PCAS 18 (2015/16)

Critical Literature Review (ANTA602)

Reducing New Zealand's Antarctic Carbon-Based Fuel Usage

Peter Morten

Student ID: 33301306

Word count: 2944 (main body of text)

Abstract

New Zealand's Scott Base and the USA's McMurdo stations share their logistical operations, with Christchurch as the gateway city. Fuel and other supplies arrive in the late summer by ship. People and supplies are delivered throughout the year by air, mainly in spring, when large wheeled aircraft can land. Liquid transport fuel, heating needs and electricity generation are mainly supplied by AN8 aircraft diesel fuel. This is expensive, produces carbon dioxide when burned and has environmental consequences if spilled.

Considerable progress has been made at Scott Base in terms of fuel efficiency, heat conservation and renewable electricity generation from wind. However, more can be done. This review considers possibilities described in the literature and on the web with respect to:

1. Liquid transport fuel savings, especially for flying to and from Christchurch. Replacing New Zealand's fifty year old Hercules C-130H turboprops with modern technology offers the greatest step forward. An extended aircraft range could wholly or partially avoid the need to refuel in Antarctica, with significant safety benefits as a bonus.
2. More wind-powered electricity generation. This would benefit McMurdo more than Scott Base. It would be a valuable contribution overall to the joint logistical pool.
3. The use of small-scale geothermal energy for heat pumps, if this is cost-effective.
4. Further passive energy saving measures at Scott Base, together with improvements in the efficiency with which diesel fuel is converted into useful heat and power there.
5. The use of solar energy at the base and in the field. This is relatively minor, as solar energy cannot be used for base-load needs, but the technology is advancing quickly.

Small 'demonstration' investments, as a test-bed for new technologies, may also have merit.

Although there are zero carbon dioxide emission summer-only stations elsewhere in Antarctica, this is not feasible for the year-round Scott Base and McMurdo stations. The best that can realistically be achieved is to improve fuel and other efficiencies, and to use renewable energy substitutes which are cost-effective, environmentally acceptable, robust and reliable in the harsh Antarctic conditions.

Reducing New Zealand’s Antarctic Carbon-Based Fuel Usage

Introduction

Much of the liquid transport fuel, heat, and power generation used in New Zealand’s Antarctic operations consist of or are produced from imported diesel fuel. Antarctica New Zealand has focussed pragmatically on energy efficiency and conservation improvements, and on reducing the risk of fuel spills. Wind generation is now part of the mix. However, diesel consumption remains high. This has consequences not just in terms of cost but with respect to New Zealand’s reputation for environmental responsibility, in a world that is increasingly focussing on the links between CO_2 emissions, climate change and Antarctica.

This review considers the progress made to date and considers possibilities discussed in the literature and on the web for reducing New Zealand’s carbon-based fuel use in Antarctica.

The Current Position

Scott Base shares many operations with neighbouring McMurdo Station, which is about ten times bigger. New Zealand’s Antarctic energy decisions are closely linked with the USA’s:

- Fuel in the USA’s and New Zealand’s operations has become largely standardised on AN8 aviation diesel for supply aircraft, helicopters, small planes, diesel-powered electricity generators, most land vehicles and general energy needs at the stations. The residual amount of mogas (petrol) and kerosene is under 1% of the total.
- Diesel fuel is delivered to McMurdo once yearly by sea, using an icebreaker and tanker, with the fuel pumped into large storage tanks at McMurdo. Some of this fuel is driven by vehicle from McMurdo to small storage tanks at Scott Base as needed.
- 21-25 million litres of diesel are delivered annually to McMurdo by tanker (Harris, 2001, ch 3.11). The annual consumption at both stations in 2009 was about 5 million litres (Meridian, 2012). Scott Base’s share of this was about 0.42 million litres (6%). On average, it now uses about 880 litres a day of fuel in summer, when up to 85 people may be resident, and 1,100 litres a day in winter, when 11 people are resident but considerably more heating is needed (Antarctica New Zealand website, 2015).
- About 4 million litres is used to supply and run the US South Pole station (Harris, 2001). The remaining 11-16 million litres, over half of the total, is used to refuel flights back to Christchurch and for land and air transport in Antarctica. Transport is thus far and away the main consumer of fuel, even before considering the quantities loaded outside Antarctica and used by the aircraft and ships servicing the bases. [1]

Scott Base needs heating. It requires a reliable source of electricity. Further energy is used for cooking, running equipment, desalinating water and for managing rubbish and sewage.

Some significant gains in fuel efficiency and handling have been made since the 1950s:

- Heavy fuel oil is no longer used. It proved environmentally unacceptable.
- Scott Base was rebuilt in 1976-77 and re-modernised from 2005-07. State-of-the-art investment in energy conservation in new and older buildings there has dramatically reduced the rate at which heat escapes. For example, most buildings are now connected by corridors, which considerably reduces the need for people to open outside doors; and windows are now routinely quadruple glazed (Brady, 2013).

[1] There is no public domain information available on how much fuel loaded outside Antarctica is used by US and New Zealand aircraft flying there or by the US vessels that resupply McMurdo towards the end of each summer.

- Waste heat from the diesel generators at Scott Base is used to heat water and to desalinate seawater. The overall conversion efficiency is estimated to be 70%, roughly double that for efficient thermal generation of electricity alone (Mason, 2006).
- Food scraps, paper and untreated timber are incinerated. Other rubbish is not, to help minimise pollution. Sewage management has been modernised (Brady, 2013).
- Some scientific and other equipment has become more energy efficient, e.g. by substituting LED light bulbs for incandescent bulbs (Mason, 2006).
- Fuel barrels have almost been eliminated, reducing the potential for spills.

Two major changes have been tried for switching to other energy sources:

1. In 1962, a 1.2 megawatt nuclear-powered electricity generator was installed at McMurdo. After 438 malfunctions including a leak of radioactive liquid, this was removed in 1973, together with 70 tonnes of contaminated soil (Foster et al, 1978). Attitudes against nuclear power have hardened since then and it seems unlikely that nuclear power will be seriously considered again for Antarctica, within the foreseeable future. No Antarctic research station uses it currently.
2. Meridian, a New Zealand-based electricity generation company, installed three wind generators on Crater Hill, between McMurdo and Scott Base, in 2010. This is the world's southernmost wind farm. Its design capacity is just under 1 megawatt, and when operating at full capacity, it more than satisfies Scott Base's electricity needs. Meridian's investment was made after considerable investigation of the winds available at various sites and of the need for a robust, low maintenance system that could survive cyclones and very harsh winters. It has operated to date with over 99% availability (when winds of the appropriate speeds are blowing) and at over 100% of design capacity. It is estimated to have reduced the quantity of fuel burned in Scott Base and McMurdo combined by about 11% p.a., i.e. excluding aircraft usage (Meridian, 2012). The surplus power is sent to McMurdo.

On the other hand, over the years, the number of buildings and people at Scott Base has grown steadily. This has tended to increase the amount of energy needed. For example, Scott Base still has 0.6 megawatts of diesel generating capacity installed in three generators, at least one of which is always on (Antarctica New Zealand). By comparison, its electricity generation capacity in 1957 was just 0.04 megawatts (Harrowfield, 1997).

Potential Sources of Further Savings

As is discussed below, carbon-based fuels will remain the main energy source in New Zealand's Antarctic operations for the foreseeable future. The goal is to reduce their use, not eliminate them. Broadly speaking, the options for New Zealand to achieve further reductions, using technology that exists already, in rough order of magnitude, are:

1. Liquid transport fuel savings, especially for flying to and from Christchurch.
2. More wind generation.
3. The use of small-scale geothermal energy for heat pumps.
4. Further passive energy saving measures at Scott Base, together with improvements in diesel fuel conversion efficiency into useful heat and power.
5. The use of solar energy at the base and in the field.

Not all of these may yet be fully technically feasible and/or cost competitive. However, it is worth noting that there are image benefits for New Zealand in demonstrating its attempts to implement renewable energy and conservation alternatives to carbon-based fuels in the pristine but undoubtedly challenging Antarctic environment, even at a cost premium.

It should also be noted in passing that some energy sources that are widely used in other cold places are not feasible in Antarctica; e.g. in Scandinavia, the main renewable energy source is biomass, mainly consisting of forestry waste (Morten, 2007). Antarctica has almost none. Neither is there any useable running water available for hydroelectric generation.

Liquid Transport Fuels (Peat, 2007)

McMurdo is only accessible by sea in late summer. There is no option but to use cargo planes extensively to transport people and supplies to the ice. Aircraft AN8 diesel dominates. There is no viable substitute for liquid fuels in aircraft. Another issue is that, for AN8 to be usable at -50°C, it needs various additives, some of which are serious pollutants if spilled.

New Zealand's primary cargo and personnel transport is the Lockheed C-130H Hercules.

- New Zealand's C-130H turboprop models were made in 1965. Modern aircraft use lighter construction materials and have a more efficient body design. For example, 4% of fuel can be saved simply by adding upturned wingtips (Airbus website).
- Jet and turboprop engines have improved substantially in fuel efficiency since the 1950s, mostly since the price of oil rose sharply in the 1970s. There have been upgrades to the RNZAF's fleet of five, but not recently. The RNZAF's website states, "*The aircraft have undergone a modernisation and structural improvement programme to ensure that they last until 2015."* They are thus due for replacement.
- The C-130H, fully laden, flies below 7,000 m, where it faces far more air friction, and hence has higher fuel consumption, than modern transports do at 10,000 m.
- It flies slowly, taking eight hours for a flight that most jet cargo planes can do in five.
- It cannot carry enough fuel to make a return flight without refuelling. The 'point of no return' is 3 to 4 hours from Scott Base. Once this is passed, there is a substantial safety risk if landing visibility is unexpectedly compromised, as was demonstrated in a 2013 flight carrying the Minister of Foreign Affairs. [2] The human life and environmental value of eliminating this risk is hard to calculate but must be large.

On the other hand, a ski-equipped Hercules can land on soft ice, unlike larger transport planes. There is still an ongoing need for such flights over the height of summer, and there are currently very few other types of cargo plane that can do this.

There would appear to be two main avenues for improvement:

1. A runway at McMurdo on which wheeled planes can land in mid-summer may become feasible. This would enable the use of a modern cargo plane such as the Airbus 319CJ, which Australia and Italy use. The A319's 'point of no return' is about an hour from McMurdo, which is much safer and means that only a partial refuel at McMurdo is needed. It flies at 12,000 m and can make the flight in five hours, and the new 'A319neo' is 20% more fuel-efficient than older versions (Airbus website).
2. The eight propeller C-130J Hercules has been in production since 1996. Over 330 have been bought. It has 40% greater range, 21% higher maximum speed, and a 41% shorter take-off distance than its immediate predecessors (Lockheed website).

Capital and maintenance costs would matter greatly in any upgrade or change decision. The RNZAF also has many types of missions, so the planes it uses must be multi-purpose. It seems unlikely that it would base its future cargo aircraft purchase decisions primarily on its Antarctic operations, which require only a relatively small number of flights each summer.

[2] This was in a Boeing 757 rather than a Hercules. Both have a similar 'point of no return'. Following this near miss, a decision was taken not to use the Boeing 757 for further personnel flights to Antarctica.

Fuel savings on other vehicles are also worth investigating. However, capital cost, safety in Antarctic conditions, robustness, ease of maintenance, ability to cope with the cold, and flexibility may all count as much or more than fuel costs in the purchasing decisions.

More Wind Generation (Meridian websites and its 2015 Annual Report)

Meridian is considering building more wind generators near Scott Base. It now has 617 megawatts of wind generation capacity installed in total In New Zealand and Australia (2015 Annual Report, p 2), which together with more large-scale geothermal generation has helped New Zealand push its total renewable electricity generation from 65% to 80%. Meridian has gained considerably more experience with wind generation since 2010. The available technology has also advanced. Factors that would affect its decision include:

- Finding a good site for additional generators. Crater Hill has limited additional space. A windy site further away could have higher maintenance and reliability costs.
- The current three wind generators already provide a large part of Scott Base's needs. Additional wind power would largely go to McMurdo, except when wind speeds are relatively low. In addition, Scott Base needs heat as well as power, so if the diesel generators are mostly switched off, an alternative heat source would be needed.
- Wind power can be produced all year round, which is good, since total energy consumption is about 40% per day higher at Scott Base in winter than in summer.
- However, wind availability is intermittent, so the need for other substantial base load generating capacity overall in Scott Base plus McMurdo would remain.

Geothermal Options

The only real alternative at Scott Base and McMurdo to diesel generators for constant base load power and heat is large-scale geothermal generation. Almost 1000 megawatts of geothermal power stations have now been installed in New Zealand, an increase of 250% in the past decade alone (New Zealand Geothermal Association website). New Zealand leads the world in this field. The potential for such a station near Scott Base was investigated in the early 1990s (Spinks, 1992). The study concluded that this was not economically feasible. One key problem was a lack of liquid fresh water for the generation of steam with which to drive a generating turbine. There was also an issue of size. Only a relatively small station would be needed for McMurdo plus Scott Base, and this is a technology where unit costs fall rapidly with size. Reliability as the main base load source would also be an issue. No such station has been built elsewhere in Antarctica.

However, there is a second simpler geothermal option with which New Zealanders are much less familiar, but which would be interesting to investigate. This is to drill down until there is a substantial temperature differential from the surface in order to drive heat pumps. The IEA has stated that 1300 megawatts-equivalent of such systems had been installed by 2014 (IEA Geothermal Country Report Norway, 2014). The report says that they cut heating costs by about 70%, have proven very reliable, have low maintenance costs and have a rapid payback period. There would be an environmental impact and it is hard to drill through permafrost, but these systems have proven very cost effective. Rinkesh (2015) has written, *"Can geothermal energy be applicable in such a cold place? The answer is yes! It can be. All we need is a good system of digging pipes and of establishing a vertical piping system."*

Further Conservation and Energy Conversion Efficiency Gains

Antarctica New Zealand has paid considerable attention already to introducing best-practice insulation, energy conservation and combined heat and power efficiency improvements. It is worth going considerably further in these areas at Scott Base than in cold climate countries, for two main reasons. Firstly, diesel fuel is much more expensive in Antarctica than elsewhere, due to the high transport costs; and secondly, winters are far more severe there.

The best combined cycle (i.e. power and heat) plants in Scandinavia achieve an energy efficiency of almost 90% (Viborg website). While Scott Base's 70% is good, more may be achievable. However, Scott Base is relatively small, so it may not be worthwhile to adopt technologies where economies of scale are important, where complexity may make maintenance and reliability difficult for the small number of staff available (especially in winter), or when the energy efficiency gains are simply too small to justify the investment. In carbon footprint terms, the whole-of-life impact also matters. Making the equipment normally has a carbon cost, which needs to be balanced against the savings.

Solar Energy

Solar panel costs are falling rapidly worldwide but this technology is still relatively immature, with some significant difficulties for application in year-round Antarctic bases.

- Although there is 24 hour daylight in summer when most people are resident, there is actually a greater need for power and heat in winter, when solar panels are useless, so diesel generators would have to remain installed. At best, solar panels could cut some fuel usage. Wind generation has much more potential at Scott Base.
- The sun has a low angle of incidence at 77° south and rotates all around the horizon every 24 hours. If installed on building walls, each panel would only generate electricity efficiently for a few hours each day.
- There is more potential for in-field use, to recharge batteries in equipment.

Solar panels are in use in some Antarctic stations. [3] If costs fall far enough and conversion efficiency rises as the technology matures, they may become genuinely useful at Scott Base. This is not a technology with which New Zealand has any special expertise. Maintaining a watching brief should suffice.

Conclusions

Much has already been done to improve energy efficiency and to reduce potential adverse environmental impacts in New Zealand's Antarctic operations. However, the use of carbon-based fuels on a large scale at Scott Base and for air and land transport to Antarctica will remain unavoidable. The most promising avenues for reducing fuel use are:

- Updating from the C-130H to the C-130J Hercules, or (if a year-round runway for wheeled aircraft can be built) purchasing a modern fuel-efficient alternative, especially if return flights from Christchurch without Antarctic refuelling then become achievable. This is the biggest potential fuel saving, with significant safety benefits.
- Additional wind generation, providing a suitable site can be found and approved. The biggest beneficiary from this would be McMurdo station, rather than Scott Base.
- Geothermally-powered heat pumps, using vertical drilling below buildings.
- Raising the Scott Base's electricity and heat energy conversion efficiency from 70%, and further heat retention investment, after allowing for the full climate change, pollution and safety costs and benefits, as well as the economic ones.

Small 'demonstration' investments, as a test-bed for new technologies, may also have merit.

---

[3] E.g. they play a key role in the first zero-emission Antarctic base, Belgium's summer-only Princess Elizabeth Station, situated at 72°S. It hosts 25-40 people in a square building whose walls are sloped at the best angle for solar panels. Its energy supply is 48% wind sourced, 40% from photovoltaic cells and 12% from thermal panels. It has an intelligent energy grid and considerable battery storage. It opened in 2009. (www.antarctic**station**.org/).

References

Energy Consumption Data

Harris C., 'A State of the Environment Report for the Ross Sea Region of Antarctica', NZ Antarctic Institute, 2001, Ch 3.9 - 3.12, gives data on transport, energy usage and fuel spills. Harris was the lead author for this part of the book. He quoted Kennicutt MC, Wylie DJ and Wolff GA, 'Summary of Existing Environmental Data, McMurdo Station, Antarctica', Texas A&M University, 1998, plus Antarctica New Zealand and National Science Foundation data.

Antarctica New Zealand's website, http://antarcticanz.govt.nz/scott-base/base-operations gives more current data on Scott Base's daily winter and summer, plus total, diesel usage. It also describes Scott Base's current diesel generator capacity and incineration policy.

Brady A.M., 'The Emerging Politics of Antarctica', Routledge, 2013, p 154.

Mason, A., 'An Investigation into Fuel Utilisation and Energy Generation in Antarctica', PCAS, 2005/06, has an in-depth description of Scott Base's energy usage patterns, including annual fuel usage at the base and in the field between 1999 and 2005.

Harrowfield, D. L. (1997). Scott Base, Antarctica: The History of New Zealand's Southernmost Station, 1957-1997. New Zealand Antarctic Society Inc, Christchurch, (quoted by Calder-Steele N., PCAS 2012/13), has data on the original diesel generators.

Morten P., 'Approaches to Energy Innovation in Northern Europe', New Zealand Ministry of Research, Science and Technology, 2007. Chapter 1 is an overview of renewable energy usage and policy in Scandinavia, Germany and the Netherlands (some of which have harsh winters), and what might be learned from these countries for application in New Zealand.

Nuclear Power at McMurdo

Foster, M.E. and Jones, G.M., 'History of the PM-3A Nuclear Power Plant, McMurdo Station Antarctica', Port Hueneme, 1978.

Antarctic Treaty Secretariat, 'McMurdo Station Reactor Site Released for Unrestricted Use,' United States Antarctic J. **15**, No. 1, 1 (1980).

Transport

Peat N., 'Antarctic Partners – 50 Years of New Zealand and United States Cooperation in Antarctica, 1957 - 2007', New Zealand Ministry of Foreign Affairs, 2007, Ch 3, provides a ten page overview of the joint transport and logistics operations. One key factor is that, unlike at many other stations, McMurdo is only accessible by sea in late summer, so there is no option but to use air transport extensively at the start of the summer season.

The RNZAF website http://www.airforce.mil.nz/about-us/what-we-do/aircraft/hercules.htm includes the quote.

Lockheed Martin's website has a great deal of information on the Hercules variants, e.g. http://www.lockheedmartin.com/us/products/c130.html . The summary data are taken from https://en.wikipedia.org/wiki/Lockheed_Martin_C-130J_Super_Hercules

Airbus similarly has considerable data available on the A319CJ and on the A320neo, e.g. http://www.airbus.com/aircraftfamilies/passengeraircraft/a320family/spotlight-on-a320neo/ and http://www.airbus.com/aircraftfamilies/corporate/acj-family/acj319/

Wind Energy

Meridian Energy, https://www.meridianenergy.co.nz/news-and-events/antarctic-wind-farm-exceeding-expectations-for-antarctic-bases, April 2012, states: *The three 330kW turbines have effected an 11 per cent reduction in the total amount of fossil fuels consumed annually by New Zealand's Scott Base and the US McMurdo Station. Harnessing the wind on site saves 463,000 litres of diesel fuel each year'.*

http://antarcticanz.govt.nz/scott-base/sustainability states: *Further developments with the potential to reduce power plant fuel consumption and greenhouse gas emissions at McMurdo Station and Scott Base by up to 50% are under investigation.*

https://www.meridianenergy.co.nz/assets/Investors/Reports-and-presentations/Annual-results-and-reports/2015/Annual-report-2015.pdf

Geothermal

Spinks A.H., "Alternative energy sources for power generation in Antarctica", Central Laboratories, 1992.

http://www.nzgeothermal.org.nz/elec_geo.html lists the New Zealand geothermal stations and their commissioning dates.

http://iea-gia.org/wp-content/uploads/2014/12/IEA-GIA-Norway-country-report-2014.pdf describes the widespread use of geothermal heat pumps, which are also common in Iceland.

http://www.conserve-energy-future.com/GeothermalEnergyColdClimates.php Rinkesh, 2015 is the source of the quote.

Energy Conservation

http://www.statensnet.dk/pligtarkiv/fremvis.pl?vaerkid=329&reprid=0&filid=16&iarkiv=1 gives a Danish example where the combined cycle overall efficiency is 88%. Cogeneration (thermal generation, plus steam generation from using the heat in the exhaust gases) has a theoretical efficiency of up to 95%.

Solar Energy

Calder-Steele N., 'Electricity in Isolation: the Progress of Power Generation in Antarctica', PCAS 2012/13, provides an overview of solar panel use at other Antarctic stations.

Hume D, and Bodger P., 'Renewable energy for Scott Base. A Win-Win Situation', p 4, http://ir.canterbury.ac.nz/bitstream/handle/10092/800/12593637_C49.pdf?sequence=1 University of Canterbury, gives data on the limited solar radiation available at Scott Base.

http://www.antarcticstation.org/assets/uploads/documents_files/brochure_pea_19_04_2013_web.pdf is a 24 page description of Belgium's zero-emission Princess Elizabeth Station.