Wind, Solar, Hydrogen, Fuel Cells...: Towards New Energy Systems for the Stations.

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The four Antarctic stations operated by Australia and France are situated on the harsh coast of East Antarctica lying some 3000 km south of Australia across the Southern Ocean. The area was first reached in January 1840 by French navigator Jules Dumont d'Urville sailing from Hobart on board *l'Astrolabe* and *la Zélée*. The ice cliffs of the coast occasionally give way to small rocky outcrops battered by katabatic winds which are the favoured locations for both animal breeding grounds and human settlements.

The first two scientific stations in this area were operated at Cape Denison in 1912 and 1913 by Douglas Mawson's Australasian Antarctic Expedition and at nearby Port-Martin in 1950 and 1951 by Expéditions Polaires Françaises. Data collected over these four years of operation showed that the average wind speed for the area was 18.5 m/s (67 km/h) with a record monthly average of 29 m/s (104 km/h) at Port-Martin. This probably makes it the windiest place on earth. The four permanent stations currently in operation at Mawson, Davis, Casey and Dumont d'Urville can all experience strong winds. Up to 90 m/s (324 km/h), average over 2 minutes, has been recorded at Dumont d'Urville. The four Sub-Antarctic stations of France and Australia, on Crozet, Kerguelen, Nouvelle-Amsterdam and Macquarie islands, also experience almost constantly strong, gusty winds.

The early expeditioners, not surprisingly, encountered reliability problems with wind turbines and despite high motivations for innovativesolutions had to admit at the time that conventional generator sets and boilers were the only satisfactory, practical answer to the reliable provision of energy required for research and for the safety of expeditioners.

Although continually improved, the present energy systems still rely on the same basic principles and consume large quantities of imported diesel fuel. Energy costs are high and exhaust gas emissions from stations are the most significant source of local air pollution in the near pristine conditions of Antarctica. The possibility of oil spills also threatens the polar environment and fragile ecosystems.

Technologies for cleaner, renewable energy production and energy storage are rapidly evolving and new, realistic options for alternative energy systems for the stations can now be considered. Preliminary investigations were conducted in 1993 in a joint French-Australian project to examine the feasibility of moving towards more efficient and cleaner stations independent or near independent of fossil fuels.

Wind, Solar...

The use of wind and solar energy is usually suggested as the "obvious" answer to the problem. A first estimate of the renewable energy potential at the stations has been made by examining meteorological data from Dumont d'Urville over the period 1986 to 1989[1] The original data are averages over 10 days periods, or decades.

Three power components have been estimated:

• Solar radiation vertical flux (W/m2)
• Wind Kinetic horizontal flux (W/m2)
• Wind Thermal horizontal flux available from the 'coldness' of the wind in relation to the 'warmth' of the sea (W/m2)

The potential solar and wind power are shown in Table 1.

Solar power can be converted by photovoltaic panels into electricity with an average efficiency of 10%. Wind kinetic power can be converted by wind turbines into electricity with 25% efficiency. Wind thermal power can be converted either into heat by a heat pump or into electricity by a thermomechanical machine driving an alternator. The recovery of this wind thermal power is only at its early development stage. The first machine components are being tested at Dumont d'Urville from January 1994. The latest estimation of expected efficiency for producing electricity is around 5% of the Carnot efficiency calculated on the total temperature difference between wind and seawater.

Taking these efficiencies into account, the estimated power recoverable is shown in Table 2 and Figure 1.

	Yearly Average	Highest Decade	Lowest decade
Solar	117	329.1 dec 1-10	0.6 jun 11-30
Wind Kinetic	726	1690 mar 21-31	228 jan 1-10
Wind Thermal	121 072	236 324 sept 1-10	0 dec21-jan20

Table 1:
Potential Wind and Solar Power (W/m^2)
Extremes and Averages, Dumont d'Urville.
(Based on 1986-89 data)[1]

	Yearly Average	Highest Decade	Lowest decades
Solar	11.7	32.9 dec 1-10	< 2.0 may1-aug20
Wind Kinetic	181.4	422.4 mar 21-31	56.9 jan 1-10
Wind Thermal	246.1	616.9 sep 1-10	< 2.0 dec 1-feb 10

Table 2:
Recoverable Electrical Power (W/m^2)
Extremes and Averages, Dumont d'Urville.
(Based on 1986-89 data)[1]

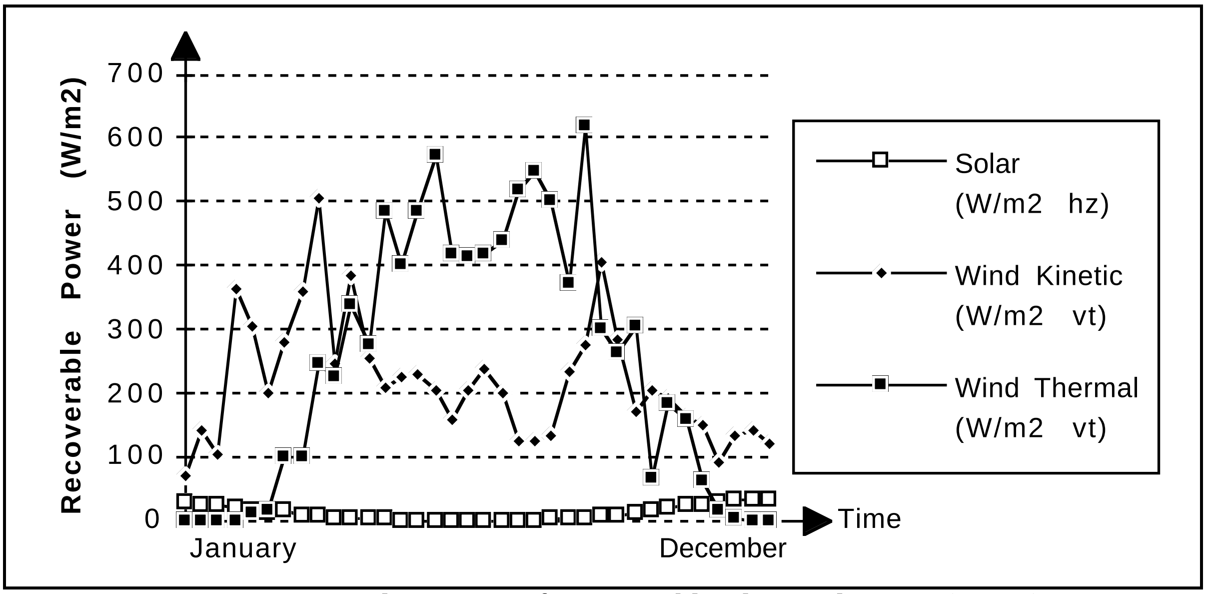

Figure 1: Seasonal variation of Recoverable Electrical Power (W/m^2).

[1] In: Guichard A. & Steel J. (1993) Alternative Energy Systems for Antarctic Stations: Investing for the Future, Second International Design for Extreme Environments Assembly, Montréal, Québec, 24-27 Oct. 1993. 17pp.

(Dumont d'Urville, based on 1986-89 data)[1]

To put this into practical perspective, in order to meet the typical annual average of 70 to 225 kW (electrical power only) required by the existing stations, it would require something of the order of :

- 6000 to 19200 m^2 of photovoltaic panels,
  i.e. an area the size of 23 to 74 tennis courts, or
- 385 to 1240 m^2 of wind turbine swept area,
  i.e. 10 to 32 turbines with 7m diameter blades, or
- 285 to 915 m^2 of condenser banks,
  i.e. a 3m high wall 95 to 305m long.

Those simple calculations, summarised in Table 3 only provide an order of magnitude for the size of energy captors. These results show that wind and solar energy cannot easily be the only answer to the provision of energy to the existing permanent stations, but can certainly be of valuable assistance. Proper sizing of systems will require elaborate simulations from specific meteorological data, precise equipment operating characteristics and stations power demand patterns. Collection of this information is under way.

Photovoltaics work well in cold temperatures and are reliable although expensive technology. The low concentration of recoverable power and long winter months of negligible solar radiation usually restrict photovoltaics to specific small scale applications.

Wind Thermal power has the most concentrated recovery potential, but its feasibility has still to be demonstrated. The potential is minimal during the long summer months but is highest in winter when the thermal needs of the stations are greatest.

Wind Kinetic is the most regular throughout the year. The reliability of wind turbines has not been fully demonstrated at the stations, especially at the more windy sites, but it is reasonable to think that satisfactory operations can be achieved with selected high-quality products after proper testing campaigns and minor adaptations. In McMurdo Sound, small 3 kW turbines (Northern Power Systems HR3) have operated since 1985 in gusts up to 71 m/s (256 km/h). At Heard Island in 1992/93, the field leader Attila Vrana successfully tested for 3 months a 12 kW turbine Vergnet-Aérowatt UM 70X which at times produced all of the electrical needs at the five persons Spit Bay station (see Figure 2). The UM 70X (now superseded by its new improved version Vergnet GEV 7.10) is a 7 m diameter two bladed horizontal axis turbine with variable pitch setting the blades at stall limit. The unit has a rated survival wind speed of 110 m/s (396 km/h), probably the highest available. This might be the largest size of turbine capable of achieving such ratings.

	Potential Power	Assumed Recovery Rate	Recoverable Power	Captor area needed to produce 70 to 225 kW	
	(W/m^2)		(W/m^2)	(m^2)	Equivalent to:
Solar	117	10%	11.7	6 000 to 19 200	23 to 74 tennis courts in area
Wind Kinetic	726	25%	181.4	385 to 1 240	10 to 32 turbines 7m diameter blades
Wind Thermal	121 072	5% of Carnot Efficiency	246.1	285 to 915	3m high condenser bank 95 to 305m long

Table 3:
Size of Renewable Energy Systems to produce electrical power at the stations.

Figure 2:
Wind Turbine Vergnet-Aérowatt UM70X at Spit Bay, Heard Island, in front of Big Ben.
(Australian Antarctic Division Photograph by Attila Vrana, 1993.)

During the testing phases, or for small to medium scale use of renewable energy to supplement power to the stations, power produced can simply be injected into the existing grid upon availability. This use of renewable energy as 'fuel and pollution saver' does not eliminate the need for the current diesel based systems but has the advantage of not requiring any storage medium. This option is ideally suited to the introductory phases of renewable energy systems.

Hydrogen...

Larger scale systems would directly feed power into the grid as much as possible, but would also require large buffer energy storage capacity to match the irregular energy supply with the demand. Hydraulic storage (i.e. using water reservoirs) is not suited to the stations and electrical storage batteries become decreasingly practical as the amount of stored energy required increases. A very promising option is to use hydrogen as storage medium: produce it on site with excess electricity, store it, then use it as needed.

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

Since the hydrogen filled dirigible *Hindenburg LZ-129* burst into flames (not exploded) on 6 May 1937 when landing at Lakehurst, New Jersey, killing 25 of the 97 people on board, hydrogen has had the reputation of being unsafe. Although hydrogen remains a hazardous substance, its safe use is now being demonstrated in established facilities world wide, with over 750 km of commercial gaseous hydrogen transport pipelines operating on a routine basis.

Hydrogen is increasingly being accepted as a practical alternative fuel and current large scale projects include producing hydrogen in Québec with hydro-electricity from Baie James and shipping it to Europe (Euro-Québec Project). The Gouvernement du Québec and the Union Européenne are funding intensive research to develop a variety of hydrogen powered equipment, from home cooking stoves to motor vehicles to aircrafts.

Electrolytic plants can produce hydrogen from water and electricity through a clean process. This is proven and reliable technology, already used at some of the stations to provide hydrogen for the meteorological balloons. Some units from The Toronto based Electrolyser Corporation have operated worldwide for over 40 years with minimal but regular maintenance. Their recent PhotoVoltaics-Hydrogen unit commercially available has already operated out of doors for 1000 days with 100% reliability in a temperature regime of -30 to +30°C. The manufacturer's research targets for systems with fuel cells include 18 months unattended operation at temperatures to -50°C.

It is proposed that, as a first step towards the clean production and use of hydrogen at the stations, the existing Electrolyser units be powered with a combination of wind-turbines and photovoltaic arrays instead of from the diesel based power grid. The excess hydrogen not required by the meteorological balloons will be used for small scale pilot projects, which could include powering a vehicle with a modified combustion engine, providing some space heating with a catalytic heater and generating electricity with a fuel cell unit.

Fuel Cells...

Conceptually simple and environmentally attractive, a fuel cell is an electrochemical device which efficiently recombines hydrogen and oxygen into water, releasing electrons and heat with negligible polluting emissions and noise. It offers an attractive solution to the production of electricity in a compact, quiet, highly efficient, and exceptionally clean manner. The modular structure of the cells assembling gives a large flexibility in systems sizing. Used by NASA aboard space vehicles as far back as the Apollo program, fuel cells are now moving towards the large scale commercial production stage through intensive research and investment.

Different types of fuel cells are under development, such as the Phosphoric Acid, Molten Carbonate (also referred as Direct) and Solid Oxide Fuel Cells, respectively known as PAFC, MCFC (or DFC) and SOFC. The Phosphoric Acid is the most developed and ready for market release while the Solid Oxide seems the most promising. In Australia, Victorian based Ceramic Fuel Cells Pty Ltd (in which BHP and CSIRO are partners) is actively developing Solid Oxide Fuel Cells technology.

The useability and final efficiency of a fuel cell based system also depend widely on its power conditioning component. Leading development in this field is being undertaken in Western Australia by Perth based Murdoch University Energy Research Institute (MUERI) and Advanced Energy Systems Pty Ltd.

Fuel cells and diesel generator sets produce similar types of energy: electrical and thermal. This makes possible the addition of fuel cell units to the existing powerhouses in parallel with the diesel generators. An effective power conditioning system as being developed in Perth would even provide additional capacities to the powerhouse and lead to an improved use of the diesel generators by adding new load regulation capabilities.

Although the most efficient and clean option is to use hydrogen locally produced from renewable energy, fuel cell units can also operate on traditional fossil fuels such as diesel, LPG or kerosene. A 'reformer' extracts from such fuels the hydrogen which then feeds the cells. Even though the presence of the reformer decreases the overall efficiency, such units are already competitive with the traditional generator sets and, first and foremost have much lower emissions. This versatility allows the fuel best suited to the application to be chosen. For example, this can be the cheapest, the easiest to ship or the least hazardous.

Introducing such fuel cell units operating on imported fuels, without solving all the problems, could cut down the quantities of fuel to be shipped, and considerably lower the polluting emissions at the stations. The US National Science Foundation is funding research to demonstrate the Molten Carbonate Fuel Cell (MCFC), or Direct Fuel Cell (DFC), to power the permanent and temporary scientific research stations of the US Antarctic program using diesel or sulfur free JP8 (SFJP8) fuel.

...Towards New Energy Systems for the stations.

Wind and Solar Power, Hydrogen and Fuel Cells offer a wide range of combinations to move towards improved energy systems. While smaller and simpler stations, as well as field camps, could move towards energy sustainability with wind and solar power coupled with hydrogen systems, the larger existing stations will probably have to remain partly dependent on imported fuels. Fuel cells have the capability of using those fuels in the most efficient and clean manner. Some of the possible combinations are synthetised in Figure 3.

The effective use of wind and solar power needs both the availability of reliable equipment and a detailed assessment of the potential at the stations to satisfactorily design and size the systems. Intensive equipment testing campaigns are under study in collaboration with Vergnet-Aérowatt. The detailed assessment of renewable energy potential is under way, and the Australian Antarctic Foundation has provided a special scholarship for a higher degree research student at IASOS to contribute to this work from March 1994.

Safe technology for hydrogen production and handling exists and only requires minor testing in Antarctic field conditions. Demonstration of hydrogen uses requires more work as most hydrogen powered devices are still under development. Some testing can start now with simple available products like vehicle engines or space heaters. The presence at some stations of Electrolyser units not used to their full potential allows experiments to be commenced quickly and cheaply.

The development of fuel cells and associated power conditioning equipment is being actively pursued worldwide and some units are reaching the commercial stage. The Australian activity in this area is most interesting and a possible collaboration with MUERI and Advanced Energy Systems could lead within a few years to the installation of an experimental unit.

A lot of work is still required before efficient, cheap and environmentally friendly energy systems can be a mainstay for the stations, but we can now catch a glimpse of its reality.

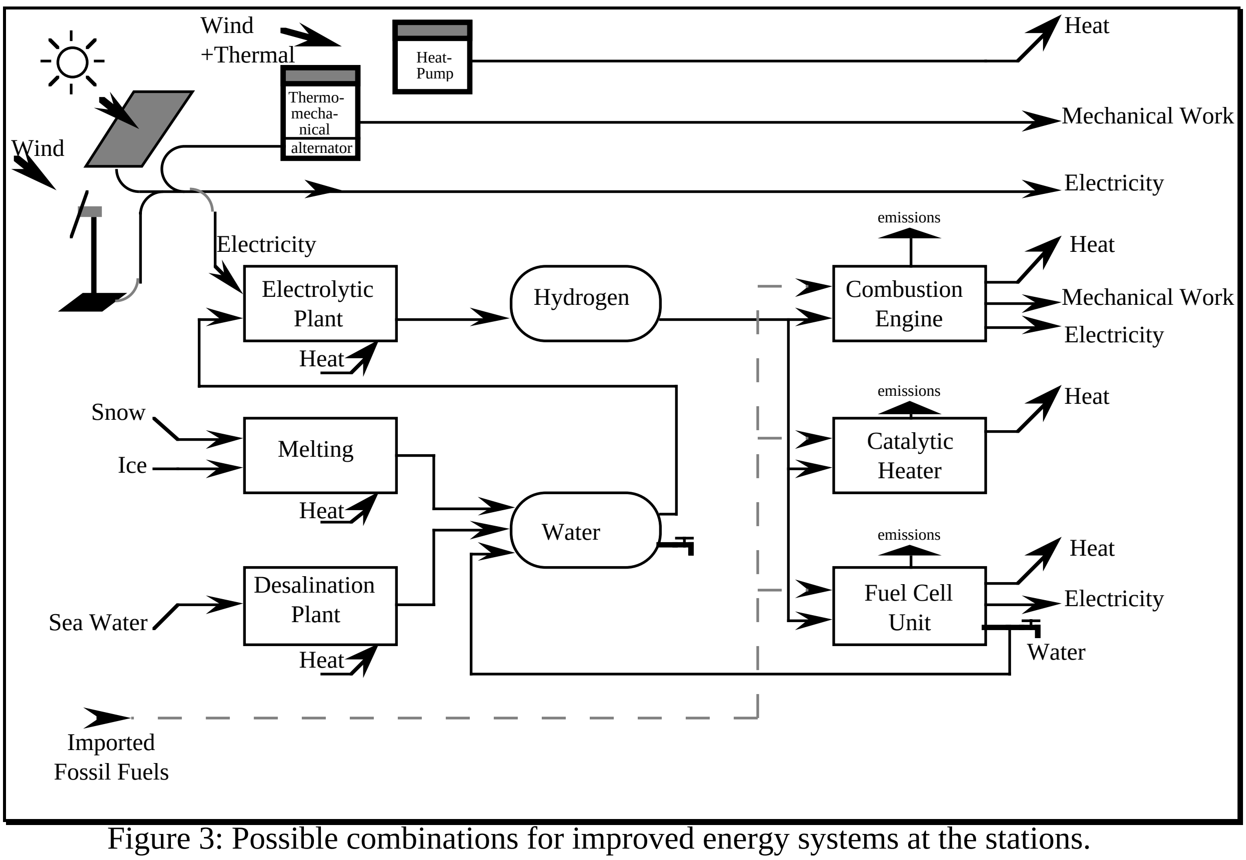

Figure 3: Possible combinations for improved energy systems at the stations.