of stress in penguin colonies (the research of which has already begun) (Weimerskirch, H. 2018). There is also the clear risk of aerial collisions with bird species, as well as the potential impact of UAV's being lost to the environment.

Regarding scientific investigation, UAV's have a respectable history of use in Antarctica. In 2007, the British Antarctic Survey (BAS) conducted the first over-flight by UAV in Antarctica. The Japanese Antarctic Programme undertook long distance meteorological monitoring by UAV in 2008. The Norwegian-U.S traverse of East Antarctica (2009) used UAV's for ice thickness measurements, aerial imagery and weather data. Multiple Universities have utilised UAV's in the Antarctic to collect data in a more efficient way (Brears, R. 2011).

In terms of legislation, due to its recent emergence, there is very little in terms of regulation. This could pose a significant problem for future control of the technology. COMNAP's Unmanned Aerial Systems (UAS) working group prepared a handbook designed at mitigating and managing UAV risks. This include, communication plans, risk management, operating parameters as well as record taking (COMNAP. 2016). Though Antarctica's governance is not as clear cut as it is in individual countries, for instance each territory may have more or less restrictive regulations on UAV use. An example of this is McMurdo and New Zealand. Currently McMurdo has a much more restrictive approach than that of New Zealand, due to the close proximity of the two stations, this indistinct guideline could lead to problematic situations (Turner, J. 2016).

It is clear that this technology will need to be carefully managed, as potential impacts could be significant. On the other hand, this technology has an incredibly positive outlook in helping meet the challenges set by COMNAP, as well as having the potential to aid in a range of endeavours.

Emergent technology:

Though UAV's are an emergent technology themselves, the following section will look at the future potential uses for this technology (as well as looking at its Unmanned Marine Vehicles (UMV's)).

Photo-imagery:

The practical use for UAV (and UMV) for GIS related work, such as photogrammetry and 3-D modelling will be fundamental for future environmental surveying. The autonomous nature of these devices means that these devices can be deployed in areas, which may be inaccessible to human presence, as well as being able to survey for prolonged periods of time (confronting COMNAP's challenge 2). These devices have already been used for surveying agricultural land, in addition to archaeological sites, and has shown promise in Antarctica as well. 3-D imaging Antarctica would hugely help with risk mitigation in terms of crevasse detection, as well as their use in ecological surveys (both marine and terrestrial). UAV (UMV) have a great advantage, in that they are able to produce high temporal and spatial resolution images and allow for rapid response in where immediate access to 3D geo-information is crucial (Remondino, F. 2011).

Communication:

Given the remote nature of Antarctica, it is not surprising that communication is both scarce and basic. This can promote risks, especially for those out in the field. A potential solution to this limited range communication could be the use of UAV as a mobile network. By equipping UAV's with a communication network, and incorporating what known as a 'cooperative path' plan (as communication strength is relative to the distance between each device), the UAV's can be used as 'way points' a long which communication could seamlessly run, even to remote locations (Beard, R. W. 2004).

The only constraint on this is battery constraints, though technology is constantly improving this. In 2015, the AtlantikSolar 2 (a solar powered fixed-wing UAV) flew for 81.5 hours. If these devices (equipped with a communication network) were multiplied and organised on a cooperative pathway which optimised coverage, it would allow uninhibited communication across remote areas, such as Antarctica. This same UAV was tested in the Arctic and flew for 5 hours, returning fully charged, which is promising for use in Antarctica (on its flight the UAV also mapped a crevasse which a few days later calved a portion off a glacier, consolidating the UAV's future use in environmental monitoring) (Atlantiksolar. (2013).

Logistics:

UAV use in terms of logistics is another promising future, due to no fuel requirements. UAV's are far less expensive and environmentally impacting then a helicopter, and are uninhibited by challenging topography that would constrain land vehicles (e.g. Hagglunds). As one of COMNAP's main challenges (2) is 'extraordinary logistical requirements', this technology could help to confront this challenge. Already commercial UAV are being utilised in aerial deliveries, either by an intelligent network (completely autonomous), or by pilot. There are obvious limitations in regards to air space and other regulations. Though Antarctica poses a unique opportunity, as away from the main air strips, there is very little airspace in use (though operations would still have to be communicated to minimise risk). The use of UAV would make equipment logistics to field camps far more economical and, as well as reduce emissions (DHL, 2014).

Unmanned Marine Vehicles:

Unlike UAV's, UMV's are more restricted in their applications, though they do have the ability to study areas of the marine of the environment that have been previously inaccessible (e.g. underneath ice shelfs). The National Science Foundation (NSF) successfully tested a UMV in the Antarctic, producing high-resolution, 3D maps of the Antarctic sea-ice (at depths of 20 to 30 metres). This technology could be used not only for mapping the marine environment, as well as ecological surveys, but it could also be coupled with sensors in order to measure sea ice/ice shelf thickness. In the future, greater depth extents could see further, previously unstudied regions monitored. The potential for oceanographic measurements is also apparent (e.g. tidal data, ocean circulation) (Rees, C. 2014).

The use of these devices is the Antarctic environment is also being used as an indicator for materials and functions that will be needed for the exploration of Jupiter's moon, Europa. The Icefin autonomous vehicle has been used in Antarctica, this project has provided a roadmap for maximising scientific data collection, with low-risk, low-logistical impact needed for polar (and inter-planetary) science (Spears, A. 2016).

Limitations:

- You will always need people to interpret data 'on the ground'.
- UAV's require specialised pilots (at least at present).
- Environmental impact from lost UAV's could be substantial.
- UAV's mimicking predators could cause changes in animal behaviours, impacting on Antarctica's ecology.
- Troublesome regulatory framework.
- Privacy and security concerns.
- Battery constraints

Feasibility:

UAV's and UMV's, come in a range of configurations, some of which are suitable for use in the Antarctic. These autonomous vehicles will play a critical role in future operations in Antarctica, as well as confronting both challenge 1 and 2 outlined by COMNAP. Though they will require adaptations which optimise their efficiency in the Antarctic climate, whilst minimising risk. Currently regulation is the biggest setback to the use of autonomous vehicle in Antarctica, due to the complicated politics of the region. These regulations will likely be adapted as future advantages and limitations become apparent.

Conclusion:

In summary, emerging technologies have the ability to help confront the challenges underlined by COMNAP in their ARC project. The problem with emergent technologies is that they need to go through rigorous testing, especially in the Antarctic environment before they can be deployed. The emerging technologies outlined in this report all show promising potential for future use in the Antarctic context (especially UAV), and therefore should be further researched for application integration.

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Appendices:

(Figure 1: UAV configurations).

	Advantage	Disadvantage	Visual
Fixed-Wing	• Long range • Endurance	• Horizontal take-off, requiring substantial space (or support, e.g., catapult) • Inferior maneuverability compared to VTOL (Vertical Take-Off and Landing)	 Source: Indra Company
Tilt-Wing	• Combination of fixed-wing and VTOL advantages	• Technologically complex • Expensive	 Source: sUAS News
Unmanned Helicopter	• VTOL • Maneuverability • High payloads possible	• Expensive • Comparably high maintenance requirements	 Source: Swiss UAV
Multicopter	• Inexpensive • Easy to launch • Low weight	• Limited payloads • Susceptible to wind due to low weight	 Source: Microdrones