ADAPTING TO CLIMATE CHANGE

01. ENERGY GENERATION FROM SPENT MUSHROOM COMPOST

Summary

It is estimated up to 350,000 tonnes of spent mushroom compost (SMC) is produced annually. Although a waste product, it retains valuable carbon and nutrients. Potential uses of SMC include re-composting into new substrate, combustion to generate energy, or production of biogas plus nutrient-rich digestate. Biomass combustion systems vary in their efficiency. Biogas can generate heat and energy for use on farm, while biomethane for fuel is possible with additional steps. There is emerging use, including commercial applications, of biogas and biomethane produced from SMC in Europe, and in conjunction with other technologies can convert remnant waste SMC into fertilizer and building products.

Background

It is estimated that each kg of mushrooms requires production of 3-5kg compost. At least 70,000 tonnes of mushrooms are produced annually, suggesting up to 350,000 tonnes of SMC is potentially available for energy production. Farms usually sell or give away their SMC, or may even pay to have it taken away.

It may be possible to recycle SMC, mixing it with new materials and additives to make new substrate for mushroom production. However, impediments include concern about pests and diseases, transport costs back to compost facilities considerable distances from farms and the mixing of compost with casing during removal at the end of the crop.

Using SMC to generate energy has a dual benefit of utilising an existing waste product, while directly reducing energy costs. Adopting this practice would significantly reduce the environmental footprint of mushroom production, moving it closer to 'carbon neutral'. With this comes environmental, financial and marketing advantages.

Energy for cooling, heating and equipment is one of the biggest costs of operation for both composting facilities and mushroom farms. Energy costs are generally highest in summer to meet cooling requirements. Rising temperatures are likely to increase costs, as farms build in capacity for more frequent, extreme and lengthy heatwaves. Major energy uses on farm include:

- Cooling / heating of grow rooms
- Heat and steam generation during room cookout
- Cooling / heating of processing and packing areas
- Postharvest cooling and storage of mushrooms
- Equipment such as forklifts, pumps, fans, belts etc.

SMC can potentially be burned to produce heat – which can then directly heat steam for cookout, or generate electricity to run the farm. It can also potentially be used to generate biogas. Biogas can also generate heat directly, generate electricity, or be further refined into an LPG equivalent to run forklifts and trucks. These options will be discussed.

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01. ENERGY GENERATION FROM SPENT MUSHROOM COMPOST

Biomass combustion

The simplest way to produce energy on-farm is through combustion of SMC.

A study by Finney et al[1] examined using raw SMC (including the casing material) and pelletised coal tailings (mining waste) to generate energy. Three methods were tested:

1. ***Fluidised bed combustion*** – fuel is placed on a bed of heated sand with jets of oxygen blown through it, promoting rapid high temperature oxidation
2. ***Packed bed for combustion and gasification*** – solid fuels are oxidised on a grate with air supplied from below, reaching very high temperatures (>1,000°C)
3. ***Pyrolysis*** – materials are heated to extreme high temperature in the absence of oxygen, producing energy plus stabilised carbon "biochar"

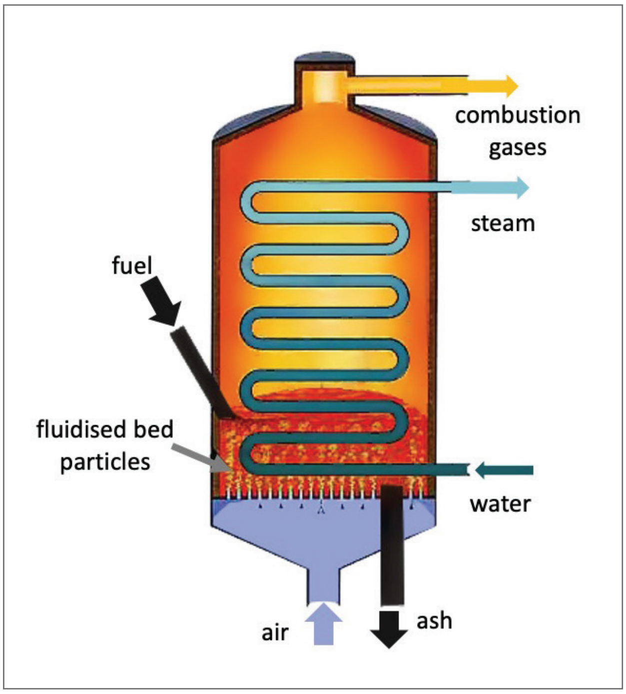

Figure 1. Fluidised bed combustion (From photomemorabilia.co.uk)

The fluidised bed produced more energy than the packed bed. However, both methods were self-sustaining and produced useful amounts of heat and, therefore, power. The process was improved if the SMC was combined with coal tailings and pelletised, as pellets burn more efficiently. While pyrolysis produced reasonable volumes of biochar as well as liquid and gaseous fuels, the authors considered yields were not high enough to justify investment in this technology.

Compost was dried to 15% moisture content before it could be burned. Biomass combustion is much more efficient if wet casing is separated from the underlying SMC.

The Mush Comb system has been developed in the Netherlands to separate casing from the compost at the end of the cropping cycle. Primarily aimed at shelf farms, the system could be adapted for tray systems (B. Holtermans, pers. com.).

Removing the casing layer at least doubled the energy potential of SMC in trials conducted in the UK. The casing layer contains a high level of chalk, which does not burn. According to Dr John Burdon, removing the casing, pelletising, and using efficient fluid bed boilers could make SMC a viable fuel for energy production.

Bio-hydrogen

Researchers in Taiwan[2] have developed a process to convert SMC to hydrogen gas. Hydrogen is considered a potential alternative to fossil fuels for powering vehicles. One of the benefits is that burning produces only water.

The production process is complex, involving grinding the compost, reacting it with sulfuric acid, then combining with sewage sludge and heating to 37°C to produce hydrogen, along with other compounds. Although a potentially useful technology in the future, it is in early stages and likely to be expensive to implement on farm.

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[1] Finney KN, Ryu C, Sharifi VN, Swithenbank J. 2009. The reuse of spent mushroom compost and coal tailings for energy recovery: Comparison of thermal treatment technologies. Bioresource Tech. 100:310:315.

[2] Li Y-C et al. 2011. Hydrogen production from mushroom farm waste with a two-step acid hydrolysis process. Int. J. Hydrogen Energy. 36:14245-14251.

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01. ENERGY GENERATION FROM SPENT MUSHROOM COMPOST

Biogas production

WHAT IS BIOGAS?

Biogas is produced by the anaerobic digestion of organic matter. It is typically 50-70% methane and 25-45% CO_2 with other gases in small volumes. Biogas can be easily be stored, then used as needed to provide heat (e.g. steam for cookout) or generate electricity. The process also produces nutrient rich digestate, useful as fertiliser[3].

Alternatively, hydrogen can be added, converting the biogas into biomethane, a product equivalent to natural gas. Compressed biomethane can be used to power vehicles. For example, Waitrose in the UK has introduced a fleet of 50 compressed biomethane-fuelled trucks, reducing their CO_2 emissions by more than 80%[5]. Biomethane is also being used to fuel buses in Nottingham and British Post Office long-haul trucks[6].

Biogas has a number of advantages over solar and wind for energy generation. They can provide a continual supply of electricity and heat, are relatively unaffected by environmental conditions and provide a high rate of returns for the space occupied[7].

According to the World Biogas Association, converting more organic wastes to biogas could reduce global emissions by up to 12% by 2030[8]. Although there are an estimated 132,000 small, medium and large digesters around the world, in 2017 there were only 242 in Australia, half of which were landfills. The Australian Renewable Energy Agency[9] (ARENA) recently (2019) commissioned an extensive review of biogas opportunities for Australia. The review can be downloaded here [10].

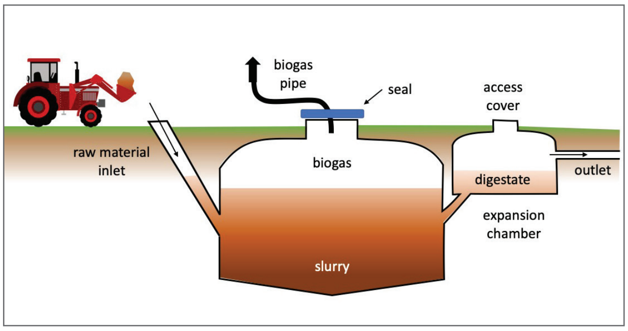

Figure 2. Derived from Tilley et al., 2014[4].

Figure 3. Waitrose truck powered by biomethane. Photo by Scania Waitrose.

	BIOGAS	WIND	SOLAR
Units	8,000 KWh	2,000 KWh	850 KWh
Generation capacity	3 MWe	2 MWe	0.6 MWe
Yield	24 GWh	4 GWh	0.53 GWh
Households potentially supplied	8,000	1,333	176

Table 1. Energy yield per 1.5ha of space used. From Christiaens, 2009.

3 Carlu E, Truong T, Kundevski M. 2019. Biogas opportunities for Australia. ENEA Consulting.
4 Tilley E. et al. 2014. Compendium of Sanitation Systems and Technologies. 2nd Revised Ed. Swiss Agency for Development and Cooperation. https://sswm.info
5 www.waitrose.com/home/inspiration/about_waitrose/the_waitrose_way/caring_for_the_environment.html
6 Morton C. 2019. Decarbonising transport: the biomethane solution. https://advancedfleetmanagementconsulting.com/eng/2019/11/03/decarbonising-transport-the-biomethane-solution/
7 DeBeer E. 2014. https://edwarddebeer.wordpress.com/2014/02/26/biogas-vs-wind-energy-vs-solar-energy-2/
8 Anon. 2020. Putting biogas at the heart of the economy. Energy World, February 2020. p22-24.
9 ARENA https://arena.gov.au
10 Biogas opportunities for Australia (March 2019) https://arena.gov.au/assets/2019/06/biogas-opportunities-for-australia.pdf accessed 14/2/2020

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01. ENERGY GENERATION FROM SPENT MUSHROOM COMPOST

USING SPENT COMPOST TO PRODUCE BIOGAS

Four key factors determine the feasibility of biogas for mushroom growers:

1. The suitability of spent mushroom compost and mushroom waste as a substrate for biogas
2. The quantity of spent mushroom compost and mushroom waste available each day
3. The cost of electricity
4. Capital investment required and the payback period

There has been considerable work on generating biogas from mushroom farm wastes, particularly trimmed stalks and spent mushroom compost (SMC). The process could provide extra value for mushroom farms as biogas digestors produce CO_2, which can be used in growing rooms to control pinning.

A recent review of biogas production notes that fungi are effective at breaking down lignocelluloses in different types of organic wastes. This makes the compost easier for the biogas-producing microbes to digest, removing the need for pre-treatment with physical or chemical processes[11].

However, it is still unclear how much biogas can be produced from SMC, and the extent to which this is affected by the inclusion or not of the casing layer. According to Dr Thomas Helle, (Novis GmbH, Tübingen, Germany), mushroom compost is difficult to ferment, being low in nutrients and high in insoluble fibre. However, addition of certain fungal additives and enzymes can increase biogas production by 200-300%[11]. Increasing the temperature also helps to reduce salt content in the digestate produced.

THE SMARTMUSHROOM PROJECT

The "SmartMushroom" project (www.smartmushroom.eu) currently underway. in Europe is testing production of biogas from SMC. The aim is to recycle SMC (including casing) into biogas plus a pelletised organic fertiliser.

The SMC is digested using a two-stage anaerobic process. Biogas produced can be used to generate electricity, as well as fuel a dryer to remove moisture from digestate and remaining SMC. The dried material is pelletised (along with additional nutrients if required), forming a readily transportable organic fertiliser.

A pilot plant has been built in La Rioja, Spain's largest mushroom growing area. The plant is using wastewater from a nearby jam factory (which is high in sugar) plus glycerine (100% organic dry matter) as co-substrates. The plant uses 2t of SMC daily, producing approximately 343,000L of biogas. This is used to run a dryer at 65-80°C, processing the remaining SMC and digestate into fertiliser pellets.

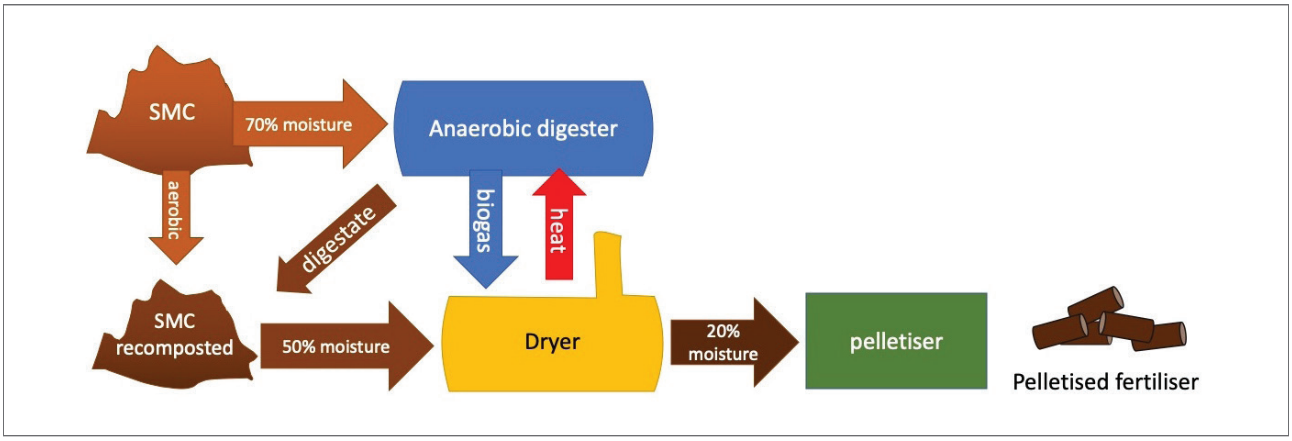

Figure 4. The SmartMushroom process. Derived from www.smartmushroom.eu

[11] https://biooekonomie.de/en/interview/biogas-mushrooms

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ADAPTING TO CLIMATE CHANGE

01. ENERGY GENERATION FROM SPENT MUSHROOM COMPOST

The refined SMC is an excellent source of phosphorus, potassium, nitrogen and trace elements, with a C:N ratio of 20:1 or less. Initial trials have been conducted using pellets formulated for a range of vegetables including tomatoes, cucumber, capsicum and leafy greens. The pellets improved root development and promoted earlier flowering and fruit development compared to control plots.

The economic feasibility study suggests that a plant capable of processing 10,000t SMC annually would have a payback time of 4.3 years and a pre-tax internal rate of return of 21%. While this includes a saving from not having to pay to dispose of the SMC, it does not include any income from supplying electricity to the grid;

Construction cost = 2.2 million euro
Operating cost = 307,000 euro/year
Throughput = 10,000t/year
SMC utilisation savings = 6 euro/t = 60,000 euro/year
Powerplant size = 1.25 megawatts thermal
Pellet sales = 90 euro/t

More detailed results will be available after July 2020. If successful, further plants are planned in six European countries.

IMPROVED SUSTAINABILITY THROUGH BIOGAS

Digestate from biogas production also has other uses. There is interest in testing this material as a partial replacement for peat, although salt content may prove limiting. The digestate also contains readily extractable fibres. German researchers[91] are developing natural fibreboards based on combining these fibres with bio-based resins. The boards have properties that may make them superior to wood-based boards and are readily composted at the end of their life cycle.

Even without these processes, biogas offers an opportunity for sustainable use of resources[12]. With 350,000 tonnes of spent mushroom compost SMS produced each year in Australia it should be considered as a promising alternative for clean energy production as mono- or co-substrate in anaerobic digestion.

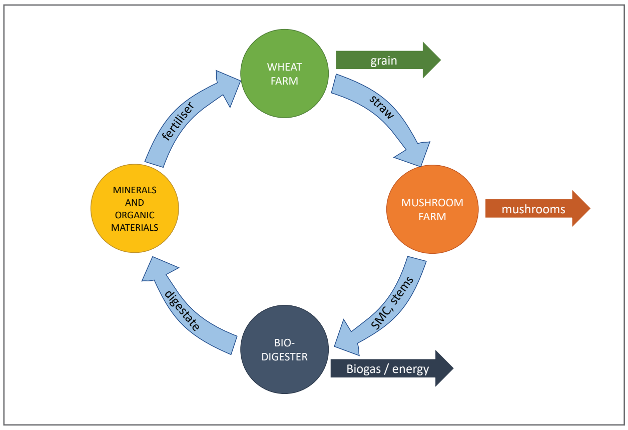

Figure 5. The "virtuous circle": sustainable production of biogas from mushroom wastes. Derived from Perez-Chavez et al. 2019[11].

There are a number of companies offering biogas systems in Australia - including:

- Bioenergy Australia.
  https://www.bioenergyaustralia.org.au
- Utilitas
  https://utilitas.com.au/
- Biogass Renewables Pty Ltd.
  http://www.biogass.com.au/
- Hitachi Zosen INOVA
  http://www.hz-inova.com/cms/en/home/
- ReNu Energy.
  https://renuenergy.com.au/

Biogas system providers can test SMC for suitability and advise on the payback period on capital investment. Costs may further be offset by sales of credits to the LRET scheme or funding through the Australian Renewable Energy Agency (ARENA).

For example, in 2014 Utilitas conducted a study on biogas production from vegetable wastes. At that time, electricity could be produced by biogas for about $80 - $160/MWh, with a payback period on capital investment of five years. Electricity returned to the grid earns a maximum of $110/MWh, so biogas is only economically viable if energy produced is used on-site. However, this is unlikely to be an issue for mushroom farms as energy is readily utilised on-site.

12 Perez-Chavez AM, Mayer L, Alberton E. 2019. Mushroom cultivation and biogas production: A sustainable reuse of organic resources. Energy for Sustainable Dev. 50:50-60.

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ADAPTING TO CLIMATE CHANGE

02. ALTERNATIVE CASING MATERIALS

Summary

Peatlands are a major carbon sink, sequestering 0.5 gigatons of CO_2 annually. Conversely, draining peatlands is a major source of greenhouse gases, equating to nearly 6% of global anthropogenic emissions. Banning or restricting peat mining is therefore an easy way for countries to meet emissions targets, and this is already occurring in some European countries.

While peat cannot be totally replaced, consumption can be reduced. Up to 50% peat may be replaced by products such as recycled organics, spent mushroom compost, recovered and recycled peat or materials made from bagasse. Research is continuing into these options.

Current practice

The industry sources peat from Germany, Ireland, the Netherlands, Canada and the Baltic states. Most farms use a 90:10 or 80:20 blend of hard, black peat to blonde (Canadian) peat, although at least three use 100% German black peat.

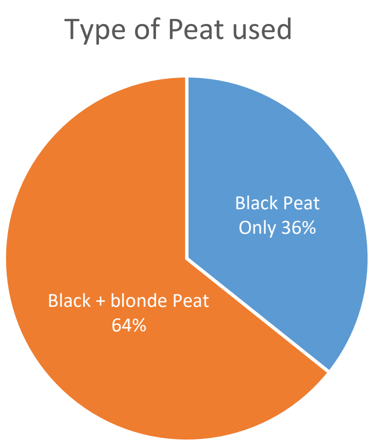

Figure 1. Type of peat used by conventional mushroom farms in Australia.

The supply of peat from Germany and the Netherlands is nominally guaranteed for the next 50 years. However, this could change as concern about climate change increases. Although the supply of peat is unlikely to stop altogether, costs are likely to rise and availability decline.

Alternatives already trialed include coconut coir, brown coal products, spent barley from breweries, composted green waste and spent diatomaceous earth.

Background

Peatlands are the biggest land-based carbon store on the planet. They absorb up to 0.5 gigatons of CO_2 each year, representing 1-5% of human-sourced greenhouse gas emissions globally[1].

Conversely, **10%** of global emissions from the agriculture, forestry and land use sectors is caused by draining peatlands. This equates to almost 6% of global human-sourced CO_2 [2]. This is because allowing oxygen

1 Friedlingstein PRM et al. 2014. Persistent growth of CO_2 emissions and implications for reaching global targets. Nature Geosci. 7:709-715.

2 International Union for Conservation of Nature, https://www.iucn.org/resources/issues-briefs/peatlands-and-climate-change

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02. ALTERNATIVE CASING MATERIALS

into the anaerobic environment of the peatlands allows it to rapidly decompose, emitting large amounts of both CO_2 and nitrous oxide (N_2O).

Drained peatlands are also extremely susceptible to fire, especially when combined with increasingly hot, dry conditions. Such fires can smoulder underground for weeks. For example, the 2019-2020 underground peat fire near Port Macquarie took 210 days to extinguish, and then only after 260mm of rain was combined with pumping 65 megalitres of reclaimed water onto the wetlands[3].

According to the International Union for the Conservation of Nature (IUCN), "*the protection and restoration of peatlands is vital in the transition towards a low carbon economy*". They further propose a moratorium on peat exploitation, and for peatlands to be included alongside forests in agreements relating to climate change (e.g. carbon credits/debits), geodiversity and biodiversity.

Figure 2. Mining of peat bogs, such as this one in Ireland, is increasingly restricted. *Photo by D. Turner.*

It is likely the European Union will introduce regulations to limit or ban the draining and extraction of peat to reduce European greenhouse gas emissions. According to Achim Steiner, previously the executive director of the UN Environment Program, protecting and restoring peatland is "low hanging fruit", making it one of the most cost-effective options for mitigating climate change[4];

Ireland has already closed 17 peat bogs and plans to close the remaining 45 bogs by 2025[5].

The EU "Peat Life Restore" project aims to restore peatlands in Germany, Estonia, Latvia, Lithuania and Poland to meet the objective of reducing greenhouse gas emissions by 40% by 2030 from 1990 levels.

Peat used for casing is likely to become both more difficult to access and more expensive.

Alternative casing materials

While alternative casing materials have been widely researched since the 1980s, South Africa has long been a leader in this field. African mushroom producers were unable to use locally available peat due to high clay content, and it is now also protected from exploitation. Purchasing peat from Europe was initially impossible, and later prohibitively expensive. As a result, South African company Mabu Casing has developed a casing material based on sugarcane waste (pith) that has been processed to make paper. The process is confidential, but results appear to be commercially viable.

A variety of other materials have been investigated as peat replacements including[6]:

- Carpet wool
- Coffee grounds
- Composted mushroom stalks
- Composted vine shoots
- Composted water weeds
- Cotton husks
- Fine particle tailings from coal mining
- Floculated rock wool
- Eucalyptus sawdust
- Lignite
- Loamy top-soil
- Mineral soil
- Palm fibre
- Paper pulp
- Pine sawdust

[3] Bungard, M. 2020. Fire near port Macquarie extinguished after 210 days. https://www.smh.com.au/environment/weather
[4] https://www.newscientist.com/article/dn13034-peatland-destruction-is-releasing-vast-amounts-of-co2/
[5] https://www.theguardian.com/world/2018/nov/27/ireland-closes-peat-bogs-climate-change
[6] Pardo A, de Juan JA, Pardo JE. 2003. Characterisation of different substrates for possible use as casing in mushroom cultivation. Food Ag. Environ. 1:107-114.

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02. ALTERNATIVE CASING MATERIALS

Spent mushroom compost

The casing material that has received most attention is spent mushroom compost (SMC). This is an attractive option as it can reduce both the cost of casing and issues with disposal of spent compost. Numerous research papers detail methods for using SMC alone, or in combination with other materials (including peat), as casing. The main drawbacks of SMC are its variable composition, relatively poor water holding capacity and high salt content[7,8].

However, ageing and leaching have been shown to be effective at overcoming these issues. The electrical conductivity (EC) of SMC can be reduced from approximately 7.0 µS/m to 2 µS/m by either natural weathering or active processing. In Iran, SMC is actively processed by leaching with 3.5 to 4m^3 of water/tonne over three weeks. Repeatedly immersing and draining the material can achieve the same result within only seven days[9].

Even after leaching and pasteurisation, SMC is unlikely to completely substitute for peat. In Ireland SMC leached to 4µS/m and heat treated at 60°C was successfully mixed 20:80 with peat, but adding more SMC to the peat reduced yields[10]. Similarly, Malard

	TIME REQUIRED	
	Natural weathering	*Processing*
Method		
Windrow / pile / bunker	2 years	3-4 weeks
Leaching	2 years	2 weeks
Draining	6 days	
Pasteurisation	4 days	
Blending	1 day	
Result		

Table 1. Processes and time required to ensure SMC is suitable for inclusion as casing material. From J. Burdon, presentation at 2018 mushroom conference, Sydney.

7 Riahi H, Zamani H. 2008. Use of spent mushroom compost and composted Azolla as an alternative for casing soil. Proc. ISMS. 17:333-339.
8 Barry J et al. 2008. Partial substitution of peat with spent mushroom substrate in peat-based casing blends. Proc. ISMS 17:288-309.
9 Rowley C, Burdon J. 2019. Using spent mushroom compost as a casing amendment. Aust. Mushroom J. 2019: 37-41
10 Barry J et al. 2008. Partial substitution of peat with spent mushroom substrate in peat-based casing blends. Proc. ISMS 17:288-309.

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mushrooms in Iran mixes SMC that has been leached to 2µS/m as a 50:50 blend with peat. Although the material is normally pasteurised, trials indicated this may not be necessary (M. Mirzadeh, pers. com.).

Recycling casing

It may also be possible to partially re-cycle casing soil, if it can be separated from compost. To ensure good separation, mycelium should be allowed to thoroughly colonise the underlying compost under high CO_2 (1%), before the casing is added[11]. At the end of the cropping cycle the casing is removed, ground, steam sterilised and then inoculated with bacteria. This can be blended 30:70 with fresh peat.

This separator system is commercially available as the "MushComb Separator". The separator works with the emptying conveyor and winch in shelf rooms. The separator is placed against the shelving, with the emptying winch on the other side. Casing is unloaded onto a separate conveyor and taken off to the side[12]. The process does not limit the speed of unloading for the room; it can operate at 17m/minute, which is faster than most emptying systems.

Separating wet peat from the underlying compost also facilitates use of the SMC for other purposes – whether incineration, fertiliser production or other uses.

The cost of a single arm separator and additional casing conveyor is approximately 50,000 euro, or

Figure 3. The Mush Comb unit (a) is used to separate the casing from compost during room unloading. The separator is used with a multi-arm emptying machine (b) as the crop is removed after final harvest (c). Conveyors take compost into the waiting trailer, while casing is diverted to a container at one side (d). The separated casing soil (e) and compost can then be recycled or used for other purposes.

Photos by Mush Comb (www.mushcomb.com) and The Mushroom People (themushroompeople.com).

[11] Oei P, Albert G. 2012. Recycling casing soil. Proc ISMS 18:757-765.
[12] www.mushcomb.com

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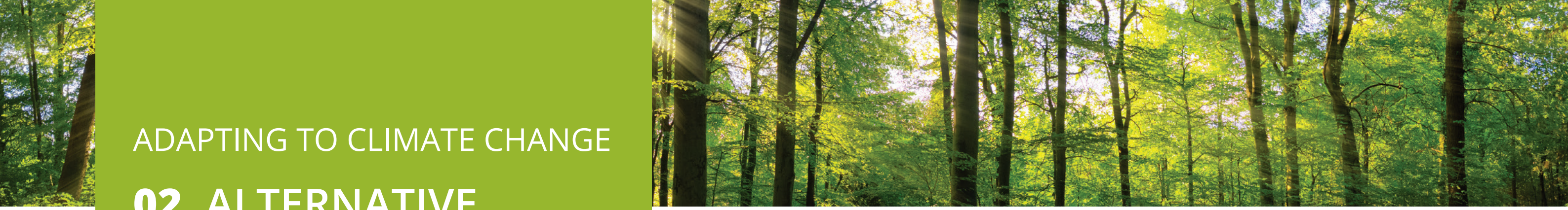

02. ALTERNATIVE CASING MATERIALS

$A81,500 in June 2020. This is the simplest system, using the existing emptying winch and conveyor. The separator is placed between the shelving and existing winch, with the new conveyor unloading to, for example, an adjacent container. If there is not an existing emptying unit, this can be added for an extra 35,000 euro ($A57,000). A machine which includes the separator, emptying unit and all conveyors into a single unit is approximately 125,000 euro ($A204,000).

Recycled organics

Recent Australian trials conducted by AHR have focussed on using recycled organics from green waste as casing materials. The green waste is prepared from landscape wastes rather than the more variable materials collected from domestic recycling. It is thoroughly composted, ground and aged for 6 to 12 months before use. The recycled organic material has an advantage over SMC in that the initial EC value is low, at 2.2 to 3.2 dS/m.

Blends of up to 50% recycled organics (RO) with peat resulted in similar yield and quality to peat alone. There was no difference between pasteurised and non-pasteurised material. While these are initial trials only, the results appear promising. Commercial trials are now being conducted using a 50% blend of recycled organics with black peat.

Figure 4. Mushrooms cased with; a 100% recycled organics (RO); b 50:50 RO and peat; c 25:75 RO and peat; d 100% peat

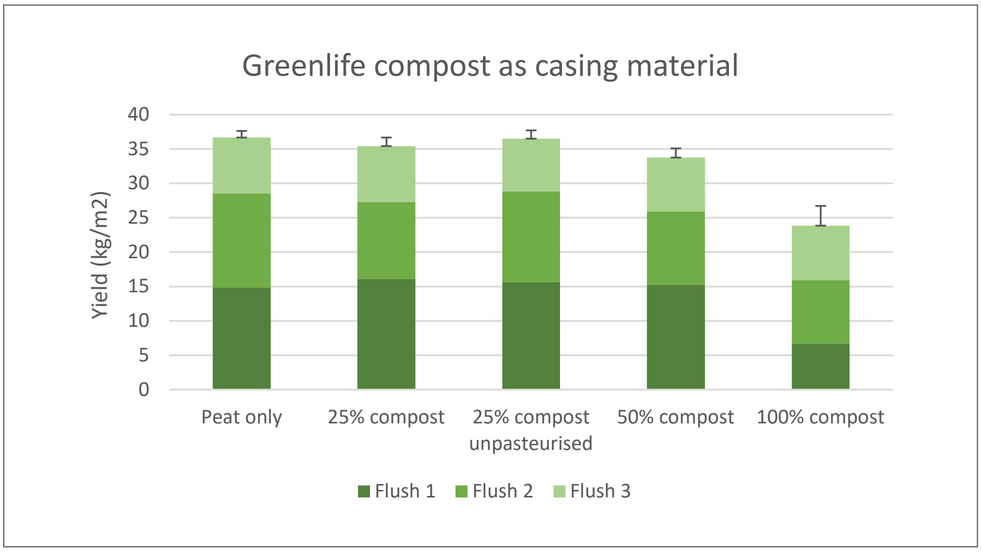

Figure 5. Mushroom yields from blocks cased with blends of recycled organics and peat at the Marsh Lawson Mushroom Research Unit (AHR data). Bars indicate the standard error of each mean 'total yield' value.

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ADAPTING TO CLIMATE CHANGE

03. GOVERNMENT ASSISTANCE OPPORTUNITIES

Summary

Both federal and local governments provide numerous types of incentives or assistance to encourage businesses to reduce emissions and improve energy efficiency. These are often changing and can be searched for on the business.gov.au website. Depending on business size, mushroom growers and composters could be eligible for several schemes listed below.

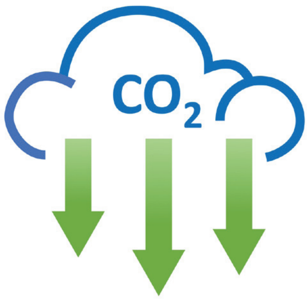
Background

As part of Australia's international climate change target commitments, a suite of policies was developed in 2017 to help reduce domestic carbon emissions. This includes increasing renewable energy production capacity, improving energy use productivity, and encouraging businesses to reduce emissions.

There are numerous forms of assistance provided by federal and state/territory governments. Key opportunities are listed below. These change frequently, or eligibility may depend on meeting specific criteria, such as business size or region. To search for assistance opportunities see www.business.gov.au/grants-and-programs, then enter your business postcode, business type (Agriculture, Forestry and Fishing), and select assistance to 'recycle waste or reduce my energy use'.

Windy Hill Wind Farm. *Photo by C. Mackinney.*

Emissions Reduction Fund



Under this program, participants earn Australian Carbon Credit Units as reward for emissions reductions. The credits can be sold to government, or on the secondary market to generate income.

To qualify, an emissions reduction project needs to be developed and registered by the Clean Energy Regulator. Note that the Emissions Reduction Fund does not actually provide funding to participants – the financial incentive is through the sale of carbon credits.

The emissions reduction project would need to result in a significant reduction in emissions - projects that a mushroom or compost producer may consider are:

- Equipment upgrades – e.g. boiler system, air conditioning
- Waste heat capture and re-use
- Fuel switching

Information at http://www.cleanenergyregulator.gov.au/ERF

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03. GOVERNMENT ASSISTANCE OPPORTUNITIES

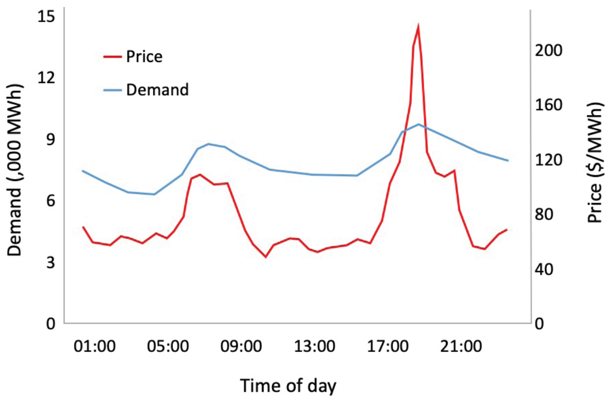

Figure 1. Demand for electricity on a Monday in NSW, and the resulting variable spot prices paid for electricity to meet surges in demand. From AEMC.

Large-scale Renewable Energy Target

This program encourages large-scale investment in renewable power, through the creation of tradeable certificates for generation of renewable energy. Certificates can be sold to entities such as electricity retailers to meet their obligations under the large-scale renewable energy target. They could also be sold to companies who want to voluntarily offset emissions or energy use. The program is legislated to end in 2030.

A mushroom farm or compost producer would need to apply to become an accredited power station to participate in the program. Once accredited as a 'power station', large-scale generation certificates can be created for electricity generated by the power station's renewable energy sources (e.g. solar/wind). The certificates are managed by the Clean Energy Regulator.

A large-scale solar system is defined as a photovoltaic system which exceeds 100kW capacity. A system below this capacity may be eligible for certificates under the small-scale renewable energy target.

Information at http://www.cleanenergyregulator.gov.au/RET

Wholesale demand response in the electricity market

The cost of electricity surges when the network is under strain (Figure 1). Any effort to reduce or shift electricity demand during those periods can benefit a large electricity consumer. This is called demand response, and a new rule was recently announced by the Australian Energy Market Commission. This formalises an arrangement where electricity consumers are paid for electricity they avoid using during peak times.

The program is called the Wholesale Demand Response Mechanism and is due to start in October 2021. During times of high energy demand, large energy users can be paid to reduce electricity consumption. It will also give large energy users the ability to schedule their demand into the market, based on electricity prices.

To participate, a business will need to enter an agreement with a demand response service provider, who then 'sells' the unused electricity to the wholesale market.

Mushroom composters and producers could take advantage of this program by using backup diesel or gas generators during peak times.

Information at https://www.aemc.gov.au/rule-changes/wholesale-demand-response-mechanism

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Clean Energy Finance Corp

Low cost finance is available for smaller-scale renewable energy projects. Applications for finance can be made through a number of banks and financiers via the CEFC website.

Information at https://www.cefc.com.au/where-we-invest/sustainable-economy/asset-finance/

Energy saving programs

State and territory governments provide schemes to assist businesses save energy. That includes assistance for businesses to assess resource and energy use, and identify opportunities for improvements.

There are also programs such as the NSW Energy Savings Scheme where businesses are encouraged to invest in technologies that reduce their energy use. Certificates are generated for the energy saved, and parties such as electricity retailers purchase the certificates back from the business.

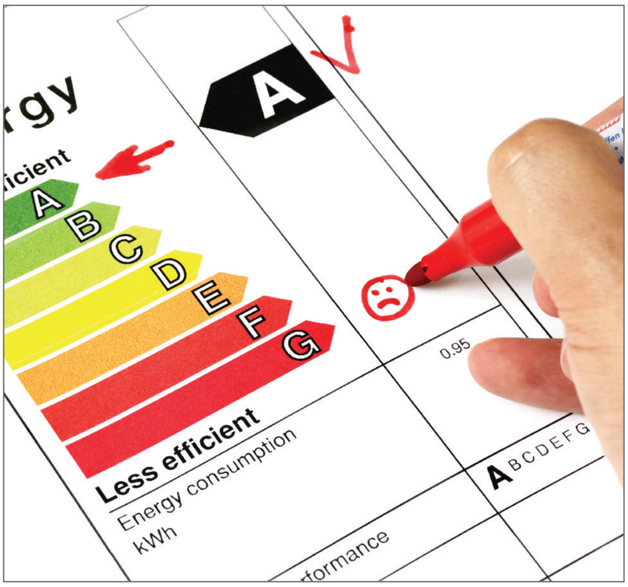
A number of these programs are listed by state/territory on the Smart Energy Council website and the energy.gov.au website:

- https://www.smartenergy.org.au/government-energy-saving-schemes
- https://www.energy.gov.au/business/grants-and-funding

Conducting an energy efficiency assessment

The Australian Government has resources available to help conduct an energy efficiency assessment on a business. That includes understanding energy use in the business and identifying opportunities to improve efficiencies.

Information at https://www.energy.gov.au/business/large-businesses/energy-management/conduct-energy-efficiency-assessment



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ADAPTING TO CLIMATE CHANGE

04. EFFICIENT ENERGY USE

Summary

Mushroom farms and compost facilities are big energy users. On average, every tonne of mushrooms produced costs $533 in electricity. However, costs are higher for small operations. Energy costs may either increase or decrease in the future, depending on future government policy. Nevertheless, increasing energy efficiency has clear financial benefits for mushroom producers.

Opportunities to reduce costs include:

- Efficient cooling using centrifugal chillers and well-maintained evaporators, with multiple units installed so as to always operate close to capacity
- Refining cookout times and temperatures based on pest risk analysis
- Converting to metal shelf systems instead of wooden trays
- Ensuring insulation in rooms, vents and around doors is intact, sealed and dry
- Ensuring the facility itself is well insulated, walls shielded from the sun and shaded if possible, with a light coloured roof equipped with wastewater sprinklers for evaporative cooling
- Vacuum coolers for mushrooms, operated only when full
- Precise management of grow room environments
- Energy recovery system used to pre-condition grow room air

Load shedding by electricity providers can provide another cost saving opportunity; facilities are compensated if they switch to an alternate energy sources such as diesel generators or solar systems during peak demand periods.

Current practice

Electricity for cooling, heating and equipment is one of the biggest operating costs for both composting facilities and mushroom farms. Energy costs are generally highest during hot periods due to cooling requirements; several farms report increases of about 50% in electricity costs in summer.

Key energy uses on farm include:

- Cooling/heating of grow rooms
- Heat and steam generation during room cookout
- Cooling/heating of processing and packing areas
- Postharvest cooling and storage of mushrooms
- Running equipment such as forklifts, pumps, fans, belts etc.

Estimates of the electricity cost per tonne of mushrooms produced (from the farms surveyed) ranges between $393/tonne and $2,011/tonne, with a

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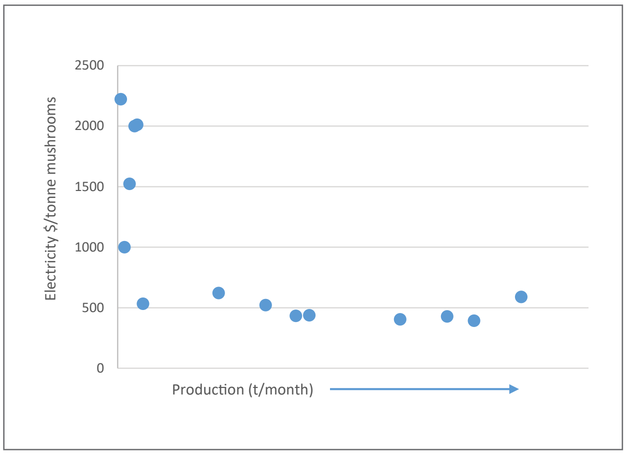

Figure 1.Cost of electricity per tonne mushrooms produced; each point is one farm. *AHR data*

median of $533/tonne. Small farms pay much more for electricity per tonne of mushrooms grown compared to large farms, even if they have installed solar systems.

Interruptions to electricity supply are a major risk, as even a relatively short blackout can result in total crop failure. Only five of the surveyed farms did not have backup generators, three of which were exotic mushroom producers.

Background

In 2017, the federal government commissioned an enquiry into the future security of the National Energy Market[1]. This was to consider the effects of government policy on the price and reliability of energy supplies.

There is much uncertainty about future policy in this area, which can change with an election, or simply party leadership. It may also change as Australia seeks to meet greenhouse gas reduction targets. Some scenarios considered were:

- Business as usual (BAU), with continued uncertainty over abatement policy and investment decisions
- A clean energy target (CET), where emissions targets must be met
- An emissions intensity scheme (EIS), where rewards and penalties are awarded to power generators based on emissions compared to an industry baseline

Perhaps surprisingly, energy costs are highest under the BAU scenario, primarily due to ongoing uncertainty about investment. It is expected that wholesale energy prices will rise gradually from 2020 onwards, plateauing about $90/MWh.

Wholesale prices are lowest under a CET scheme, followed by an EIS. This is because incentives provided to low emission energy producers entering the market puts downward pressure on prices. These reports suggest that electricity prices will continue to increase under current government policy. However, if a clean energy target is mandated, with or without a carbon price, then wholesale energy costs may fall.

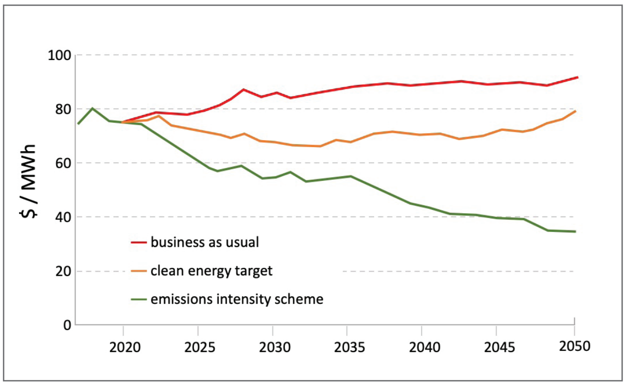

Figure 2. Estimated changes in wholesale electricity prices under different policy scenarios. Derived from: Gerardi and Galansi (2017)[1]

[1] Gerardi W, Galanis P. 2017. Report to the Independent review into the future security of the national energy market. 21 June 2017. https://www.energy.gov.au/. accessed 9-4-2020.

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04. EFFICIENT ENERGY USE

Energy is a major cost to all mushroom producers. Rising temperatures are likely to increase costs further, as farms build in capacity for more frequent, extreme and lengthy heatwaves. If energy costs decline slightly, more efficient use of energy would directly improve farm profitability.

Efficient energy use

GROW ROOMS

Across all horticulture industries, there is an increasing trend to “Smart Farming” systems, where environmental variables are continuously monitored and, where possible, controlled. Mushroom producers are ahead of most other industries in this respect, as most farms already manage temperature, humidity and atmospheric composition with technology. However, there may be opportunities to refine growing systems further with new technologies.

Case study

In 2016 Premier Mushrooms in Colusa, California identified energy costs as a key restraint on further expansion. They invested several hundred thousand dollars in new systems to accurately regulate temperature, RH and CO_2. Room insulation was upgraded, more efficient lighting was installed and strip curtains and other related improvements were added to reduce energy use. They also changed the cooling method in the growing rooms to a centrifugal chiller from an air-cooled system. Centrifugal chillers are highly efficient, typically producing a cooling effect 2 to 3 times greater than the energy input[2]. These improvements allowed the farm size to increase by 33% without increasing energy costs[3].

Considerations for grow room cooling equipment:

- Flooded type evaporators have chilled water in tubes running through a jacket containing refrigerant, and are highly energy efficient
- Centrifugal chillers are usually most efficient when running at about 80% of full load; they are frequently inefficient when running at <50% of capacity
- Using multiple chillers allows units to be turned on or off, so all are running efficiently at close to capacity
- Increasing the chilled water supply setpoint to match cooling requirements can reduce power consumption by between 1.5 and 2% per degree
- Chiller condensers and evaporators require periodic maintenance to remove accumulated scale and annual “rodding” to ensure efficient heat transfer between the shell and tube

COOKOUT

Cooking out crops *in situ* at the end of their productive life is the most effective method to sanitise rooms and prevent spread of disease. Cooking out with the compost inside the room prevents spread of diseases such as dry bubble and cobweb to new crops within the facility. While cookout uses high amounts of energy, it ensures subsequent crops ‘start clean’, which is a fundamental of holistic farm hygiene, disease prevention and biosecurity (W. Gill, pers. com.).

How hot for how long?

There is limited data on heat tolerance for different mushroom diseases. Most data has been determined by lab-based trials, with a report by Overstijns[4] the key reference in this area.

This work did not, however, include green mould, which is far more heat tolerant than other pathogens. Rinker and Alm[5] found that *Trichoderma* could survive 74°C for 29 hours but was destroyed by 68°C for 42 hours. However, different species and strains of *Trichoderma* vary widely in their tolerance to heat, with

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2 https://electrical-engineering-portal.com/energy-efficiency-centrifugal-water-chillers
3 https://www.farm2ranch.com/articles/news/615/mushroom-farm-reaps-benefits-energy-efficiency/
4 Overstijns A. 1998. The conventional phase II in trays or shelves. Mush. J. 584:15-21.
5 Rinker DL, Alm G. 2000. Management of green mould disease in Canada. Mush. Sci. 15:617-623.

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PEST / PATHOGEN	KILL TIME (HOURS)			
	50°C	55°C	60°C	68°C
Most flies		5		
Nematodes		5		
Mites		5		
Cecids	1			
Cobweb	4		2	
Dry bubble		4	2	
Wet bubble	4		2	
Trichoderma			9 to >36	42
Bacterial blotch	0.17			

Table 6. Thermal death points of some common pests and diseases of mushrooms. Trichoderma (at right) is far more difficult to kill than other pests. From Overstijns (1998)[6] and Rinker and Alm (2000).[7]

some reliably killed by 9 hours at 60°C while others survived 36 hours at this temperature[8].

A wide range of time and temperature combinations for cookout are recommended in the literature. For example, Pyck and Grogan[9] recommend raising the compost to a minimum of 65–70°C for 8 hours, Beyer[10] suggests 66°C for 12 hours while Curtis[11] proposes up to 24 hours at 70°C.

If disease is severe, then the entire room may need to be steamed a second time after emptying. This second treatment can vary from 65°C for 2 to 8 hours[73] to 24 hours at 66°C[74] or even 6-12 hours at 75°C[75] if timber trays are present.

These treatments are far more severe than the combinations known to kill pathogens, as shown in Table 6. This is due to the large thermal load in the rooms themselves. This is particularly an issue on older farms, where heat loss through ageing door seals, walls and exclusion mechanics allows steam to escape, necessitating longer treatment times.

No matter how rapidly air temperature is raised, it takes about 14 hours for the substrate to reach 60°C[12], while timber trays can take five- to six times longer to heat than the substrate they contain[74]. Where farms have adopted heavy, deep dug peat instead of blonde peat it also takes longer to achieve thermal kill (W. Gill pers. com.)

Unfortunately, a number of researchers have concluded that sanitisers and fungicides alone cannot control mushroom diseases in compost, so frequent cook-out is essential[13].

Conversations with growers indicate that practices used on farms vary widely. While some farms do not cook-out at all, others steam rooms for 12 hours or more.

Reducing the energy needed for cookout

When deciding on the time and temperature combination to use, growers must assume a worst-case scenario, as they are unsure what diseases may be present. However, new molecular techniques allow much faster and easier detections of pathogens. Optimising the cook-out process, so sufficient heat only is applied to kill the pests present, could provide significant potential energy savings.

6 Overstijns A. 1998. The conventional phase II in trays or shelves. Mush. J. 584:15-21.
7 Rinker DL, Alm G. 2000. Management of green mould disease in Canada. Mush. Sci. 15:617-623.
8 Morris E, Harrington O, Doyle ORE. 2000. Green mould disease – The study of survival and dispersal characteristics of the weed mould Trichoderma in the Irish mushroom industry. Sci. Cult. Edible Fungi. 15:645-651.
9 Pyck N, Grogan H. 2015. Fungal diseases of mushrooms and their control. MushTV Factsheet 04/15. www.mushtv.eu
10 Beyer DM. 2018. Best practices for mushroom post-crop sanitation: steam-off/post-crop pasteurisatio
11 Curtis J. 2008. 2008-2009 mushroom production guide. Ministry of Ag. And Lands, Brit. Columbia.
12 Gill, W. 2018. Putting the heat on the cookout. Aust. Mush. J. Spring 2018: 39-43.
13 Baars J, Rutjens J. 2016. Finding a suitable biocide for use in the mushroom industry. Sci. Cult. Edible Fungi. 114-117.

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04. EFFICIENT ENERGY USE

Testing for pathogens that are actually present in the room could allow growers to adjust cookout times and temperatures accordingly – but only if there is good information about the heat tolerance of these pathogens.

If floors do not reach high enough temperatures to kill all pathogens, they can be cleaned and disinfected further after the room is emptied. Trays can be treated with propiconazole (Safetray®) fungicide to ensure they are fully sanitised.

Cook-out energy requirements can also be reduced by more efficient growing systems. Newer mushroom farms use metal shelf systems. These allow spent compost to be removed directly from each growing room. If compost can be removed without diseases spreading to other parts of the facility, cook-out can be conducted after the room has been emptied. This reduces substantially the amount of energy required.

Even if compost is treated *in situ*, metal shelves heat much faster than wooden trays. Wooden trays are particularly difficult to sanitise, as pathogens can be harboured deep within the timber. Changing from wooden to metal systems reduces significantly the cook-out time needed to ensure proper sanitation.

In summary, the energy used for cookout may be minimised by:

- Ensuring all doors, vents and wall joints are well sealed and insulated
- Understanding what diseases and pathogens are present; times and temperatures required to control green mould are far greater than those needed to manage other diseases, which are in turn higher than those needed to control invertebrate pests
- Using a higher temperature with shorter duration where appropriate
- Changing from wooden to metal shelving
- Installing a belt system to remove compost directly from the room before cookout
- Combining cookout with cleaning and disinfection of floors, walls etc.
- Not allowing pathogen levels to build up that necessitate double cookouts

THE FACILITY

Systems such as **Profarm** (Denso Corporation, Japan) use many sensors installed across compost, power systems, atmosphere, ventilation systems, irrigation etc. to provide real-time tracking of growing conditions. This data is analysed by cloud-based software, correlating environmental changes with yield and quality data. Tracking inputs potentially allows the user to find efficiencies in energy and water use as well as optimising production.

Performance of cooling tower fans, condensers, water pumps, and air and water distribution systems can all be analysed to identify potential energy efficiency opportunities. About half the cooling load in inefficient buildings comes from solar radiation and poor lighting choices[14]. Mushroom farms have the

Figure 3. Galvanised belt and shelf systems allow more efficient cook-out than older wooden tray systems

[14] http://energy-models.com/hvac-centrifugal-chillers

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advantage of being windowless, while many farms have already installed energy efficient LED systems. Other improvements in efficiency may come from:

- Adding extra insulation to the roof
- Ensuring concrete floors are well insulated and sealed against moisture
- Checking for leaks that allow water to enter internal panelling; if insulation is wet it will be ineffective
- Light coloured roof coating to reflect solar radiation
- Spraying wastewater on the roof to provide evaporative cooling
- Maximising structural overhangs (eaves) on north facing walls
- Planting trees around the building to provide shade and evapotranspiration

Cooling

Many farms already use vacuum cooling systems to reduce the temperature of harvested mushrooms. While the capital cost of vacuum coolers is high, they are far more energy efficient than either forced air or room cooling systems. Nearly 100% of the energy used directly cools the product, instead of cooling air, cold room panels, fans, pumps, packaging etc. as occurs with forced air or room cooling. Vacuum coolers operate most efficiently when fully loaded; the same amount of energy is needed to cool a half load as a full one[15].

Figure 4. Room panelling materials that have become wet internally will not be effective insulators

Energy recovery

Energy recovery ventilators (ERVs) can provide energy savings in mechanical ventilation systems. They recycle energy from the building's exhaust air to pre-treat the outside air/ventilation air. This preconditioning of outside air reduces the load the heating, ventilation and air-conditioning (HVAC) unit must handle, reducing the required capacity of the mechanical equipment.

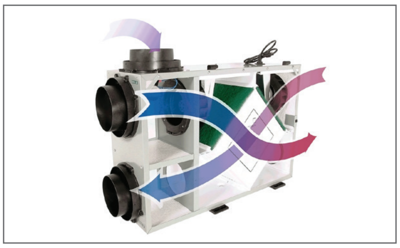

Figure 5. Energy recovery ventilators use exhaust air from inside the room to pre-heat or cool fresh air coming from outside the building. Picture by Greentek.[16]

Most heat exchangers are not sold as discrete units. Usually, they are factory installed as part of a packaged air handling system with fans, electrics, controls, casing, and a heating/cooling mechanism.

Mushroom growing rooms require a good air flow to maintain carbon dioxide concentration at a pre-set level. This makes it difficult to keep rooms at a steady temperature. Exhaust air is wasted heating or cooling energy. Most mushroom farms and composters in Australia have found HVAC cooling is their primary electricity expense.

There are a few types of energy recovery ventilators:

1. Fixed core plate: Exhaust and incoming air mixed through a matrix. Core plates are reliable because there are no moving parts.
2. Coils: Refrigerant or water is piped between the exhaust and incoming air ducts. Coils are hygienic because exhaust and incoming air does not come in contact.
3. Thermal wheel: A metal wheel rotates between exhaust and incoming air ducts. Thermal wheels are not always hygienic because some exhaust and incoming air is mixed. Thermal wheels are efficient

[15] Thompson J. 2001. Energy conservation in cold storage and cooling operations. Perishables Handling Quarterly Issue 105. UC Davis.
[16] Parry C. 2015. Fresh air without the heat loss (or gain). ReNew 127 (April-June 2014).

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at up to 80% recovery.

With a new HVAC installation, the reduced capacity requirements offset the cost of an ERV system. Texas A&M University calculated energy savings of 8.9-12.2% when combined with an ERV[17].

This is consistent with a local case study[18] in Coffs Harbour, NSW. The company reported an 11% cost saving in the HVAC system by combing a lower capacity air-conditioning unit with an ERV costing $12,500.

In another example, one Australian mushroom farm installed ArmCor ERVs at a cost of $8600 each plus GST. One ERV is installed on each growing room with 80sqm of beds. The ERV pre-heats or cools the incoming air by ±4.5°C. This allows faster reduction of CO_2 in each room by flushing, while still maintaining the set growing temperature. The devices also facilitate better control of humidity, providing significant benefits to the farm operation.

Load shedding

Load shedding occurs when there is extreme demand on the electricity system. It is most likely during extreme or prolonged hot spells, after storms or from infrastructure issues. Parts of the grid are shut down in a series of rolling blackouts to protect the remainder of the system from collapse. Essentially, load shedding occurs when supply cannot meet demand.

Peak demand for electricity tends to occur in the third or fourth day of a heatwave, as air-conditioning systems struggle to manage the accumulating heat inside buildings. Demand tends to be highest after schools and businesses return in mid- to late January, usually occurring between 5pm and 9pm on weekdays. While some of this demand can be met by solar systems, it generally occurs as output from these systems is decreasing, at the end of the day.

Normally increased demand within one state can be met by supplies from neighbouring regions. However, this is not an option during widespread heatwaves or other disruptive events.

In these periods, it is not unusual for the wholesale price of electricity to spike dramatically. Mushroom farms and composters with their own 100% backup power supply, whether a diesel generator or other energy source, are in an ideal position to capitalise on this. Large users can separate from the grid, effectively selling their demand reduction back to the grid. The supplier will be compensated for this, potentially at maximum grid price or 'spot price'.

This system provides further incentive for businesses to become energy self-sufficient during periods of peak demand. Not only does it avoid involuntary load shedding – a blackout – but provides a return on investment for energy generation systems. It also replaces the need for periodic generator tests, as they can be programmed to occur automatically as prices rise.

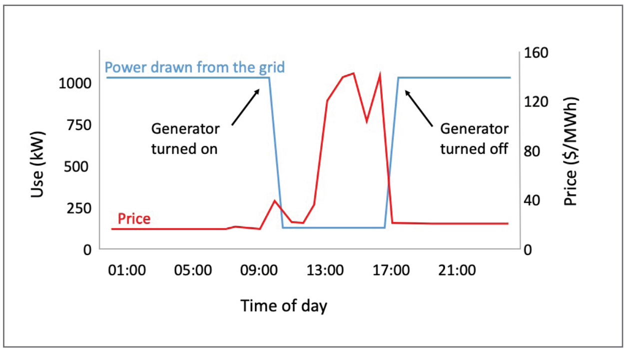

Figure 6. As spot prices for electricity rise, on-farm generators can be programmed to turn on. The system can then turn off again once prices return to normal levels, generating a significant return on investment for using this capability.

Derived from flowpower.com.au

17 Christman, K.D., Haberl, J.S. and Claridge, D.E., 2009. Analysis of energy recovery ventilator savings for Texas buildings.
18 Clarence Consultants ERV case study. Available at: https://www.clarenceconsultants.com.au/pdfs/mech_case_study_one.pdf

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ADAPTING TO CLIMATE CHANGE

05. EFFICIENT USE AND RE-USE OF WATER

Summary

Mushroom and compost producers both use a large amount of water. The availability and cost of clean water, especially in urban areas, is likely to be affected by extreme weather events and droughts. Current industry irrigation practices have not kept up with developments in other cropping systems; irrigation water is mainly applied manually using overhead sprinklers or watering trees. There is little or no use of tools that measure moisture content or control irrigation.

The main opportunities for adapting to climate variability and change are:

1. Drip irrigation to replace overhead sprinkler irrigation
2. De-salination and purification of bore water or recycled water using solar power to reduce reliance on town water and save money
3. Potential for using moisture monitoring technology to help growers manage irrigation to improve yields and quality, and reduce water use.

Current practice

Mushroom production requires large volumes of water, both for compost production and during growing, cleaning and processing at the farm. Estimates of the water required vary widely between businesses. In the case of compost production, most estimates were between 800 to 2,000 Litres/tonne compost. Mushroom farms use about 8 to 20L per kg of mushrooms produced. This suggests that 11 to 30L of water is needed to produce one kg of mushrooms. This is substantially less than the 64L/kg estimated for mushroom production in the US.[1]

Most mushroom farms, and 3 of 7 surveyed compost producers, have access to town water. Many also use bore water, rainwater tanks or pump from surface water sources such as rivers and dams. Use of surface water is more common among compost producers.

Using town water ensures water is of suitable microbial and chemical quality for all purposes on the farm. However, one key effect of climate change is likely to be reduced availability of fresh water, or at increased cost. While most farms gained exemptions from water restrictions in the most recent drought, this represents an ongoing vulnerability for many producers. Even where bore water is available, high salt content may limit its use. Recycling is also limited by accumulation of salts and other impurities. This may be one reason why only 30% of farms recycle water, and few have installed other water efficiency systems.

"Our town water supply is limited by the size of the pipes, and means we have to truck water in occasionally. The farm can't expand further unless we can improve the supply of water."

[1] Robinson B. et al. 2018. A life cycle assessment of Agaricus bisporus mushroom production in the USA. Int. J. Life Cycle Assess. 24:456-457.

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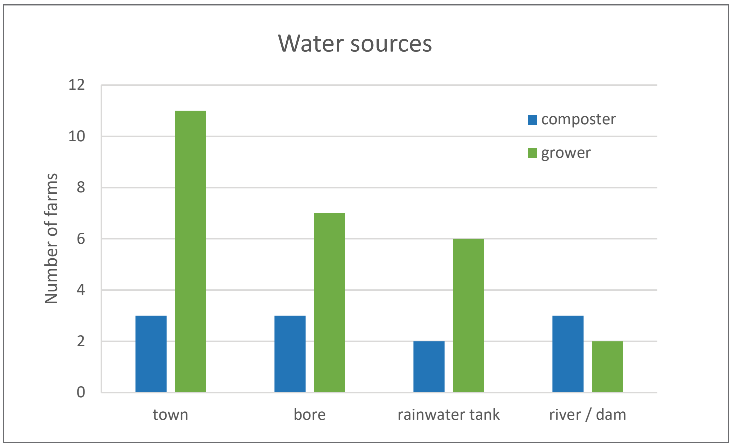
05. EFFICIENT USE AND RE-USE OF WATER



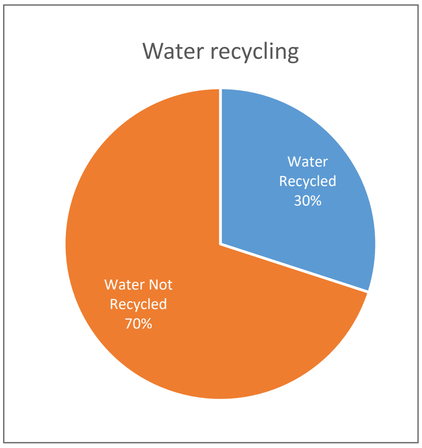


Figure 1. Water sources currently used by Australian mushroom composters and farms, and the percentage of mushroom farms recycling water for non-critical uses (e.g. cleaning).

Figure 2. Automated irrigation system with display panel.

Photo by Vullings-systemen.

Most farms irrigate mushrooms by hand, using watering trees or overhead sprinklers. Automated systems are also available which apply irrigation through fixed sprinklers or a spray arm. These are generally based simply on a timer and pressure controls, but can link with other grow room climate management systems. Examples include the Lumina 767 system by Fancom or Multiflex water supply system by Vullings-systemen. While drip irrigation systems can be installed in shelf systems, none of the mushroom farms surveyed were using this technology.

Background

Mushrooms are more than 90% water. Their production necessarily involves a considerable amount of water, much of which must be high quality. Access to water is already a key issue faced by some composting facilities and farms. Many Australian farms now use town water. While this ensures that water is of suitable microbial and chemical quality for all purposes, water restrictions during drought periods can affect farm operations.

One of the key effects of climate change is likely to be reduced availability of fresh water. While water can be recycled on-site, accumulation of salts and other impurities may limit the uses of recycled water. High salt content may limit use of bore water where this is available.

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05. EFFICIENT USE AND RE-USE OF WATER

De-salination of bore water or recycled water

New and increasingly affordable technologies are available to desalinate bore water or recycled water that contains high levels of dissolved minerals. Local desalination plants, powered by solar energy, can clean up bore water, making it suitable for irrigation of mushroom crops. There are two main types of solar desalination available:

- Reverse osmosis (RO) powered by photovoltaic cells (Solar PV)
- Thermal desalination systems using solar collectors

Reverse osmosis systems: Reverse osmosis (RO) desalinisation works by passing the water through a membrane which strips out the salts. The system produces a stream of clean, fresh water as well as one of more concentrated saline water.

Small desalination units producing up to 30 kL per day can be operated by solar photovoltaic panels. Larger plants producing 50 to 100 kL of water a day cost significantly more and require 3–phase power or stand-alone diesel generators.

A small to medium size mushroom farm (10 tonnes/week) would need about 15 – 43 kL water per day and a large farm (>50 tonnes/week) would need 75 – 215 kL water per day.

Farms would need access to a bore capable of yielding more than the daily water use by the farm, and have somewhere to send the saline wastewater, such as reject wells, evaporation basins, saline waterways and lakes.

Recycling and use of bore water can be limited by contamination with salts and organic material. Some water treatment may be required, and bore water with neutral acidity (pH), low silica and low iron require less treatment. Water chemistry will affect the efficiency of

Figure 4. A small scale solar powered desalination unit.

Photo: Eng. P. Holi

the RO membranes. Detailed water chemistry samples should be taken and analysed by an RO business. Specialist companies such as Suez supply high capacity treatment equipment for recirculating aquaculture systems which can remove dissolved salts, organic matter, bacteria and even viruses.

Economic and reliability considerations are the main challenges to improving PV-powered RO desalination systems. However, the quickly dropping cost of PV panels is making solar-powered desalination ever more feasible. The cost of a solar RO desalination unit depends on the amount of water required and the quality of the input water, especially how much salt it contains. The capita cost of a small-scale desalination plant, producing 10 to 30kL of water a day is about $20,000 to $40,000 with a running cost of about 30 to 40 cents per kL. Town water in Sydney currently (2020) costs $2.11 per kL.

An example Australian provider of solar powered RO desalination system can be found at https://www.moerkwater.com.au/farming.

Thermal desalination: A good example of this technology is the Sundrop tomato farm, near Port Augusta in South Australia. The farm uses a concentrated solar power (CSP) tower plant to supply electricity, heat and desalinated seawater to grow tomatoes. The installation produces enough electricity and heat to run the 20ha glasshouse operation. It also produces 450 megalitres of freshwater by desalinating seawater each year. Visit the Sundrop farms website for more information https://www.sundropfarms.com/

FARM SIZE	PRODUCTION (TONNE PER WEEK)	SCALE OF DESAL SYSTEM REQUIRED	WATER NEEDS (KL/DAY)*	ANNUAL WATER COST ($)**
Small	< 10	Small	15 - 43	$11,500 - $33,000
Large	> 50	Large	75 - 215	$58,000 - $165,000

* Based on water consumption of 11-30 kL / tonne mushrooms.

** Based on Sydney water cost of $2.11/kL.

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Figure 3. Netafim “Mushroom Master” irrigation system

Drip irrigation

Mushrooms are usually irrigated using a sprinkler system. However, sprinklers cannot be used when mushrooms are emerging. Netafim has developed a drip irrigation system called Mushroom Master™. The drip system maintains uniform moisture levels through the compost and casing material, reducing the need for heavy watering between flushes. For more information visit: https://www.netafim.com/en/crop-knowledge/mushroom/.

It is claimed the system reduces total water use and energy costs by up to 20%, as well as reducing the thickness of the casing required by up to 30%. Moreover, as uniform moisture improves mushroom density, quality and storage life may be improved. The system is in use by at least three farms internationally.

Measurement and management of moisture levels in compost

The levels of moisture in mushroom compost and casing are high – in the range 49 – 69%. Moisture levels significantly affect yield and quality in mushroom production. The management of irrigation in mushroom production is largely manual. Irrigation is often based on operators’ experience and judgement, with little reliance on technology to provide objective data on moisture levels in the media.

There are many moisture sensors used in crop production that may potentially have a role helping growers manage water. While these technologies are widely used in soils, they have not been widely tested in commercial mushroom production and in compost. Further research would be required to validate these tools for mushrooms. However, if proven effective they would facilitate better control of moisture levels in mushroom growing media. They would also work well with the drip irrigation system described above.

Two common examples of moisture sensing systems are:

- Time Domain Reflectometry (TDR) sensors
- Soil moisture capacitance sensors

Figure 5. Wildeye TDR soil moisture sensors and communications unit

Time Domain Reflectometry (TDR) sensors: These sensors measure volumetric moisture content. Moisture is measured by sending a high-speed electromagnetic pulse down a line of known length, and measuring its travel time and reflectance. TDR sensors are a well-established technology and widely used in agriculture to measure soil moisture. Recently, small portable systems have been developed that allow the data to be uploaded to a website, where it can be easily accessed by the grower. An example of a commercially available TDR system developed by Wildeye, with two sensor probes and a communications unit, is shown in Figure 4.

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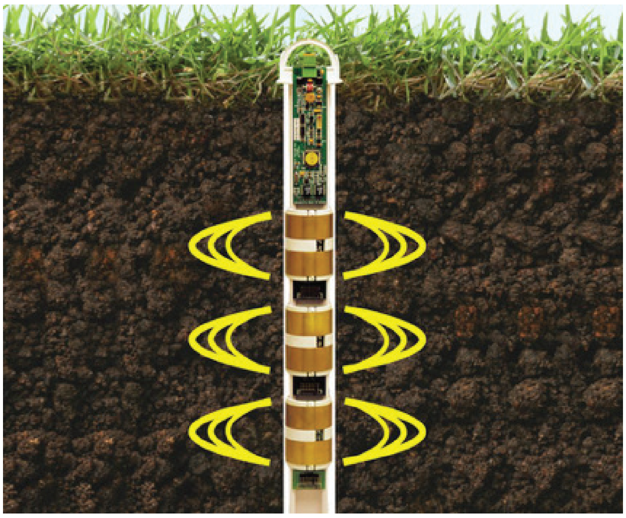

Figure 6. EnviroScan soil moisture sensors diagram showing field of measurement.

Figure 7. Standing wave sensor. Photo by ICT International

Soil moisture capacitance sensors: Capacitance sensors also measure volumetric moisture content, but by measuring the charge time for a capacitor with electrodes separated by the soil. Fast charge times indicate high moisture contents. There are many brands available commercially, with associated equipment for transmitting and storing data.

Standing wave sensors: These sensors use an oscillator to generate an electrical field along parallel needles. The signal produced by reflected signals indicates moisture content. They are less common than capacitance and TDR sensors, but are sold in Australia by ICT International.

	TDR	CAPACITANCE	STANDING WAVE
Accuracy	Excellent	Satisfactory	Good
Cost	High	Low	Moderate
Life expectancy	20 years	2 to 5 years	20 years
Needs calibration by soil type?	No	Yes	Yes
Affected by temperature?	No	Yes	No
Recommended for compost?	Yes	No	Yes

Table 1. Comparison of different types of soil moisture sensors

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ADAPTING TO CLIMATE CHANGE

06. SOLAR POWER GENERATION

Summary

The mushroom industry has already proven a strong adopter of solar power generation, with half the farms surveyed with systems already in place. Options include photovoltaic and concentrated solar systems. Using the energy generated at source is a key factor making solar viable, but the high energy requirements of both farms and composters mean this is readily achieved. Systems up to 100kW attract a government rebate. Larger systems may be financed through a 'behind-the-meter' contract, where the installer pays for the system and sells the power generated back to the farm. The payback time for solar systems depends on the price paid for electricity. If businesses are paying retail prices, the cost of their solar system could pay for itself in 40 months. However, if wholesale pricing means electricity prices are low, the payback period may be 7 to 10 years.

Background

The mushroom industry is already a proven adopter of solar power generation. The large roof area of mushroom farms makes them a clear candidate for solar photovoltaic (PV) energy. The costs of solar energy are falling while the efficiency of energy production has increased. Moreover, the panels shade the roof, reducing radiant heat load on the building.

As a result, nearly half of all Australian mushroom farms and one third of compost producers already have solar systems installed. At least half of the remainder are investigating solar options.

Battery systems to store solar generated electricity have had much lower uptake. Payback periods are longer, while the rapid rate of change in this area means many are waiting before making this further investment.

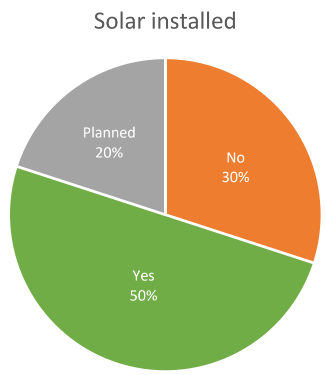

Figure 1. Percentage of Australian mushroom farms with solar already installed, solar planned or not installed.

Solar power generation

The primary indicator of viability for solar energy is whether electricity can be consumed during sunlight hours, for which typical mushroom farming is well suited. AHR studied the feasibility of on-farm solar, as well as wind and gas generation, in a recent project for the vegetable industry[1] click here for the report and factsheets. The study showed that solar photovoltaics (PV) can be viable at a 10% Internal Rate of Return (IRR) with a 5 – 7 year payback period if **electricity costs are currently more than 12 – 15 c/kWh.**

[1] Rogers, G. 2014. On farm power generation options for Australian vegetable growers (VG13051) Hort Innovation final report

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06. SOLAR POWER GENERATION

One drawback of solar energy has been the lack of storage facility; batteries. However, these too are becoming more price competitive. For example, the Tesla Powerpack system can provide up to 2.5MW power. This can be used to shift demand, reducing reliance on high priced energy, alleviate peaks in system load and provide emergency backup in the event of a power cut.

Concentrated solar power

Concentrated solar power (CSP), also known as concentrated solar thermal systems, generate solar power using mirrors or lenses to concentrate a large area of sunlight onto a receiver. Electricity is generated when concentrated light is converted to heat (solar thermal energy), which drives a heat engine (usually a steam turbine) connected to an electrical power generator or powers a thermochemical reaction[2]. Commercial providers can supply these systems as an alternative to solar PV.

RayGen has installed a concentrated solar power generator at an Australian mushroom composter. The plant co-generates electricity and heat by using mirrors to focus sunlight onto a photovoltaic receiver containing efficient photovoltaic Ultra modules. Electricity is generated in the receiver, while a closed-loop water cooling system captures and stores heat as a useful by-product.

Electricity is sold to the composter at a discount rate in a behind-the-meter contract, and surplus electricity is fed into the grid.

Economics of solar energy

Small-scale rooftop solar is defined as installations of 100kW or less – and which qualify for an upfront rebate (which are being wound back each year and eventually eliminated by 2030). Larger rooftop solar systems operate under a different scheme, along with utility-scale solar farms.

A key design feature of the *Small-scale Renewable Energy Scheme-(SRES)* is that regions with greater solar exposure receive a higher proportional subsidy, on account of their greater ability to generate electricity from rooftop panels.

The approach applied to large-scale projects under the Large-scale Renewable Energy Target (LRET) is that certificates are created per unit of renewable electricity actually generated.

100kW solar systems are among the most popular commercial solar system sizes in Australia, as this size is the cut-off point for up-front incentives through the federal government.

RayGen's PV Ultra Concentrated solar power generator. *Source: RayGen*

[2] Wikipedia https://en.wikipedia.org/wiki/Concentrated_solar_power

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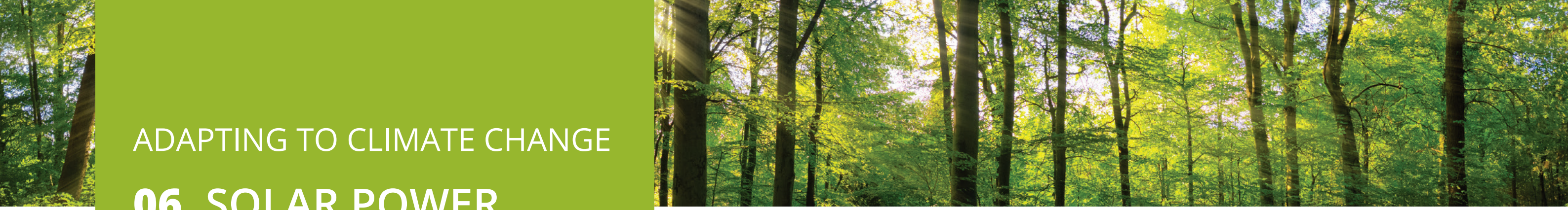

06. SOLAR POWER GENERATION

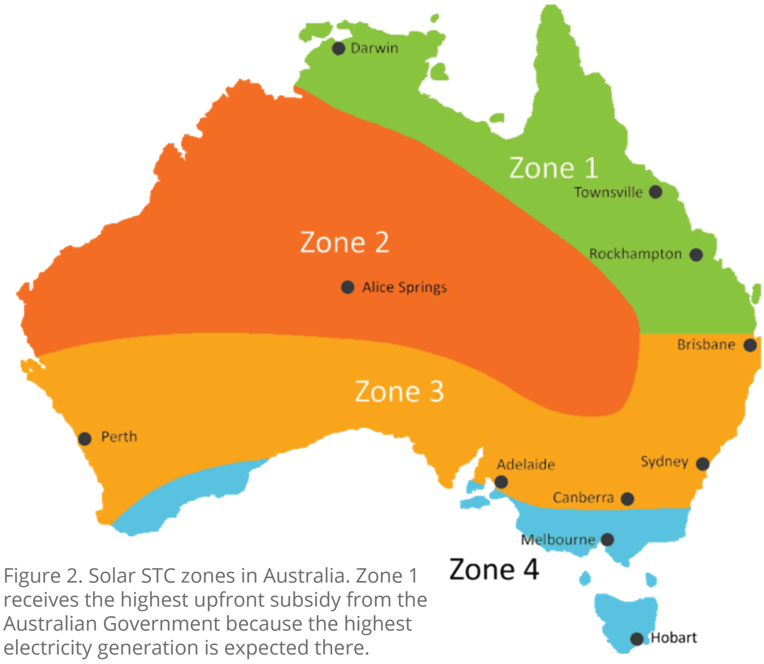

Figure 2. Solar STC zones in Australia. Zone 1 receives the highest upfront subsidy from the Australian Government because the highest electricity generation is expected there.

Source: [Solargain]

Figure 3. 100kW solar photovoltaic installed on a rooftop. *Source:* [Spinifex Energy]

COST OF SOLAR

	10kW	30kW	50kW	70kW	100kW
Adelaide, SA	$12,880	$34,580	$58,050	$79,590	$96,830
Brisbane, QLD	$11,730	$32,650	$57,400	$78,800	$97,820
Canberra, ACT	$10,760	$29,070	$53,260	$74,140	$99,560
Hobart, TAS	$15,550	$37,780	$63,350	$85,090	$93,620
Melbourne, VIC	$13,190	$32,270	$57,520	$75,650	$97,430
Sydney, NSW	$13,420	$32,760	$57,570	$75,630	$92,580
Perth, WA	$15,900	$37,410	$65,910	$83,210	$94,300

Table 1. Average commercial system prices by city & size (May 2020). STC rebate and GST included. *Source:* [Solar Choice]

FINANCING OPTIONS

Australia's banks offer discounted 'energy-efficiency' loans. These loans typically offer a 0.70% discount on headline rates for investments into clean-energy assets and are available from the major banks.

Power purchase agreements (PPAs) are arrangements in which an organisation benefits from lower electricity rates without having to purchase a system. Instead, a PPA provider pays for and owns the solar system, selling the energy it produces to the business directly at an agreed-upon rate that is lower than energy from the grid.

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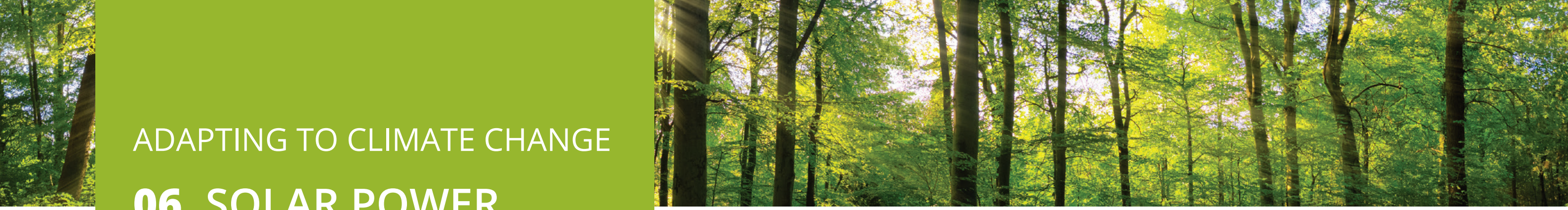

ADAPTING TO CLIMATE CHANGE

06. SOLAR POWER GENERATION

FINANCIAL CONSIDERATIONS

Price of electricity

Mushroom farms and compost yards in areas with higher prices of electricity, or which are unable to access cheap energy deals, will realise a higher return on investment from solar systems.

Wholesale electricity prices are often low during the middle of the day, when solar produces the most energy. Businesses on a retail electricity contract will benefit more than those on a wholesale electricity contract.

Feed-in tariffs

Feed-in tariffs are rebate paid for electricity exported to the electricity grid. Historically, feed-in tariffs were high in Australia, but government subsidies have been removed and replaced by STCs, which are an upfront subsidy on solar installations less than 100kW. Feed-in tariffs do remain for small solar systems, generally 5kW for single phase or 30kW for 3-phase. For maximum return on investment, a solar installation at a mushroom farm or compost yard should be designed so all electricity generated is used on-site.

SHOULD YOU INVEST IN SOLAR?

Businesses on a retail electricity contract should install solar. The economics are clear. For example, if a business is paying 20 cents per kilowatt hour ($200/MWh) during the day, a 100kW system would have a payback period of 3.3 years in NSW.

Wholesale electricity contracts are much more complex. In this case, the payback period for an investment will mostly depend on the price of electricity a business is paying during daylight hours, when wholesale prices are often quite low.

If the business has a favorable electricity deal, it may take 7 to 10 years for a solar system to provide a return.

STATE	ENERGY AUSTRALIA FEED-IN TARIFF
Victoria	12.0 cents per kWh
New South Wales	10.5 cents per kWh
Australian Capital Territory	10.5 cents per kWh
South Australia	11.5 cents per kWh
Queensland	11.5 cents per kWh

Table 2. Example of feed-in tariffs rates in Australia. *Source: Energy Australia*

	NSW	VIC	QLD	SA	AVERAGE
Wholesale price of electricity ($/MWh)	90	98	62	83	83
Electricity used on-site	100%	100%	100%	100%	100%
Purchase price (rebate included)	$92,580	$97,430	$97,820	$96,830	$96,165
Size of solar system	100kW	100kW	100kW	100kW	100kW
Payback period (years)	7.2	7.5	9.5	7.6	8.0
Internal rate of return (IRR)	14%	14%	10%	13%	13%

Table 3. Payback period of 100kW solar installations. Calculations consider the daylight hours in each area, average wholesale price of electricity. GST is included. Fixed supply charges are not considered and should not be affected by investment in solar. Calculator is available here: https://www.solarchoice.net.au/blog/solar-power-system-payback-calculator

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