Alternative energy opportunities for rural industries

Short report 7 Other technologies

by Dr Chris Colby, Dr Vince O’Brien and Bronwyn Colby
Other technologies

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Short report 7: Other technologies

This AgriFutures Australia short report introduces a selection of technologies not already discussed in previous reports as part of the Alternative energy opportunities for rural industries series. Some of these technologies can generate or produce energy, recover waste heat, and/or store energy that supports a transition to alternative energy.

Previous reports have investigated solar PV, battery storage, biofuels, wind power and hydrogen energy. However, there are others that could be immediately useful or of future interest to Australian rural producers and farmers.

The alternative energy technologies discussed in this short report are at various stages of maturity in Australia, from R&D and demonstration through to being well-established. Most are commercially available and some complement more widely known technologies, such as solar PV.

Table 1. Alternative energy technologies discussed in this short report.

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Other solar technologies

Solar hot water

Solar hot water heating systems use solar energy from the sun to produce hot water (instead of electricity like solar PV). Energy recovery achieved, and the “quality” or temperature of hot water produced, depends on the system design. The most common systems are:

- **Evacuated-tube solar hot water collectors** can achieve energy recovery up to 60-70% and achieve temperatures of 90 °C in summer.
- **Flat plate collectors** may only heat water to 60 °C and have energy recovery of 40-50%.
- **Plastic tube or strip collectors** like those widely used for pool heating may only heat water to 40-50 °C at an energy recovery of 30-50%.

Like solar PV, energy output or hot water produced by these systems depends on sunlight, which is only available during the day, is variable from day to day, and changes from season to season (especially in southern Australia). Consequently, most systems require storage tanks to hold hot water for when it is needed, and/or electric or gas hot water boosters for when solar heating is not sufficient on its own.

Solar hot water heating systems can directly heat water by passing it through the collector, but others may use heat exchangers to indirectly heat water by recirculating a separate heat transfer fluid through the collector.

Costs of solar hot water systems vary and are influenced by the scale of the system, collector design, supplier and installation costs. Rebates can be available to offset the cost, depending on system size and/or location, but are usually targeted at smaller residential systems.

Solar hot water heating generally only makes sense when you need hot water (e.g., for heating, cleaning, processing). It is still most widely used in residential or small business situations for domestic hot water heating. For commercial situations, the technology has struggled to compete on cost with natural or liquified petroleum gas, and even solar PV where electricity is used with a heat pump system for hot water heating.

Solar hot water heating can recover up to 60% of the solar PV panel waste heat (or up to 50% of the solar insolation), and the hot water produced ranges in temperature from 40-60 °C.


Solar photovoltaic thermal (PVT) hot water production

Solar PVT combines solar PV with solar hot water heating (or sometimes air heating). Solar PV is only 20% efficient in converting sunlight into electricity. Much of the other 80% of sunlight shining on solar panels is converted to heat. This heat can cause solar panels to heat to 60-70 °C, especially during summer, which can reduce their electrical output by 10-20%.

Solar PVT technologies attach or integrate tubes or piping with the Solar PV panels that carry water (or ducts for air) to absorb this otherwise wasted heat and cool the panels at the same time (Figure 2). This arrangement enables hot water (or air) to be produced and improves solar PV panel efficiency (and electrical generation) on hot days.

Solar PVT hot water heating can recover up to 60% of the solar PV panel waste heat (or up to 50% of the solar insolation), and the hot water produced ranges in temperature from 40-60 °C.

The cost of solar PVT for hot water production can be more than double that of solar PV alone. And like any solar hot water heating system, hot water is only available when the sun shines. It therefore needs a hot water storage tank and/or electric or gas hot water boosters for when solar heating is not available or sufficient on its own.

At present, there are few commercial solar PVT products available in Australia. But there is growing commercial interest in the technology due to recent gas price rises, as it can produce both renewable electricity and hot water at the same time. This interest has sparked several technology start-ups, such as PVT Lab¹ and Sunovate², to investigate developing the technology.

Figure 2: Illustration of a solar PVT panel with tubes or piping underneath the panel to absorb waste heat and produce hot water. Source: Imperial College London, https://blogs.imperial.ac.uk/chemical-engineering/2018/11/06/one-stone-two-bird-synergies-next-generation-solar-technologies/.

Concentrated solar thermal (CST) uses mirrors or reflectors to concentrate (or focus) sunlight. This concentrated sunlight can be used to heat a fluid such as water, oil or molten salt, or to directly produce steam. The captured energy can be stored and used for heating or to generate electricity (via a steam turbine or organic Rankine cycle process). There are many different configurations of how mirrors are organised to concentrate the light and how this focused light is used to heat the fluid or produce steam (Figure 3).

For electricity generation, an advantage of CST systems is that by storing a heated fluid or molten salt, they provide a dispatchable energy supply to meet grid demand. This makes them more flexible than traditional solar PV plants.

In Australia, with its abundant solar resource and land, there has been much talk over the past two decades about large CST plants for grid power generation. But none have been built due to a lack of technology demonstration and a perceived high cost that makes them uncompetitive against solar PV plants and wind farms.

The only three CST plants that appear to have been built are:

- 9.3 MW facility in New South Wales to pre-heat feed water for the Liddell coal-fired power plant.
- 30 MW thermal-collector tower where concentrated sunlight is turned into steam for heating and to drive a turbine to generate electricity.
- A hydroponic tomato farm in South Australia has also installed a 39 MW state-of-the-art solar thermal system to heat its greenhouses, generate electricity and desalinate seawater (Figure 4).

Despite its low uptake to date, CST is a technology that could help Australia tackle the problem of insufficient dispatchable electricity supply as coal-fired power stations are shut down and gas turbines are phased out.

Despite its low uptake to date, CST is a technology that could help Australia tackle the problem of insufficient dispatchable electricity supply as coal-fired power stations are shut down and gas turbines are phased out.
Heat pumps for hot water or air heating

Heat pump technology uses electricity to heat water or air. It operates on the same principle as the heating setting on a reverse-cycle air conditioner – by transferring thermal energy from the air outside using the refrigeration cycle (Figure 5).

In the same way as reverse-cycle air conditioners, heat pump technology uses a smaller amount of electricity to transfer a larger amount of heat. For example, a 1 kW heat pump system can produce up to 3 kW of heating from 2 kW of heat extracted from outside air. This property is called the coefficient of performance (COP), which is the ratio of heating provided to the energy consumed by the system.

\[
\text{COP} = \frac{\text{Heating provided (Q)}}{\text{Electrical input (W)}}
\]

This COP value is not fixed and can vary from as low as 2 up to 5 depending on the outside temperature and the temperature of hot water (or air) being produced. A lower outside temperature reduces the COP and vice versa; and a higher hot water temperature reduces the COP and vice versa.

Depending on what tariffs are being paid, the COP of heat pumps can make electricity more competitive (and sometimes cheaper) than gas for heating. For example, if an electricity tariff is 30 cents/kWh, then at a COP of 3, its equivalent gas tariff would be 2.8 cents/MJ or $28/GJ (i.e., 30 cents/kWh ÷ 1/COP ÷ 1 kWh ÷ 3.6 MJ).

Heat pump technology is becoming popular in Australia for residential hot water heating where gas supply is not available or to replace gas altogether, especially where renewable electricity from solar PV can be used.

To minimise the size and cost of the heat pump equipment and/or to maximise the use of solar PV, these systems are installed with hot water storage tanks. The tanks balance out peaks in heating demands and/or hold the hot water until it is needed.

Commercial interest and applications of the technology are emerging, again in response to rising gas prices and/or where businesses want to avoid gas for heating to reduce their greenhouse gas emissions.

Figure 5: Illustration of how heat pumps operate to extract heat from outside air and use it to heat air or water. A lesser amount of electrical energy is used to bring a larger amount of heat energy in from outside and heat water or air. In this example, 1 kW of electricity transfers 2 kW of heat from outside, delivering 3 kW of energy for heating (i.e., a COP of 3).

Phase change materials (PCM) energy storage

While not a technology that can generate alternative energy, a phase change material (PCM) is a substance that releases or absorbs energy during a phase transition (e.g., evaporation, condensation, freezing, melting, salt dissolution). It can therefore store and release alternative energy.

The most immediate and widely used example of a PCM is water, which many rural producers and farmers often use for heating and cooling. For example:

- **Evaporative cooling**, where evaporation of water from a liquid to a gas absorbs energy, thereby cooling the air around it.
- **Ice**, where melting of frozen water absorbs heat from water around it, thereby cooling it.
- **Steam heating**, where steam is condensed in a tank jacket or heat exchanger to heat a fluid on the other side.

Other practical examples include:

- **Dry ice**, where sublimation (or vaporisation) of solid carbon dioxide (CO₂) can be used to keep packaged product cold during transport over long journeys.
- **Hot and cold packs in medical kits**, which dissolve a salt (e.g., ammonium nitrate or urea) in water to create a heating or cooling effect from energy released or absorbed by the salt’s reaction with the water.

Many existing and new PCMs are being developed for commercial application, which could help rural producers or farmers. Some of these commercial applications include:

- **Ice storage of refrigeration energy**, where vessels store refrigeration energy by freezing water into ice using daytime solar PV, enabling the refrigeration energy to be released at night or another time (Figure 7).
- **Building materials**, where PCMs are being embedded into building materials like concrete or dry wall, or between building panels, to absorb and release energy to keep a room or space temperature stable, balance HVAC demands and/or store daytime heating for night-time use (or vice versa).
- **Food preservation**, where pads or packaging materials contain PCMs to keep the food cold or chilled during transport, even if refrigeration or freezing fails or is not available.
- **High-temperature energy storage systems**, which use metals or minerals (e.g., salts, silicon) that melt at high temperatures to store energy from concentrated solar thermal (CST) or bioenergy plants, so it can be used later to generate electricity or provide heating.

Figure 7: A commercial ice-based energy storage system for refrigeration energy. Source: Evapco, www.evapco.com.au/products/thermal-ice-storage/ice-pakr-thermal-energy-storage-units.

Figure 8: Example of a commercial PCM product that can be incorporated into building materials. Source: Architecture & Design, www.architectureanddesign.com.au.
Organic Rankine cycle (ORC) waste heat recovery

The organic Rankine cycle (ORC) is a process that generates electricity from lower-temperature waste heat. It is commonly considered when waste heat temperatures are not high enough (<250 °C) for viable electricity generation from steam.

The process works like a refrigeration process in reverse (Figure 9):

- A process fluid is evaporated by waste heat into a high-pressure vapour that can be used to drive a turbine to generate electricity.
- After the turbine, the resulting low-pressure vapour is condensed back into a liquid and pressured using a pump so it can be evaporated again to repeat the process.

The efficiency of the ORC process in recovering electricity depends on the process fluid properties and the temperature of the waste heat. The process fluid is usually a conventional refrigerant or other hydrocarbon-based material (e.g., pentane), which boils at a lower temperature than water. In many cases, the ORC process can reach an (electrical) efficiency of up to 25% at waste heat temperatures of 200-250 °C, but this efficiency can drop to less than 10% at 100 °C.

ORC technology can be used by rural producers and farmers to recover electricity from waste or low-grade heat produced from geothermal, solar or bioenergy sources (Figure 10).
Geothermal energy

Geothermal energy is a renewable heat source that relies on heat generated from deep within the Earth, mostly from decay of radioactive elements. It is why the temperature of the Earth’s core can be up to 5,000 °C. This geothermal energy from the core is constantly radiating outward and warming rocks, water, gas and other geological material (Figure 11).

In most parts of the world, the geothermal temperature gradient is about 25 °C per kilometre of depth from the surface (e.g., at 10 km deep, the temperature would ordinarily be 250 °C). However, there are locations where geothermal activity and higher temperatures emerge closer to the surface, which makes the energy easier and more affordable to access.

Geothermal energy has been, can be or is used in various ways to produce electricity or heat. For example:

- **Deep bore hole steam or hot water extraction** — water is injected deep below ground (to 10 km) to produce steam or hot water brought back to the surface, for heating or to produce electricity (using a steam turbine or other fluid via the organic Rankine cycle3).

- **Subsurface heating or cooling**, where pipes are laid 3-5 m below the surface to extract or disperse heat in air or water that is usually used (but not always) in combination with a heat pump for heating or cooling a house, office or factory.

While there are many examples of geothermal energy being successfully used overseas, it has had little uptake to date in Australia. Despite several demonstration and operational plants being built for electricity generation in Australia, none are operating at the time of writing. There are examples of subsurface systems installed for housing, but these have usually been more expensive than traditional heating and cooling systems, and application has therefore not been widespread.

Nevertheless, geothermal energy could offer future opportunities for rural producers and farmers wanting to address rising gas prices or reduce their greenhouse gas emissions. Perhaps the most immediate opportunity is a subsurface geothermal heating or cooling system for space heating, coupled with a heat pump (as the more stable ground temperature can increase the COP and reduce the electricity demand of such systems).

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3 The organic Rankine cycle (ORC) is a process that generates electricity using a turbine in the same way as steam, but that uses a lower boiling point fluid, which is usually an organic-based compound similar to refrigerants.
Hydro power or electricity uses the flow and pressure of water through a turbine to generate electrical power (Figure 13). The technology already has a long history of use in Australia for large-scale electricity generation.

The main hydro power schemes are:

- **The Snowy Mountains Scheme**, built from the 1950s to 1970s, has about 3,800 MW of installed generating capacity across 10 hydro power stations.

- **Hydro Tasmania** has up to 30 hydro power stations in Tasmania, with 2,300 MW of installed generating capacity.

In addition, there are at least another 70-80 hydro power stations across Australia, adding another 1,700 MW of installed capacity4,5 (Figure 14).

In 2020, hydro power produced 23.3% of the total clean energy generated in Australia and 6.4% of all electricity. However, there is often community resistance to new large-scale hydro power schemes in Australia because it usually requires the damming of rivers. Consequently, most new hydro power projects are investigating coupling existing hydro power stations with solar PV and wind energy, to store surplus renewable electricity – like a battery – for later use (when solar and wind power may not be available). This approach is often referred to as pumped hydro energy storage (PHES) because the renewable electricity is used to pump water back up the hill into the dam.

There is growing interest in micro hydro systems. These mini hydro power systems can be installed in small rivers or streams, or on water supply or irrigation pipelines where there is a spare head or pressure that can be recovered as energy. They can have a capacity of up to 100 kW. There are several Australian companies that supply micro hydro systems.

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**Figure 14**: The Warragamba Dam hydro power station. Source: Adobe Stock, stock.adobe.com/au/
Tidal power

Australia is home to some of the largest tides in the world, where sea levels rise and fall. This rise and fall can be exploited to generate renewable electricity. This is usually achieved by the following strategies:

- **Tidal (in-)stream generator**, where a turbine placed in the sea converts water flow caused by tidal movements into power.

- **Tidal barrage or lagoon**, where barrages or lagoons are used to store water between low and high tides, which can be released later through a pipe with a turbine to generate power.

Tidal power is limited to coastal areas of Australia and situations where sea level changes or tidal flows can be easily captured or exploited to extract power.

There are often environmental concerns about using the technology. Turbine blades can accidently kill or harm marine life. Where barrages or lagoons are installed, ecosystems can be altered and adversely affected. Corrosion of tidal power equipment, which is immersed in sea water, requires expensive metal alloys and ongoing maintenance, and access can be difficult.

ARENA estimates that Australia could generate up to 2.4 GW of electricity from tidal power. Since 1996, there have been about 10 tidal power installations in Australia. Most were less than 100 kW, with the largest (40 MW) at King Sound in Tasmania, although it’s no longer operating. A proposed 40 MW tidal power station for Derby in Western Australia is in the final stages of government approval.

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Wave energy

Wave power uses a device, generally called a wave energy converter (WEC), to capture energy from the rise and fall of waves in the sea or other water bodies and convert it to renewable electricity.

There are a variety of mechanisms and types of WECs that have been developed to capture wave energy and convert it to electricity. A common design is floating turbine platforms or buoys that rise and fall with the swells, absorbing the wave energy and causing a hydraulic pump to rotate a generator (Figure 17). But there are many other types of WECs being developed. CSIRO reports there are more than 200 wave energy devices in various stages of testing and demonstration.8

Wave energy is very much an emerging technology still being demonstrated and that remains commercially unproven. Like tidal power, its use is essentially restricted to coastal areas. Operating in the sea, it also has issues related to corrosion and access for maintenance. A major challenge is connecting the WECs to the shore with transmission cables to transfer generated electricity to where it will be used.

Figure 17: Illustration of wave power generation using different types of surface absorbers. Source: Alternative Energy Tutorials, www.alternative-energy-tutorials.com/wave-energy/wave-energy-devices.html.

Nuclear energy (fusion and fission)

Despite being used in many other countries, nuclear energy remains a highly politicised issue in Australia and is banned by the Australian Government, despite its tremendous potential as a low-emissions alternative energy source.

Most community objections are based on nuclear power being used as a weapon and/or the tragic consequences of where plants have failed and caused environmental contamination and health problems for local populations (e.g., at Chernobyl in modern-day Ukraine, Fukushima in Japan).

It is important to differentiate between the two different and distinct types of nuclear energy:

- **Fission**, where heavy atomic elements like uranium or thorium break up into lighter elements, releasing energy to produce steam and generate electricity. Fission is used by existing or proposed nuclear power plants and to build radioisotope power generators for space applications. Its reaction by-products are radioactive for many years after and are unsafe if released as a result of plant or generator failure.

- **Fusion**, where small atomic elements, such as hydrogen, are combined into larger atomic elements, also releasing energy for generating electricity. Fusion can release several times more energy than fission and does not produce long-lived radiative waste. However, it is still being researched and commercial viability and applications could be several decades away.

It is hard to know when nuclear energy might be developed in Australia, if ever. However, current public reluctance may soften given the recent commitment by the Australian Government to build nuclear submarines and growing awareness that it may be necessary for Australia to meet its future net zero emissions commitments.

Even then, nuclear energy is technologically complex, has high upfront costs, creates significant operational and legacy environmental risks, and will always be a controversial issue in Australia.

For rural producers and farmers, nuclear energy is unlikely to be a technology they can adopt for themselves any time soon, unless there is a major technological advance and Australian Government policy change.