ALTERNATIVE ENERGY SYSTEMS FOR ANTARCTIC STATIONS: INVESTING FOR THE FUTURE.

by
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ABSTRACT

A French-Australian co-operative research project focused on energy systems at Antarctic research stations has been initiated. Its aims are to investigate the current energy requirements of the Australian and French stations and to conduct a feasibility study on the use of alternative energy systems. This is designed to reduce the quantity of fuel used and the impact on the environment.

This paper outlines the various issues addressed, presents the first options identified and provides a basis for identifying directions for future work.

Keywords: energy, Antarctic, renewable, environment.

RESUME

Un programme de recherche Franco-Australien sur les systèmes énergétiques des stations scientifiques Antarctiques a été initié. Ses objectifs sont de mener une investigation des besoins en énergie des stations Australiennes et Francaises, et d'étudier les possibilités d'utilisation de nouveaux systèmes énergétiques. Le but final du projet est de réduire les quantités de fuel utilisées et l'impact des stations sur l'environnement.

Cette communication expose les problèmes rencontrés, présente les premières options identifiées et fournit une base de reflexion pour identifier les orientations à donner aux recherches à venir.

Mots clés: énergie, Antarctique, renouvelable, environnement.

CONTENTS SUMMARY

PAPER

1. Introduction.

The harsh coast of East Antarctica lies around 3000 km south of Australia across the Southern Ocean. It was first reached in January 1840 by French navigator Jules Dumont d'Urville sailing from Hobart, Tasmania, on board *l'Astrolabe* and *la Zélée*. The ice cliffs occasionally give way to small rocky outcrops which are the favourable locations for both animal breeding grounds and human settlements. These remote sites experience high katabatic winds (up to 326 km/h recorded, average over 2 minutes, Dumont d'Urville, January 1972) and are further isolated in winter when the continent is surrounded by hundreds of kilometres of sea-ice.

The settlements are scientific stations operated by national organizations. Australia and France currently run four permanent stations on this coast: Mawson (67°36'S, 62°52'E), Davis (68°36'S, 77°58'E), Casey (66°18'S, 110°32'E) and Dumont d'Urville (66°40'S, 140°01'E), plus four others scattered in the Indian and Southern Oceans on the Sub-Antarctic islands of Crozet (Alfred-Faure, 46°26'S, 51°52'E), Kerguelen (Port-aux-Français, 49°21'S, 70°12'E), Nouvelle-Amsterdam (Martin-de Vivies, 37°50'S, 77°34'E) and Macquarie (54°30'S, 158°57'E). These eight stations are at present serviced by a total of four ships: *L'Astrolabe*, the *Aurora Australis*, the *Icebird* and the *Marion Dufresne*. The first three are ice strenghtened vessels.

Access to the Antarctic coastal stations is limited to the summer months. They remain totally isolated for the winter months when sea-ice fills the surrounding waters. Sub-Antarctic islands can receive limited supply voyages in winter. The stations typically house 15 to 35 expeditioners throughout winter, up to 100 in summer, and while some minor use is made of solar and wind energy for powering equipment in the field, they rely almost entirely for electricity and heating on conventional, mid-sized, diesel generator sets and oil fired boilers.

This approach has been dictated by the primary need for practicality and a very high degree of reliability. Intensive research demands a constant power supply and serious system failures can rapidly jeopardize the safety of expeditioners. At the time when most stations were established (the 1950s and 60s), investigations and trials showed that conventional generator sets and boilers were the only satisfactory, practical answer to the provision of energy.

Energy costs are high and exhaust gas emissions from stations are the most significant source of air pollution in the near pristine conditions of Antarctica. The possibility of oil spills also threatens the polar environment and fragile ecosystems. Technologies related to cleaner energy production, to renewable energies and to energy storage are rapidly evolving and new, realistic possibilities of alternative energy systems for Antarctic stations now arise.

France and Australia are leading Antarctic Treaty nations and have recently been successful with a joint policy initiative which resulted in agreement to a Protocol on Environmental Protection to the Antarctic Treaty (the Madrid Protocol). As part of the program to translate the environmental policy into action, a joint project has been initiated involving the Antarctic operating agencies and research institutions in France and Australia. The immediate objective of the project is to investigate the current energy requirements of the Australian and French Antarctic research stations and to conduct a feasibility study on the use of alternative energy systems designed to reduce the quantity of fuel used and the impact on the environment.

The main partners of this program are the French Institute for Polar Research and Technology (IFRTP), the Australian Antarctic Division (AAD), the Laboratoire des Sciences du Génie Chimique (LSGC/CNRS) and the Institute of Antarctic and Southern Ocean Studies (IASOS) at the University of Tasmania.

The long term objectives are to make Antarctic stations independent or near independent of fossil fuels and to minimize their impact on the environment. This would directly improve the quality of support to Antarctic research and would provide a significant contribution towards the ongoing international efforts to enhance the protection of the Antarctic environment.

2. Current Systems.

All source data used to describe and analyse the current systems has been obtained from operators of the stations through the Engineering Section of the Australian Antarctic Division and the Service Technique de l'Institut Français pour la Recherche et la Technologie Polaires which have both been of great assistance.

2.1. System Overview.

The main component of the energy system of a typical station is a central powerhouse comprising two to four diesel engines driving three phases alternators of 100 to 125 kVA capacity. Heat is recovered from cooling water jackets, and sometimes from exhausts. Additional thermal needs are fulfilled by boilers. Both engines and boilers are fueled with Special Antarctic Blend (SAB) diesel fuel shipped in by polar supply vessels and stored on the station in bulk storage tanks. Fuel farms can usually store enough SAB for the station to operate normally a whole year plus 'survive' an additional winter in case fuel cannot be delivered in the next summer season. Full storage capacity can be up to 1 060 000 litres at a single station with the tanks covering an area up to 1280 m^2 (Mawson).

The SAB fuel used is, like normal Diesel, registered as Flammable Liquid Class C and dangerous Good Class 3.3. The main difference lies in a much lower pour point. Some of its characteristics of interest are :

Density @15°C :	0.805 kg/litre
Flashpoint :	64 °C minimum
Pour Point :	-36 °C
Sulphur Content :	0.1 % wt max.
Lower Heat Value :	35 274 kJ/litre (or 9.8 kWh/litre)
Purchase Price :	≈ $A 0.38 (bulk, in Hobart)

When freshwater has to be produced from seawater, heat recovered from the engines is directly used in the powerhouse to desalinate seawater (e.g. Dumont d'Urville) and individual boilers provide heating to the buildings. In other cases, the recovered heat is reticulated through hot water mains around the station to feed heating systems through various exchangers, to melt ice (e.g. Casey and Mawson) or to melt snow (e.g. Davis). Boilers are also used to maintain the temperature of the reticulated hot water if needed.

Dumont d'Urville produces its freshwater through the highly energy intensive desalination process. This requires all the heat recovery from the engines plus 46 kW from boilers, that is

113 kW or 45% of the station's average power. Melting ice at Casey and Mawson requires 10 to 20 kW while melting snow at Davis uses around 27 kW.

The three Australian Antarctic coastal stations are mostly equipped with in-line six cylinder Caterpillar 3306 marine engines which drive 125 kVA alternators. The engines cost around $A 35,000 each and are replaced after 35,000 hours. This allows advantage to be taken of the continuous improvements being made in engine design, especially in efficiency. Each generator set usually generates an average electrical power of 75 kW. Using the Lower Heat Value (LHV) of SAB fuel, the efficiencies of electrical production and heat recovery are respectively around 35 and 32%, giving a combined efficiency of 67%. Dumont d'Urville has 30 year old generators which have corresponding efficiencies of 31, 30 and 61%. Boilers typically have a higher efficiency approaching 80 %. Thus, the higher the proportion of thermal energy demand, the better the overall efficiency. This is well illustrated by the fact that Dumont d'Urville has roughly the same overall fuel conversion efficiency as Casey and Davis. Table 1 gives some energy figures for three stations.

Station	**Casey**	**Dumont d'Urville**	**Davis**
Position	66°18'S 110°32'E	66°40'S 140°01'E	68°36'S 77°58'E
Year (winter population)	1992 (17)	1992 (35)	1992 (30)
SAB used in generators (litres)	585 359	200 000	526 527
Electrical Production (kWh)	1 993 075	613 200	1 756 302
Generators Heat Recovery (kWh)	1 835 374	588 000	1 650 908
Boilers Production (kWh)	1 073 725	980 000	1 044 204
Total Energy production (kWh)	4 902 174	2 181 200	4 451 414
SAB consumed in gen. & boilers (litres)	722 337	325 000	659 739
Overall efficiency (%)	69%	68%	69%
Average Electrical Load (kW)	227 (41%)	70 (28%)	200 (39%)
Average Thermal Load (kW)	331 (59%)	179 (72%)	307 (61%)
Average Total Load (kW)	558 (100%)	249 (100%)	507 (100%)

Table 1: Some Energy Figures for Casey, Dumont d'Urville and Davis Stations

(Data Source: AAD and IFRTP)

Energy needs throughout the year are influenced by two main factors: the level of activity on the station, which is highest in summer, and the thermal and lighting needs which are highest in winter. The latter factor leads to a maximum requirement in winter. Figure 1 illustrates energy production at Davis from January to December 1992. The high thermal energy production from boilers for November and December is an artefact. The original data used is not the amount of fuel actually consumed but the amount transferred from the main fuel farm to the tanks feeding the boilers. Sometimes, large amounts are transferred to provide for the busy months to come.

The most recently rebuilt stations have larger buildings and high standard sophisticated mechanical services characterised by higher component efficiency, but their complexity and extent result in higher total energy demands. Dumont d'Urville, rebuilt in the sixties, consumed in 1992 around 325 000 litres of SAB for a winter population of 35 expeditioners while Casey, rebuilt in the eighties, needed 722 000 litres for 17 persons in very similar climatic conditions. This shows that approximately 4.5 times the fuel per capita was required at Casey than at Dumont d'Urville.

Between the first half of 1992 and the first half of 1993, SAB consumption at Casey dropped about 12% due to the ongoing tuning of the new system. However, the energy demand will remain large. Casey offers high levels of comfort but this requires high standards which may be inappropriate for the Antarctic situation when the expressed aim is efficiency and minimal environmental impact.

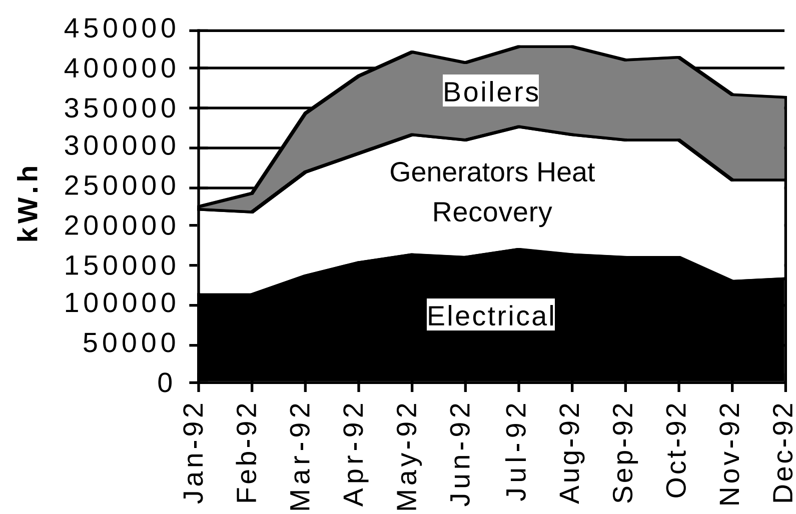

Fig. 1: 1992 Seasonal Variation of the Monthly Energy Production at Davis Station.
(Data source: AAD)

2.2. Financial Costs.

The annual fuel supply for the four Australian stations costs around $A 1 million to purchase in Hobart and represents about 10 % of the total volume of cargo shipped south. Ten percent of the total shipping cost (excluding pure marine science cruises) is approximately $A 2 million, so on the basis of average shipping costs, the cost of SAB upon delivery in Antarctica is tripled.

Allocating a share of the shipping costs is not quite so simple. In addition to the cargo, each voyage delivers and retrieves expeditioners necessary to the accomplishment of the various scientific programs and sometimes performs en-route marine science activities. Even allocating 5 % of the shipping cost to fuel transportation still doubles the initial purchase price.

A detailed cost analysis undertaken in 1991 by the Engineering Section of the Australian Antarctic Division used this conservative estimate of 5 % of the shipping cost dedicated to fuel. This gave a final cost of $A 0.68 per electric kWh produced at the stations. This is about 7 times the commercial price of domestic electricity in Tasmania, and 14 times the off-peak price. The fuel itself represented 55 % of the electricity cost and equipment depreciation and maintenance represented 45 %. Such figures are a good example of the high cost of the current energy supply.

The rebuilding of the Australian Antarctic stations is almost complete and the amount of dry cargo to be transported south is expected to be reduced. However the volume of fuel needed will be similar. This will increase the share of the total charter costs attributable to fuel transport.

2.3. Environmental Aspects.

The polar environment and its ecosystems are known to be very fragile. In addition, most stations are located in especially rich biological areas. Great care is needed in conducting operations.

2.3.1. Fuel Spills.

There is a clear distinction between routine operational pollution and accident hazards. The most likely and probably most damaging of such hazards is a fuel spill. It can either originate from a ship grounding or sinking, from transfer problems when pumping from ship to shore or simply leakage from a tank at a fuel farm. High priority is given to the prevention of such incidents and spills have so far been restricted to small quantities. Operations can unfortunately have to take place in difficult conditions, thus increasing the risks. The Exxon Valdez incident in Alaska has demonstrated the extent of possible impacts on a fragile polar environment, but it must be noted that the impact of the light volatile SAB diesel fuel would be far less serious than for heavy Bunker Fuel Oil (0.971 kg/litre @15°C) usually involved in tanker spills.

2.3.2. Atmospheric Emissions.

The second problem is due to the atmospheric emissions inherent to the operation of engines and boilers. They consist of gases and Dry Particulate Matters (DPM). To get an idea of the emissions generated by Antarctic stations, we can conduct a crude estimation of the contribution of the powerhouse engines. These calculations are based on the 1992 electrical production of the four Australian Stations, assuming that it has been entirely generated by 3306-DIT engines, each producing an average electrical power of 75 kW. In practice, there are a variety of engines load conditions and exhaust emission rates, but the order of magnitude of the calculation is correct. The results are summarised in Table 2.

Period: January to December 1992		Total 4 Stations	Per Capita
Total Station occupancy	(persons-days)	52 148	366
Average Occupancy	(persons)	142	1
Winter Population	(persons)	92	0.65
Generators SAB Consumption	(litres)	1 935 321	13 583
Corresponding Engine Hours	[at 22 l/hr]	87 969	617
Emissions (kg) of:	assuming a rate of:		
Carbon Dioxide - CO_2	126.496 kg/h	11 127 744	78 100
Nitrogen - N_2	723.538 kg/h	63 649 013	446 720
Oxygen - O_2	82.143 kg/h	7 226 049	50 716
Water - H_2O	50.054 kg/h	4 403 207	30 904
Carbon Monoxide - CO	0.726 kg/h	63 866	448
Nitrogen Monoxide - NO	1.418 kg/h	124 740	875
Other Nitrogen Oxides - NO_x	2.166 kg/h	190 541	1 337
Hydrocarbons - HC	0.068 kg/h	5 982	42
Sulphur Dioxide - SO_2	0.161 kg/h	14 163	99
Dry Particulate Matters - DPM	0.092 kg/h	8 093	57

Table 2: Estimated Annual Emissions from Generators at four Australian Stations.
(Data source: AAD)

• Gaseous Emissions.

For reference, the annual production of CO_2 from fuels and cement is around 18 billion tonnes worldwide and 5 billion in the US (World Resources Institute, 1992). The 11 128 tonnes produced at the station represent then 0.62 Millionth of the worldwide emissions.

Any passive gas released in the atmosphere is mixed and tends to give an homogeneous concentration around the globe. One of the latest models for the southern regions (Law et al., 1992) estimates that the time needed to reach 67% of this final uniform concentration at the latitude 70°S at a level of 850 hPa (≈1500m) is about:
•220 to 227 days for gases originating from the northern midlatitudes (44-54°N);
•65 to 85 days from the tropics (5°S-5°N);
•2 days from the southern midlatitudes (44-54°S).
It can be seen that gaseous emissions originating in Australia reach the stations extremely quickly and that within a year any emission on the globe has been widely spread. In absolute terms, the stations are very minor contributors of the pollution affecting the atmosphere immediately above them.

Per capita figures give a completely different view. Annual CO_2 production by powerhouses at the Australian stations is about 78 tons per person. The total CO_2 figures for the world and the US are 3.6 and 20 tons per person, that is about 22 and 4 times less.

• Particulate Matters.

Particulate Matters are much heavier than gases and an important proportion will deposit on the surface. While gaseous emissions are more associated with global pollution, Particulate Matters are associated with local pollution. Composition varies with the fuel used, and it has to be noted that the powerhouses do not produce lead particules as SAB is lead free. The prevailing winds probably blow most of the particulates out to sea where their impact is expected to be much lower than on the breeding grounds surrounding the stations. The real impact will be difficult to assess, especially with the lack of detailed base line studies.

Table 2 gives an annual particulates amount of 8 tonnes for the generators of the four Australian stations. A study by SCAR (1989) estimates the amount of particulate emissions produced annually in the Antarctic Treaty Area to be around 300 tons, of which less than 200 tons are produced on or adjacent to land. This is compared with the 10 000 to 15 000 tons produced by an industrialised city of about 4 millions people (e.g. Sydney). Once again, per capita figures give a different view. The city emits 2.5 to 3.75 kg per person while the Antarctic stations powerhouses produce 57 kg per person, 15 to 13 times more.

3. Renewable Energy Potential.

The examples given in this chapter are based on a set of standard meteorological data from Dumont d'Urville for the period 1 January 1986 to 31 December 1989. The original measures are: global solar radiation on an horizontal plane from 0 to 24h; wind speed at 10 m high averaged over 10 minutes every 3 hours; and spot temperature every 3 hours.

Data was processed to give averages over the standard "decades" used in meteorology (3 decades per month, corresponding to the days 1-10, 11-20 and 21-end of the month). For each of the 36 decades of the year a data point is obtained representing an average over the four corresponding decades of the four year period. We will consider the three data sets obtained (Solar Radiation on an horizontal plane, Wind Speed, Temperature) to define a "Typical Year" for which we will assess the renewable energy potential. Parameters of this Typical year are illustrated by Figure 2 and some characteristics are summarized in Table 3.

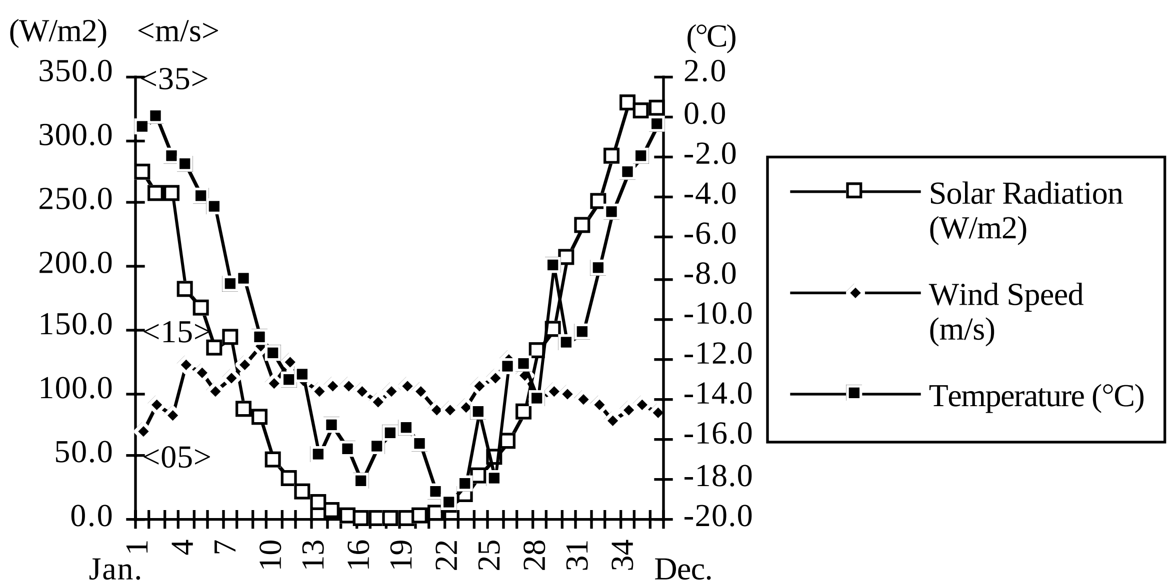

Figure 2: Meteorological Parameters during a "Typical Year" at Dumont d'Urville.
(Based on 1986-89 data)

	Yearly Average	Highest Decade	Lowest decade
Solar (W/m2)	117	329.1 (dec 1-10)	0.6 (jun 11-30)
Wind (m/s)	10.2	13.8 (mar21-31)	7.1 (jan 1-10)
Temp. (°C)	-10.7	0.0 (jan 11-20)	-19.2 (jul 21-31)

Table 3 (left):
Extremes and Averages of Typical Year.

3.1. Solar Radiation.

High latitudes are characterized by high seasonal variations in solar radiation. This makes solar energy inadequate to year round operations but can make it useful for particular summer applications. PhotoVoltaic (PV) panels typically transform solar radiations into direct current with an efficiency of 10%.

Figure 3 shows the seasonal variation of the energy recoverable from an horizontal photovoltaics array at Dumont d'Urville during our Typical Year, assuming a 10% efficiency. The peak power over a decade is 32.9 W/m^2 (December 21-31) while the yearly average is 11.7 W/m^2. It is interesting to note that over the best three summer months (November to January), the average recoverable power is 28.2 W/m^2.

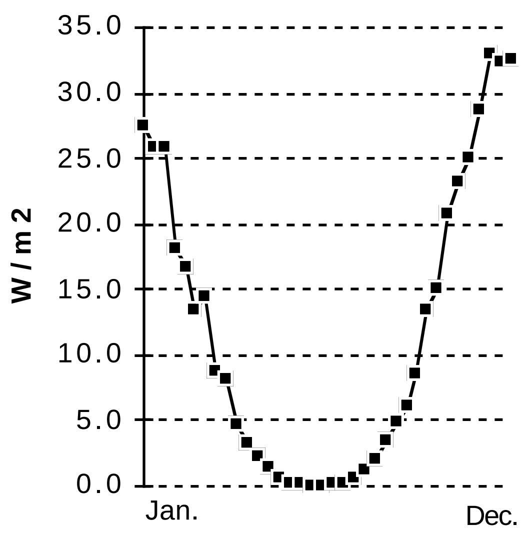

Figure 3:
Seasonal variation of the power recoverable from an horizontal PV array.

3.2. Wind Speed and Temperature.

The Energy content E of 1 m^3 of air (in J/m^3 or Pa) relative to an arbitrary "o" reference state is (Le Goff et al., 1993):

E =

$$|P-P_o| \quad \text{(I). Atm. Pressure Energy}$$

$$+ \; 0.5\,\rho\,|u^2 - u_o^2| \quad \text{(II). Kinetic Energy}$$

$$+ \; C_p\,\rho\,|T-T_o| \quad \text{(III). Thermal Energy}$$

$$+ \; L_{lv}\,|C-C_o| \quad \text{(IV). Drying Energy}$$

Where:
P= atmospheric pressure (Pa) (≈990 hPa along East Antarctic coast)
ρ= density of the air (kg/m^3) (≈1.3 kg/m^3 at 990hPa and -10°C)
u= wind speed (m/s)
Cp= specific heat capacity (≈1003 J/kg/K)
T= temperature (°C or K)
C= concentration of vapour (kg/m^3)
L_{lv}= latent heat of vaporisation of water (≈2470 kJ/kg at 20°C)

The gradients corresponding to each of these four energy components can be either time or space related depending on the choice of the reference state, but time gradients are not very practical to work with. Out of the four space gradients, two can be both consistent and practically recoverable: the speed gradient (ΔV between the air in motion and a fixed structure) and the temperature gradient (ΔT between the cold air and the 'warm' seawater). At Dumont d'Urville, like at the three other Antarctic coastal stations, the seawater is at a fairly constant temperature of about To= -1.8°C, close to its freezing point.

For our Typical Year, the two corresponding energy components (II-kinetic) & (III-thermal) are calculated for 1m^3 of air. By multiplying them by the wind speed, we obtained the amount of energy passing in one second through 1m^2 of vertical wind cross-section. The resulting unit is then (W per m^2 of vertical wind cross-section), noted (W/m^2 vt), relatively consistent with the unit used for solar energy (W per m^2 of horizontal surface or W/m^2 hz). The kinetic and thermal wind power, along with the solar power, are illustrated by Figure 4 and Table 4.

	Yearly Average	Highest Decade	Lowest decade
Solar	117	329.1 (dec 1-10)	0.6 (jun 11-30)
Wind Kinetic	726	1690 (mar21-31)	228 (jan 1-10)
Wind Thermal	121 072	236 324 (sept 1-10)	0 (dec21-jan20)

Table 4 (left):
Wind and Solar Power (W/m^2),
Extremes and Averages of Typical Year at Dumont d'Urville.
(Based on 1986-89 data)

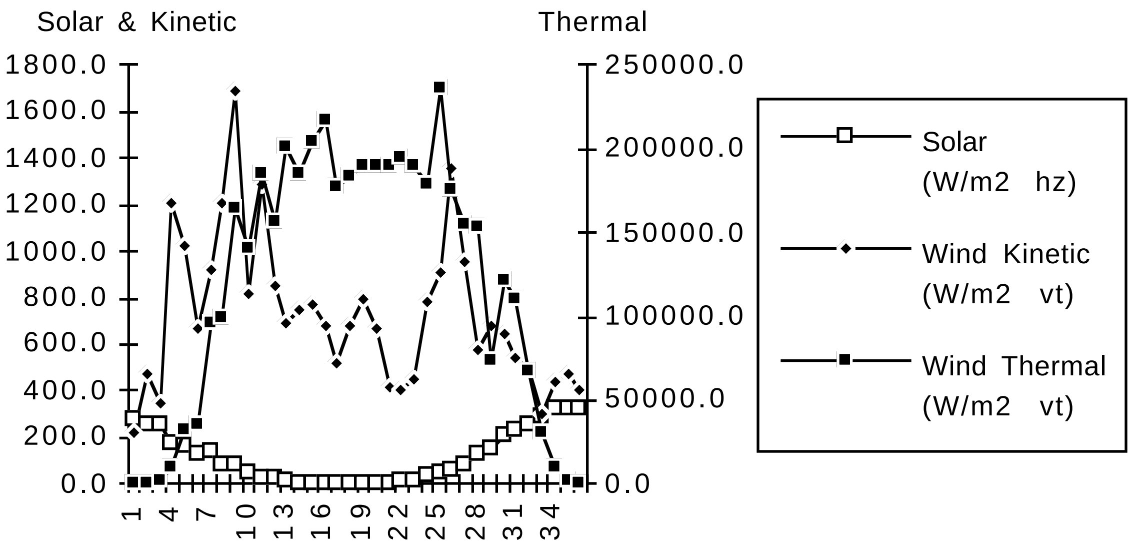

Figure 4: Typical seasonal variation of Wind Kinetic, Wind Thermal & Solar Power
(Dumont d'Urville, based on 1986-89 data)

The speed gradient can be used to drive a wind turbine. A realistic efficiency for a basic and reliable two bladed horizontal axis turbine producing electricity is:
ØWindTurbine= 25%.
This is the proportion of the wind kinetic power which will be transformed by the turbine into electrical power.

Le Goff et al. (1993) detailed the process of recovering the wind thermal power with the help of thermo-mechanical machines for electricity production or multistage absorption heat pumps for space heating. We will base our calculations on the first type of machines for proper comparisons with photovoltaics and wind turbines which provide electrical outputs. It has to be noted that heat pumps would produce heat with better efficiencies and should be well suited to space heating in the stations as their production capabilities would be coupled with the heating demands.

The thermo-mechanical machines are inspired from OTEC (Ocean Thermal Energy Conversion) machines. Their efficiency in converting Thermal to Mechanical power is:
ØTM= ØCarnot.ØReal.ØUsable
where:
ØCarnot is the "limit" Carnot efficiency of the machine cycle.
ØReal is the proportion of ØCarnot practically attainable in the machine.
ØUsable is the proportion of temperature gradient usable, that is the temperature drop ΔTusable of the air when passing through the exchanger.

With temperatures given in °Kelvin, the Carnot efficiency of the cycle is:
(ΔT-ΔTusable/2)/To
Values put forward for ØReal and ØUsable are of the order of 25%. They have to be confirmed and refined by proper in-situ trials of prototypes. A typical efficiency for an alternator converting Mechanical power into Electrical Power is ØME= 80%. Then the final Thermal to Electricity efficiency ØTE is:
ØTE= ØTM.ØME
which should be in the order of:
ØTE= 0.05 ØCarnot

The electrical power recoverable throughout the Typical Year from both the wind kinetic and thermal energies have been calculated for such efficiencies. The results are illustrated by Figure 5 and Table 5.

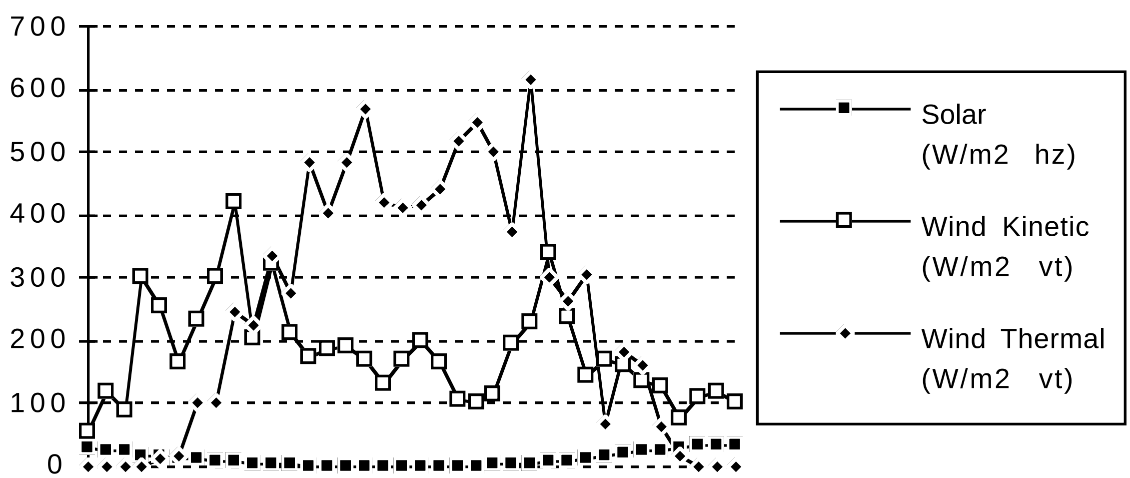

Figure 5: Typical seasonal variation of Recoverable Electrical Power.
(Dumont d'Urville, based on 1986-89 data)

	Yearly Average	Highest Decade	Lowest decades
Solar	11.7	32.9 dec 1-10	< 2.0 may1-aug20
Wind Kinetic	181.4	422.4 mar21-31	56.9 jan 1-10
Wind Thermal	246.1	616.9 sep 1-10	< 2.0 dec1-feb10

Table 5 (left):
Recoverable Electrical Power (W/m^2),
Extremes and Averages of Typical Year.
(Dumont d'Urville, based on 1986-89 data)

3.3. Recovering the Energy.

*Solar Panels

Photovoltaics work well in cold temperatures and are reliable technology. However, the low concentration of solar radiation (see Figure 5) requires large surface areas of panel arrays which are susceptible to damage in high winds. The other disadvantage is having virtually no production during the long winter darkness. Their use is therefore generally restricted to summer field camps with installed capacities ranging from twenty to a several hundred watts, sometimes coupled with small wind turbines.

For example, 60 to 90 w solar panels units successfully power radio repeaters linking Mawson to the Prince Charles Mountains, Davis to the Vestfold Hills and Casey to Law Dome. Near Dumont d'Urville, a 2 kW unit will, from 1994, provide power to an isolated accommodation-workshop shelter for lighting, cooking, radio transmission and gas-boiler control.

Photovoltaic panels typically transform solar radiation into direct current with an efficiency of 10% and cost of the order of $A 1,000 per m^2 (or $A 10 per rated watt, the ratings being generally based on a solar radiation of 1 kW/m^2).

*Wind Turbines

Small-scale wind generators were used and tested in the Antarctic as early as the first post-war expeditions of the 1950s. High failure rates due to both low temperatures and high powerful gusty winds, energy storage problems and the continuing need for complete back-up systems led to their withdrawal, with the exception of a few small field installations for charging batteries for scientific and communications equipment.

Most of the recent developments in wind turbine technology have been concentrated on large machines for industrial windfarms but small and medium size machines have found a niche and their technology is rapidly improving. Suppliers offer reliable (in most conditions) machines generating direct current rated up to a few kilowatts or grid-compatible alternating current from a few kilowatts to 50-60 kW. A survey is being carried out of such wind generators available on the world market. Their suitability for Antarctic conditions (very high, gusty winds with snow and ice particles and low temperatures) will be assessed. So far, most trials have not involved the manufacturers. The best way of achieving a reliable effective wind turbine for such conditions is by cooperation programs with selected manufacturers.

In recent times, tests on larger types of wind generators have been carried out by the French on a vertical axis Darrieus rotor in the sub-Antarctic at New Amsterdam Island (1986-88), by the Germans on a vertical axis H rotor in the Antarctic at Georg Von Neumayer Station (1991 to date) , and by the Australians on a horizontal axis turbine in the sub-Antarctic at Heard Island (1992-93).

At New Amsterdam Island, the 10 m diameter Darrieus rotor VAWT D10-2 (67.7 m^2 swept area, rated 30 kW at 13.5 m/s) was designed and constructed by the Centre d'Etudes Nucléaires de Grenoble which installed and monitored it in collaboration with the technical services group of the station. It showed good capabilities with daily energy production of 400 kWh recorded for wind speeds ranging from 12 to 25 m/s. High winds led to failures but there is still potential for improvements (Perroud et al., 1991).

At Georg Von Neumayer Station, the 10 m diameter H rotor (56 m^2 swept area, rated 20 kW from 9 m/s) has been developed as a joint project between the Alfred-Wegener-Institute, Germanisher Lloyd, Hochschulke Bremerhaven and Heidelberg Motor. It is characterized by simplicity (permanent magnet, no mechanical transmission). It has a survival wind speed of 68 m/s and a minimum operating temperature of -55°C. In its second year of operation, it is running continuously without interruptions and breakdowns and produces roughly 5% to 15% of the energy requirement of the station (Heidelberg et al., 1990; and Kohnen, pers. com., 1993).

At Heard Island, the 7 m diameter two bladed horizontal axis turbine Vergnet-Aérowatt UM 70X (38.5 m^2 swept area, rated 12 kW at 12 m/s) showed good performance in extremely variable, high, gusty winds. The unit operated over a three months period during which it produced an average of 62.2 kWh per day. Over the time of actual operation, the average output was 6.1 kW (Vrana, in preparation). This unit has a rated survival wind speed of 110 m/s which should make it worthwhile testing in the East Antarctic coastal stations where any outdoor structure has to be designed to withstand winds of 90 m/s.

*ThermoMechanical Machines and Heat Pumps

Preliminary studies have been performed by Laboratoire des Sciences du Génie Chimique (LSGC) in France on the exploitation by such machines of thermal gradients between the wind and Antarctic/Arctic waters (Le Goff et al., 1992, 1993). As seen in section 3.2, calculations indicate that if good overall practical efficiencies can be obtained, this method could provide, for the same cross section of wind used, more energy than rotating machines which exploit the kinetic energy of the wind. The potential for energy production is less constant throughout the year than from wind kinetics, but has the advantage of providing most energy in winter when heating requirements are greatest. The strong point is that this method involves far lighter and more reliable machines as no moving parts are exposed.

The first step towards proper assessment and development of such machines will be taken in January 1993 with the installation at Dumont d'Urville of the key component of the concept: the condenser or 'cold' captor. The experiment will be conducted in association by LSGC/CNRS and the technical services of IFRTP with direct funding and logistical support from IFRTP.

4. Possible Evolutions.

4.1. Short Term: Improvements.

Improving the current systems is the first logical step. It is, and has always been, one of the main preoccupations of the engineering staff running the stations. Power distribution networks at the stations are being tuned to progressively optimise and stabilise power needs. Incremental efficiency improvements have allowed effective increases in research activities and comfort with minimal power supply increases.

With the increasing capabilities of sensors, monitoring and control systems, computing systems and communications, new possibilities arise for detailed analysis and control of energy fluxes and consumption patterns. A first step has been taken with the installation, during the rebuilding of Casey, Davis and Mawson, of a Local Monitoring and Control System (LMCS) and some preliminary energy audit studies have been undertaken (Hall 1992). The Australian Antarctic Division (AAD) intends to develop the LMCS as a tool to provide data for more detailed analyses in order to identify areas where further efficiencies can be obtained with the current system of power production and distribution.

Devices such as electric lamps, pumps, transceivers and computers are regularly upgraded to more energy efficient products as technology advances. This is mostly carried out when new equipment is installed or devices are replaced on a routine basis.

While efficiencies are increased, work is done on lowering polluting emissions. Most improvements in this area are linked to engine technology and occur as engines are replaced or upgraded. Work on fuel composition and exhaust gas treatment could also lower atmospheric pollution, but further improvements can only have a marginal effect on emission levels compared to the introduction of alternative fuels or radically new systems. The Antarctic station operators will continue to take advantage of advances in this field while current technology is in use.

4.2. Medium Term: Introduction of New Fuels or Technologies.

• Introducing New Fuels.

The introduction of new fuels can address the pollution problem but can not solve the problems of purchasing the fuel and transporting it at high cost to the stations.

Preliminary investigations have been carried out by IFRTP on the use of power kerosene, as an alternative to diesel oil, to power the planned French–Italian inland station at Dôme C in the Australian Antarctic Territory (IFRTP 1992). Kerosene combustion is characterized by very low sulfur emissions. The use of kerosene will be monitored by IFRTP when Dôme C Station is operational.

The use in large quantities of fuels such as natural gas, liquid petroleum gas (LPG) and hydrogen has not yet been seriously considered for Antarctica because of assumed handling and storage difficulties. The technical and practical aspects of using alternative fuels are under review to assess their practicality and potential environmental impacts when used in conventional combustion engines, in catalytic combustion and in fuel cells.

• Introducing Renewable Energy as 'Fuel and Pollution Saver'.

This approach consists of using wind turbines, thermomechanical machines, heat pumps or photovoltaics to supplement the current systems. It will directly save fuel and reduce emissions.

The main disadvantage is that this does not eliminate the need for the entire current system. But such an option is ideally suited to the experimental phases of renewable energy systems.

• Introducing Fuel Cells.

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 energy demands of the Antarctic stations (Steel and Guichard, 1993).

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.

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.

Internally reforming fuel cells initially operating on the current fuels used in Antarctica can be modified to operate directly on hydrogen, bypassing the reforming process, with higher efficiencies and lower emissions. The next ideal step would then be to feed the fuel cells with hydrogen produced on site with the help of renewable energy.

4.3 Long Term: A Sustainable Station.

The ideal long term solution would be to achieve a sustainable station making use of the locally available renewable energy potential (see section 2). In addition to being clean, this eliminates the need for non-renewable fossil fuels and the difficulties and cost of transportation to Antarctica.

The first problem is the practicality and reliability of the various machines to be used to recover the renewable energy. Once this overcome, the biggest restriction on the viability of renewable energy systems is the necessity for large buffer storage capacity to match the irregular energy supply with the demand.

The most common types of storage are hydraulic storage, largely unsuitable for this situation (due to freezing of water in the Antarctic and environmental concerns in the Sub-Antarctic), and batteries which become decreasingly practical as the amount of stored energy required increases. However, intensive research work is under way around the world on battery storage systems, particularly by car makers in relation to electric vehicles.

Two other types of storage are being extensively investigated: hydrogen production and thermochemical separation of chemical components. The latter type complements the heat pumps and is being studied in connection with those machines at LSGC. At IASOS an investigation has commenced of all aspects of hydrogen production, handling, storage and utilization. This includes electrolytic plants, cryogenic and compressed gas storage and distribution, combustion engines, catalytic combustion and fuel cells.

Electrolytic plants produce hydrogen from water and electricity through a clean process. This is proven and reliable technology. Some units from The Electrolyser Corporation have operated for over 40 years with minimal but regular maintenance (every 10 to 20 years, some part replacements; minor part replacement more often but very inexpensive). Their recent PhotoVoltaics-Hydrogen unit commercially available has already operated for 900 days with 100% reliability -Out of doors- in a temperature regime of -25 to +25°C. Research targets for systems with fuel cells will include 18 months unattended operation at temperatures to -50°C (The Electrolyser Corporation, pers. communications, 1993).

The Hydrogen option is very versatile as the produced and stored hydrogen can be reconverted through various clean and efficient processes into electricity and heat (fuel cells), heat (catalytic burners) and mechanical work (combustion engines) to fulfill all station energy needs.

5. Conclusions.

The provision of energy to Antarctic stations is costly, difficult logistically and has significant environmental impacts. This makes any improvement of energy systems at the stations far more cost-effective than for most other places on earth.

Improving the energy systems is, and has always been, an everyday job for the technical staff of the agencies operating the stations. This staff has valuable experience and great motivation to pursue the development and implementation of new solutions.

The French and Australian Antarctic and Sub-Antarctic stations with their extreme conditions and comprehensive facilities offer valuable sites to develop and test advanced energy systems. In addition, the high international profile of activities conducted in Antarctica would allow successful systems to obtain substantial international recognition.

Researching and implementing clean and efficient alternative energy systems in Antarctica could have an invaluable role in perfecting and demonstrating promising systems to be used around the world.

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