Progress

A Stirling idea

Left to right: The system's innovative solar dish uses polished stainless steel rings. The back of the solar dish showing placement of the salt cell tank which in turn connects to the Stirling generator below. Detail of the salt cell tank and generator. Neil Armstrong

An innovative Australian spin on the simple age-old technology of the Stirling engine could be the answer to one of our region's more pressing problems – the need for a cheap, portable, low maintenance renewable energy unit. The economical 'solar Stirling' generator is all the more remarkable for its combined desalination and heating or cooling capacity.

Unlike other renewable energy systems, the solar Stirling system is unique in that it combines the simple efficiency of early 1800s Stirling engine technology with an inventive spin on conventional solar, wind and heat cell technologies. The resulting unit can be attached to any electrical or thermal desalination system, or to an absorption chiller for air conditioning or refrigeration. The only by-products are hot water and electricity, and a single unit will repay its CO_2 footprint (the amount of CO_2 generated in its production) within 18 months.

The 'hybrid solar Stirling and wind turbine micro-power system' was developed by Patrick Glynn of the CSIRO Sustainable Mining Group, Peter Olds of OLDS Engineering, and Control Technologies International Pty Ltd (CTI), in response to the need for an uninterrupted power supply at a remote Queensland mine site. While photovoltaic cells were an option, Glynn says the initial capital and ongoing maintenance – such as battery replacement – was high. There was also the challenge of battery backup in periods of prolonged bad weather.

'The problem got me thinking about a project I'd been working on in the 1970s with Philips Electrical, involving a Stirling engine coupled with an electrically charged phase change material heat cell,' Glynn recalls. 'There was some discussion about using solar energy to charge the heat cell, but the technology wasn't advanced enough to pursue the idea.'

With the problem at the forefront of his mind, Glynn chanced upon Peter Olds and his Stirling engine museum in Maryborough, Queensland. The pair struck up a collaboration, which resulted in a modified version of the 200-year-old Stirling design (see box), which could produce 3 kW hours of electricity and easily supply the 21 kW hours per day consumed by the average home.

'Extensive development has been completed on this engine so that we can retain its reliability and efficiency, and manufacture and produce it at a reasonable price,' Glynn says.

Desalination technology

The rotary mechanical energy generated by the modified Stirling engine can be used to drive a desalination unit which, like other components that attach to the engine (see below), has been designed with performance, and production and maintenance costs in mind. Designed by Glynn and CTI, the desalination unit uses a vacuum to reduce the boiling point of salt water to 40–50°C. This reduces the energy input into this typically energy intensive process (see **Making water – hold the salt**, page 23). The unit can supply 300 litres of distilled water per hour, 24 hours a day, and produces 'latent' heat (see 'Just add salt', below), which is siphoned off and reused.

'If we capture the latent heat of vaporisation from the condensing pure water, we can be as efficient as, or even better than, a reverse osmosis system – and no CO_2 is produced,' Glynn says.

The distilled water is purified using a

Patrick Glynn and Control Technologies International Pty Ltd's Jim Slade beside a working prototype of the solar Stirling unit. CTI/Glynn/Olds

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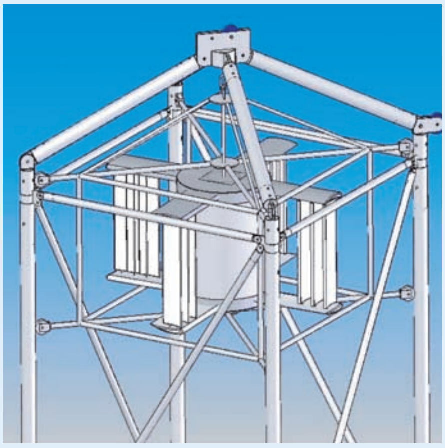


Left to right: CTI’s unconventional wind turbine provides auxiliary power to maintain heat in the salt cell. The turbine uses efficient Venetian-blind-type sails. A two-dish system in situ, similar to those being employed on Fraser Island. Neil Armstrong

colloidal silver electrode system developed by CTI. These inexpensive and long-lasting (five years) electrodes kill bacteria and viruses in a single pass. At around $1000, the desalination unit would be a robust, portable and easily maintained alternative for remote areas or developing countries. In emergencies or disasters where water supplies are compromised – such as during the recent Asian tsunami crisis – it could be a godsend.

‘We wanted the whole renewable energy-desalination system to be as simple as possible. In fact, it can be put together with a screwdriver and pliers,’ Glynn says.

Solar rings

Like the desalination unit, the key components of the solar Stirling renewable energy system – a solar dish and thermal cell – are a study in ingenuity.

Take the solar dish. Conventional solar dishes are one of the more expensive elements of a renewable energy system, given the skill and precision required in making them, the cost of materials, and the need for maintenance. CTI has found a way around this, producing a dish for about $1700 compared to the $10 000–12 000 for a conventional dish.

‘The solar dishes currently on the market have reflective material or mirrors that are usually coated with a clear polymer to protect the surface. This coating is degraded over time by ultraviolet rays and the glass mirrors are susceptible to damage by hail,’ says CTI’s Jim Slade.

‘CTI has overcome these problems by using polished stainless steel rings, which are cut to emulate sections of a parabolic mirror and set on a simple spoke frame. The dish has a larger solar capacity than a parabolic dish of equivalent square area because the concentrator rings are set flat instead of dished, requiring less area for the same-presented collection face. And because of the method of construction, the CTI dish can be any size.’

The stainless steel rings can be packaged flat for transport and assembled on a skeleton frame using a clamp that ensures the rings are attached at the correct angle and distance. CTI has also developed a low cost solar tracker to enable the dish to track the sun in summer and winter.

Just add salt

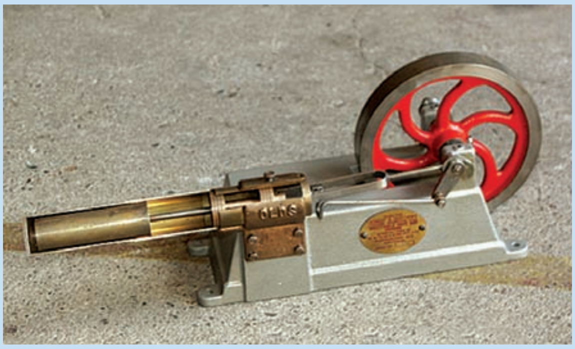
Attached to the solar dish is a ‘phase change’ heat cell containing salt and

The Stirling heat engine

The Stirling heat engine, invented by Scot Dr Robert Stirling in about 1816, is very efficient– far more efficient than an internal combustion engine. It converts heat into useable mechanical energy (via a drive shaft) by the heating (expanding) and cooling (contracting) of a captive gas such as helium or hydrogen.

In another solar-powered Stirling engine, hydrogen is alternately heated and cooled to drive a piston up and down, converting solar heat to electricity. The system is closed (no fuel or cooling water is required) and produces little noise during operation.

So far, Stirling engines have never made it into common use because they have had very low power-to-weight and power-to-volume ratios. That is, they have been big and heavy for the amount of power they provide.



A cut away of a beta type Stirling engine, showing the displacer, power piston and crank with flywheel. Peter Olds

Progress

A solar Stirling prototype being demonstrated for Maryborough school children. CTI/Glynn/Olds

graphite (as a heat conductor). This cell can store 9.5 times more energy than the same sized lead-acid battery used in photovoltaic systems. It can also store 100% of the solar energy directed into it, compared to only 15% for photovoltaics.

'Our system will operate at least four times more efficiently in combined heat and power mode than photovoltaics, and the salt cells will last in excess of 25 years, or the operational life of the Stirling engine,' Glynn says.

As the salt cell absorbs energy from the solar dish, the salt reaches temperatures of 600–900°C. While more energy is absorbed, the temperature remains the same but the salt changes phase from solid to liquid and stores energy as 'latent' heat that can be siphoned off to heat air and water.

'The process is the same as when you boil water to make steam,' Glynn explains.

'To boil 1 litre of water at 100°C you will have to put in about 300 kJ of energy. To change it to steam at 100°C you need to put in another 2.2 MJ or approximately eight times that amount of energy. The temperature stays the same, but the water changes phase from liquid to gas and absorbs energy as latent heat.'

Glynn and Slade say the innovative aspect of this technology is the ability to store thermal energy from the sun within a cell containing salt or other material; to convert this stored energy into mechanical energy with a heat engine; and then to generate electrical energy in the same way organic fuel is used in an internal combustion engine. 'Instead of having a fuel tank of diesel or petrol, we have a fuel tank of hot salt,' Slade says.

'The beauty of salt is that you can take it to 900°C, where it melts; then you can take it to 1500°C. Nothing changes; it just holds the heat. Then it slowly releases the heat until it's solid, and continues to release heat for a number of hours after that.'

'When you measure diesel or petrol, you're measuring kilowatts of energy that are dormant in the fuel and released when the fuel is compressed or burnt. In the case of salt, energy is dormant as latent heat. As the heat is used up, the temperature of the salt drops, just like the level in a fuel tank would drop. When the temperature gets to 550–600°C the efficiency drops, and we need the sun to top it up to 900°C.'

Putting it together

When the Stirling engine is connected to a 5 m solar dish and salt cell, Glynn says it can produce up to 5 kW hours of electricity and 20 kW hours of hot water (at 50°C), on an intermittent basis and at a combined heat and power efficiency of more than 80%. This is enough to cover domestic electrical (5 kW/h) and hot water (3 kW/h) needs and an absorption chiller for air conditioning (12 kW/h) - with energy storage for approximately four days without sunshine.

The Stirling engine operates at two contrasting temperatures at the same time - around 50°C on one side and up to 900°C on the other. In a domestic situation, cold water feeding into a hot water system is diverted into the cold side of the engine, to cool it. On the other side of the engine, air heated by the salt cell drives a power piston,

Hot water is a free by-product of the Stirling engine, and can be stored in the existing hot water tank with an electric backup.

which turns a crankshaft, to run an alternator that feeds electricity through an inverter. This provides a stable 240 V into a house.

Hot water is a free by-product of the Stirling engine, and can be stored in the existing hot water tank with an electric backup. Any excess can be used in an absorption chiller for air conditioning.

Glynn says the whole system will retail for about $15 000, with government grants. For another $7000 a wind turbine designed by CTI can be added. The turbine consists of Venetian-blind type sails which close onward to the wind, to provide a large surface area, and open up to reduce drag as the turbine rotates. The turbine will connect to 7 kW of electric heating elements embedded in the heat cell so that energy from the wind can be used to keep the salt in liquid phase.

Demonstrating the technology

A demonstration of the solar Stirling power system will be set up at Dilli Village on Queensland's Fraser Island. This Sunshine Coast University campus consists of about 16 buildings drawing 22–25 kW of power from diesel generators. As Fraser Island has some of the most remarkable freshwater lakes in the country, the University wants to remove the diesel generators – and the resulting threat of contamination – from the site. Two solar Stirling power units and a wind generator will be installed to supply the power requirements and Glynn is confident they will do the job.

Glynn says the demonstration offers the exciting prospect of mass-producing 200-year-old Stirling technology and 100-year-old high temperature energy storage technology; and not before time.

'Easy access to oil has meant that developments in these and other areas have been under-funded or ignored,' he says.

'Hopefully when we demonstrate the solar Stirling project, we'll get long overdue investment in this technology.'

● **Wendy Pyper**

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