Alternative Energy Options for Antarctic Stations

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Abstract

The purpose of this paper is to describe the unique problems of designing an alternative energy system for the Australian and French Antarctic research stations and the possible options that can be pursued to obtain a clean, efficient, safe and reliable energy system. The adoption of the alternative systems will rely on the further technological and commercial development of equipment and the collaboration of industry.

Résumé

Le présent article expose les problèmes particuliers liés à l'élaboration de nouveaux systèmes énergétiques pour les stations scientifiques Françaises et Australiennes de l'Antarctique. Diverses options visant à l'obtention de systèmes non polluants, à bon rendement, sûrs et fiables sont détaillées. Nous verrons que leur adoption dépend de développements technologiques en cours et de l'engagement de programmes de coopération avec les fabriquants d'équipements.

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1. Introduction

Research stations in the Antarctic have special needs for efficient, reliable, safe and environmentally friendly power systems to provide electricity, heat and potable water. The energy demands are dominated by the requirement for heating followed by the production of electricity, with water production, generally by desalination or ice melting, also requiring significant energy input.

The combustion of fossil fuels in powerhouses is the single largest local contributor to Antarctic produced airborne pollution.

Reducing the use of fossil fuels is important as it has the potential to:

- promote the protection of the Antarctic environment;
- reduce the cost of Antarctic research;
- alleviate the demand on the logistical support program, for fuel transport and handling; and
- enhance the credibility of Australia's and France's prominent positions in the international effort to reduce environmental impacts in Antarctica.

2. Current Station Energy Systems

Since the 1950s and 60s when the research stations were being developed, most energy demands were met by diesel generators and oil fired boilers. At the time, these methods were the most convenient, established and reliable means to support the needs of the stations where safety was, and still is, of highest priority.

The generator sets typically consist of 125 kVA alternators driven by diesel engines, with water jackets providing additional heat recovery from cooling water and exhausts. The fuel almost exclusively used by the stations is Special Antarctic Blend (SAB) diesel which has been chosen primarily for its cold temperature performance. The characteristics of SAB as tested by Mobil Oil, Hobart are:

Lower Heating Value: (LHV)	35,274 kJ/litre
Density @ 15°C :	0.805 kg/litre
Sulphur Content :	0.05 %wt

As an example, the fuel consumption by the Australian Antarctic and Sub-Antarctic stations, with the corresponding electrical and thermal production is represented in Table 1.

Table 1: Australian Antarctic Stations Energy Production and Consumption, 1992:

January to December 1992	Casey	Mawson	Davis	Macquarie
Total SAB used in powerhouse (l)	679,120	643,032	659,739	195,399
Average Electrical Load (kW)	227	251	200	67
Generators Electrical Production (kWh)	1,993,075	2,200,685	1,756,302	587,675
Total Thermal Production (kWh)	2,909,099	2,076,298	2,695,112	623,103
Total Energy Production (kWh)	4,902,174	4,276,983	4,451,414	1,210,778
Station Population (average)	32.9	43.2	44.8	21.6
Energy use per capita (kWh / person)	408	271	272	99

Data Source: Australian Antarctic Division, Engineering Section.

The remoteness of the Antarctic continent requires a major logistical program for the provision of SAB diesel and support of the research stations. The seasonal window for logistical operations is limited to the summer months and the fuel pumping program is both difficult and time consuming. Some conservative estimates put the cost of SAB at the point of use in Antarctica at double the purchase price in Hobart. Other estimates go further. The Australian Antarctic Division calculated the cost of electricity to be as high as 14 times that in Hobart. In addition to the financial cost there is a significant environmental cost. The transport of fuel by sea involves the risk of spillage. The potential for significant ecological damage to the fragile polar environment by such an event has been demonstrated by the *Bahia Paraiso* grounding in the Antarctic Peninsula and the *Exxon Valdez* incident in Alaska.

3. Alternative Energy Opportunities

The environmental and scientific values of Antarctica have recently received more attention, with the recognition of the importance of the interactions of the polar regions with the global environment. Increasing emphasis is being placed by the nations active in Antarctica on environmental management. These nations recently adopted a Protocol on Environmental Protection to the Antarctic Treaty, and through the Council of Managers of National Antarctic Programs have identified various practical initiatives, including the application of alternative energy, to implement the principles of the Protocol.

The main constraints in the implementation of alternative energy systems in Antarctica are:

- The remoteness of the stations and the logistical problems in supplying and storing fuel;
- The harsh environmental conditions imposing restrictions on traditional renewable energies, such as wind and solar;
- Strict environmental protocols that need to be adhered to in the construction of any structures; and
- The difficulty in obtaining outside support and assistance, especially in the winter months.

With these constraints in mind, it became apparent that a wind energy hydrogen fuel cell system offered promising possibilities for an efficient, reliable, safe and environmentally clean system.

Due to practical and financial constraints, a sustainable energy system should be able to be implemented in stages. This will also enable the project to be modified over time to take advantage of technological developments.

3.1. Renewable Energies

Antarctica is a continent of harsh environmental conditions which test the performance and survival of conventionally designed equipment. The critical conditions influencing the design of renewable systems are:

Maximum Wind Speed	90 m/sec
Minimum Temperature	-40 °C

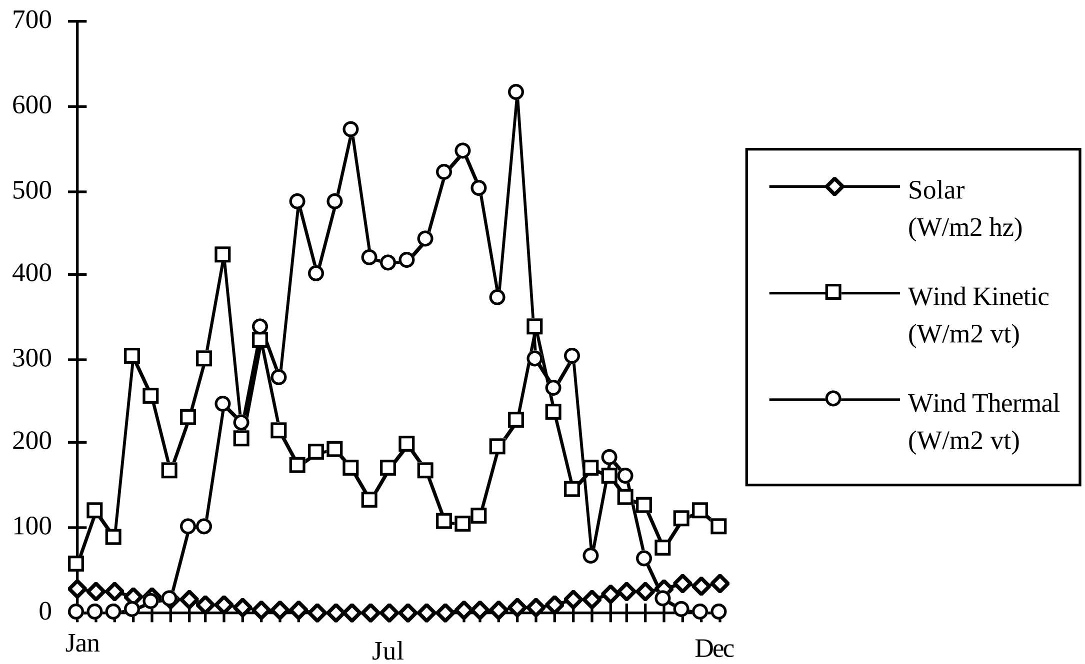

Fig. 1: An Estimate of Recoverable Energy at Dumont d'Urville.
Data Source: Le Goff, H., Laboratoire des Sciences du Génie Chimique

Min. daily Solar Irradiance (by clear sky) 0 W/m^2

An example of energy recoverable by Solar Cells, Wind Turbines and Thermo-Mechanical machines at the French station of Dumont d'Urville is summarised in Fig. 1 (Guichard & Steel,1993). The global solar radiation was measured on a horizontal plane, at ground level, from 0 to 24 hours; wind speed at 10m high averaged over 10 minutes every 3 hours; and spot temperatures every 3 hours.

Thermal wind energy has the greatest abundance with a yearly average of 246 W/m^2 vt (vertical crossection). Wind kinetic energy is less abundant but more constant over the year (181 W/m^2 vt) and solar energy an average of 11.7 W/m^2 hz (horizontal panel). This has influenced the adoption of a renewable energy component based upon wind energy recovery. Solar energy is only practical in the summer months, as the irradiance in the winter months is as low as 0.1 W/m^2.

Electricity production by thermo-mechanical machines operate on the cooling power of the wind, the temperature T of which is

medium, the sea for example. Thermo-mechanical machines have some potential and are actively being developed with the support of the French Polar Institute. A prototype is scheduled to be installed at Dumont d'Urville in the 1993/94 summer season.

3.2. Hydrogen as an Energy Carrier

In Antarctica energy storage systems are required so that energy is available at all times. Hydrogen is increasingly being accepted as a practical alternative fuel and is potentially well suited to the needs of the Antarctic. The advantages of hydrogen are:

- versatility in energy production method;
- negligible polluting emissions; and
- can be locally produced by the electrolysis of water.

The storage system represents the greatest problem for the large scale introduction of hydrogen as part of a sustainable energy system. The conventional methods of liquefying or compressing hydrogen require substantial energy input and heavy bulky storage cylinders. Though they are commercially available technologies there is increasing interest in the developing technologies of metal hydride and methods offer increased safety and may also be cheaper.

The safe use of hydrogen has been demonstrated in established facilities world wide and now includes over 750km of commercial gaseous hydrogen transport pipeline (Hoenigmann, 1992).

3.3. Fuel Cell Power Systems

The conceptually simple and environmentally attractive fuel cell offers a solution to the production of electricity in a compact, quiet, highly efficient, and exceptionally clean manner. The electrochemical reaction driving the fuel cell occurs between hydrogen and oxygen in a device consisting of an anode, cathode and electrode. Fuel cells operating on alternate fuels to hydrogen require the fuel to be reformed into hydrogen. This can be achieved in an external reformer or can be internally reformed in the higher temperature operating fuel cells. The co-generation capabilities of fuel cells to produce thermal energy and potable water can assist in meeting the demands of the research stations.

4. System Options

A comprehensive assessment of products is being carried out. To initiate the project, a testing program involving small pilot plants is desirable. The modular expansion capabilities of the components would better enable the system to gradually be expanded.

4.1. Introducing a Fuel Cell Unit

An internal reforming fuel cell unit can be introduced as a singular component connected to the station electrical grid. This will reduce the electrical load on the diesel generator sets and also assist in the production of heating and water for the station.

The US National Science Foundation is funding research to demonstrate the Molten Carbonate Fuel Cell (MCFC), or Direct Fuel Cell (DFC) as they are becoming increasingly known, to power the permanent and temporary scientific research stations of the US Antarctic program using diesel or sulfur free JP8 (SFJP8) fuel.

The DFC is a internal thermo-chemical reformation unit operating at 650°C which is sufficiently high to permit diesel or SFJP8 fuel to be reformed internally within the stack. The SFJP8 fuel has all the desired characteristics such as high heating value, satisfactorily high flash point, high viscosity and useability in many of the existing Antarctic facilities.

Lower Heating Value: 42,800 kJ/litre (LHV)
Density @15°C: 0.775 to 0.840 kg/litre
Sulphur Content: < 1ppm

The DFC unit can be assembled in 50 kW modules. A pilot facility of this size would have characteristics as calculated in Table 2.

Introducing a fuel cell unit using diesel as a fuel enables the unit to be installed and tested without the need for any additional infrastructure. This will reduce the capital cost and allow a suitable demonstration of the fuel cell technology.

Technological development is continuing with other internal reforming fuel cells. The CSIRO Division of Materials Science and Technology in Melbourne is actively investigating the Solid Oxide Fuel Cell (SOFC) which with its high operating temperature (900-1000°C) will have the capability to reform a variety of fuels. The availability of either test or commercial units is believed to be some time off, though the potential of the SOFC units is encouraging and warrants monitoring.

The internally reforming fuel cells would be ideally suited to the implementation of the program. Initially operating on the current fuels used in Antarctica they can be modified to operate directly on hydrogen, bypassing the reforming process, when the hydrogen system is developed.

4.2. Introducing Renewable Energy

Wind generators have been tried in Antarctica but have often failed due primarily to the extreme wind and icing conditions. A recent successful demonstration of a wind turbine was made on the sub-antarctic Heard Island. It is planned to continue a more ambitious testing program on the Antarctic continent with advanced wind turbines.

4.3. Introducing Hydrogen

It is not practicle to import hydrogen to Antarctica because of the special transport facilities required. It would be very expensive to modify existing vessels and would disrupt much of the shipping program at a time when there is a wish to further dedicate the vessels to scientific programs rather than logistical supply.

The meteorological program conducted at some of the research stations currently uses locally produced hydrogen for the meteorological balloon filling program. This is achieved by small electrolytic hydrogen generators made by the Electrolyser Corporation, with power to the unit supplied by the station electrical grid. The hydrogen is stored in a compressed gas storage vessel. Large scale electrolysis of water is viewed as the best option for hydrogen generation.

Hydrogen produced on site will need to be stored. Preliminary storage would involve compressed gas methods limiting the size of the system. The developing metal hydride and refrigerated activated carbon technologies need to be investigated to establish whether the compressed gas storage can be superseded.

Hydrogen can be used in two ways. Firstly, as an additive to diesel fuel in the current generator sets. This requires minimal modifications and improves the emission characteristics of the generator sets through the reduction of pollutants such as carbon monoxide, hydrocarbons, and sulphur compounds, and also reduces the consumption of diesel fuel.

Tests have been performed to establish optimum levels for the addition of hydrogen and other diluents to improve performance and the reduction of engine knock, which is a characteristic associated with the neat use of hydrogen. Water injection, in as small a proportion as 2460 ppm, can be profitably employed to achieve around 66% hydrogen energy substitution along with a smooth knock free engine operation and drastic reduction of exhaust smoke and NO_x emissions (Mathur and others 1992, p369-374).

Secondly, hydrogen can be used as a fuel for the commercially available Phosphoric Acid Fuel Cell (PAFC) developed by the ONSI Corporation. A suitable unit for Antarctic applications is the PC 25, being a packaged, self contained fuel cell power plant. The PC 25 is a 200 kW unit that is manufactured for use with pipeline natural gas. The unit can be simply modified to operate on an uncontaminated source of relatively pure hydrogen.

5. System Objectives

A complete renewable energy system is illustrated in Figure 2.

Table 2: Energy Generation Characteristics with respect to fuel quantity consumed.

Unit Type	Fuel Type & LHV (kWh/kg)	Electrical Production (kWh/kg)	Thermal Production (kWh/kg)	Total Energy Production (kWh/kg)	Total Energy Production (kWh/litre)	Energetic Efficiency (%)
1.Diesel Generator	SAB 12.17	4.24	3.90	8.14	6.55	66.88
2. DFC	SFJP8 14.82	5.55	3.10	8.65	6.94	58.36
3. PAFC	Natural Gas 13.25	5.09	6.34	11.43	0.00834 (@STP)	86.26

Data Source: 1. Australian Antarctic Division., Engineering Section.
2. Arctic Energies Limited., "Engineering Research on Fuel Cells for Antarctic Energy Production and Conservation as well as Potable Water Treatment and Delivery." Prepared for the Division of Polar Programs, National Science Foundation, 1991
3. ONSI Corporation., The PC25 Fuel Cell Power Plant., 1986

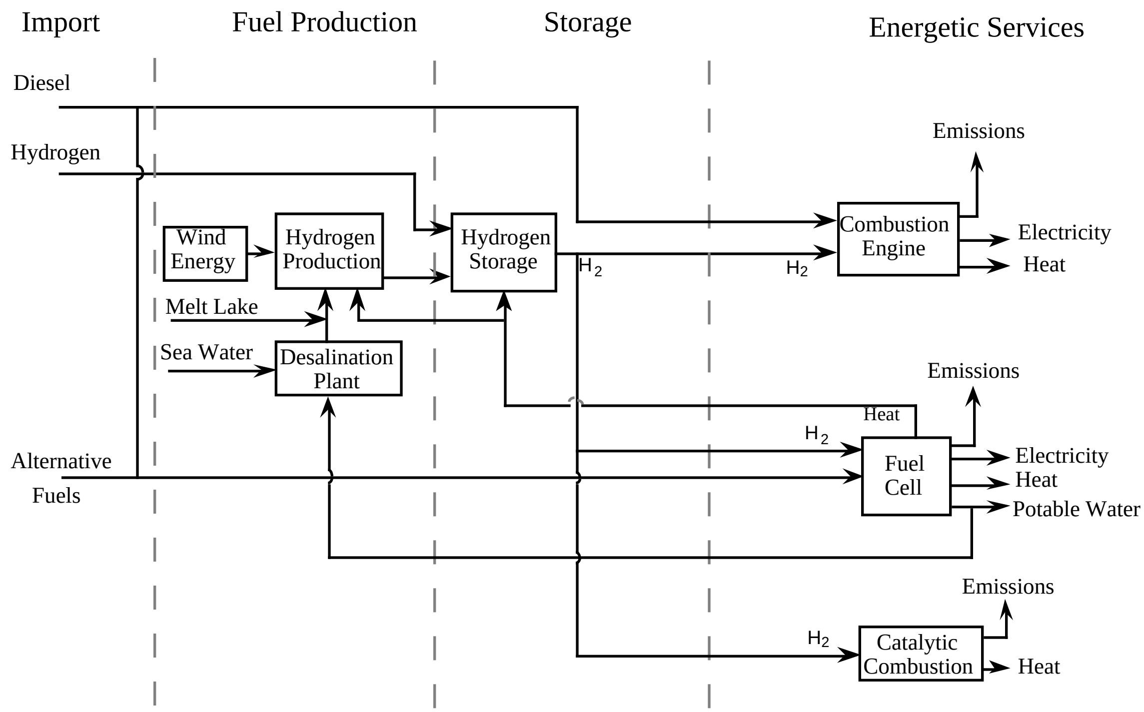

Fig. 2: Alternative Energy System Schematic.

6. Opportunities for Collaboration

The high international profile of activities conducted in Antarctica provide the opportunity for industries involved in clean, efficient, alternate energies to demonstrate their products and to obtain substantial international recognition. In addition, the Australian and French Antarctic research stations offer an established test-bed facility with monitoring capabilities to demonstrate advanced Remote Area Power Systems.

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7. Bibliography

1.Badwal, S., Foger, K. & Murray, M., 1991, "Fuel Cells: Clean Alternative Energy Technology of 21st Century.", *Gippsland Basin Symposium, Melbourne June 1991*, CSIRO Division of Materials Science.

2.Department of Defence, 1989, "Australian Defence Standard, DEF (Aust) 5208A Turbine Fuel, Aviation (Kerosine Type) Nato Code F-35 AVTUR; Specification", Commonwealth Government.

3.Guichard, A. & Steel, J., 1993, "Alternative Energy Systems for Antarctic Stations: Investing for the Future?", presented at *IDEEA Two Conference, Montréal, October 1993*.

4.Hoenigmann, W., Mauro, R., Serfass, J., Smith, D. & Bain, A., 1992, "Hydrogen Perspectives- A View of the Present and a Plan for the Future." *Proceedings of the 9th World Hydrogen Energy Conference. Paris, France*, International Association for Hydrogen Energy.

5. Le Goff, H., Schwarzer, B., De Oliviera Jr, S. & Le Goff, P., "Thermodynamical Machines Using the Energy of Cold Polar Winds." Laboratoire des Sciences du Génie Chimique CNRS ENSIC, B.P. 451, 1 rue Grandville 54001 Nancy France.

6. Le Goff, H., Schwarzer, B. & Le Goff, P., 1993, "Utilisation des Énergies Renouvelables en Milieu Polaire", *Congrés de Génie des Procédés, Grenoble, Sept. 93*.

7.Mathur, H.B., Das, L.M. & Patro, T.N., 1992, "Hydrogen Fuel Utilisation in IC Engine Powered End Utility Systems." *International Journal of Hydrogen Energy*, 17 (5): 369-374