Thermal energy Storage for Renewable Energy Uptake in Wineries

White Paper

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GLACIEM COOLING TECHNOLOGIES

University of South Australia

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1 Introduction

As significant energy users in the Australian agribusiness sector, wineries are under increasing pressure to reduce their energy cost and carbon footprint. For the wine industry, climate change represents a future plagued with uncertainty. It puts pressure on resources, with water availability of particular concern over coming decades. At its most fundamental level, parts of the industry are threatened by their very location. Some regions face the reality that some of the wine varieties they are most famous for may become unable to be grown as it will simply be too hot. Today the industry is experiencing earlier, shorter vintages as the grapevines respond to warmer temperatures.

To steer their way out of this compounding problem, wineries are looking for ways to 100% electrify and meet their electricity demand with renewable energy. Wine production is an energy intensive process, with wine requiring a significant amount of cooling, and refrigeration typically accounting for 40-60% of a facilities' electricity bill. On a warming planet with a decarbonisation imperative, processes with this level of energy use are inevitably headed for change. This shift sees a growing number of wineries, significantly increasing their renewable energy uptake. Just as in wine production, this brings with it both opportunity and risk, and requires investment in the right systems and technology. It is expected that the majority of wineries will be using 100% electrical energy for wine processing in the near future.

Utilising large amounts of solar PV to drive cooling processes, however, is problematic for several reasons. Foremost, cooling processes often require 24/7 operation with solar providing only intermittent power during daylight hours. Further, as electricity networks approach limits on PV hosting capacity, new installations are having their size restricted, or export curtailed in many areas. Further, as with all medium to large energy users, wineries are facing an increasing shift towards the separation of network demand charges (kVA) and electricity consumption charges (kWh). This has made the installation of solar systems to offset cooling costs an unattractive economic proposition.

The key for many businesses is leveraging their renewable assets through energy storage. For wineries, Phase Change Material (PCM) Thermal Energy Storage (TES) is the logical technology choice. PCM TES involves the latent transformation of water into ice (freezing), creating a large heatsink that if managed intelligently, can provide many strategic benefits:

- Solving generation / use mismatch for renewable energy
- Providing viable, cost-effective storage for otherwise wasted renewable energy
- Enabling wholesale electricity market engagement and providing opportunity for arbitrage
- Enabling peak demand reduction when deployed strategically
- Additive to site capacity, as it can be charged during periods of downtime.

This paper will examine the role of TES through the lens of the winemaker. It will describe key activities across the winemaking process in terms of their energy and cooling requirements. It will touch upon some TES systems already commissioned in the world of wine and will explore the potential role for TES in sites that have not yet engaged with the technology.

2 Industry Scale and Market

Australia has a long history of quality table wine production and several world-famous wine growing regions. The Australian Wine Industry is an important provider of wines into domestic and global markets.

With vineyards spanning ~ 146,000 hectares, Australia produced 2.03 million tons of wine grapes and 1.2 billion litres of wine in 2021, with an estimated export value of $2.6 billion. Approximately 59% of this volume is for the export market[1].

3 Energy and cooling in the winemaking process

In Australia the wine grape harvest or 'Vintage', typically begins in hotter areas like the Riverland of South Australia in January and ends in cooler regions such as Tasmania in May.

Typically, a winery will use upwards of 50% of their annual energy budget in the 3-4 months of vintage. Winemakers strive to protect grape quality attributes using temperature control at every step of the winemaking process. The whole winemaking procedures schematic diagram of different types of wine is presented in Figure 1. In the winery, temperature management is paramount as soon as the truck enters the gates:

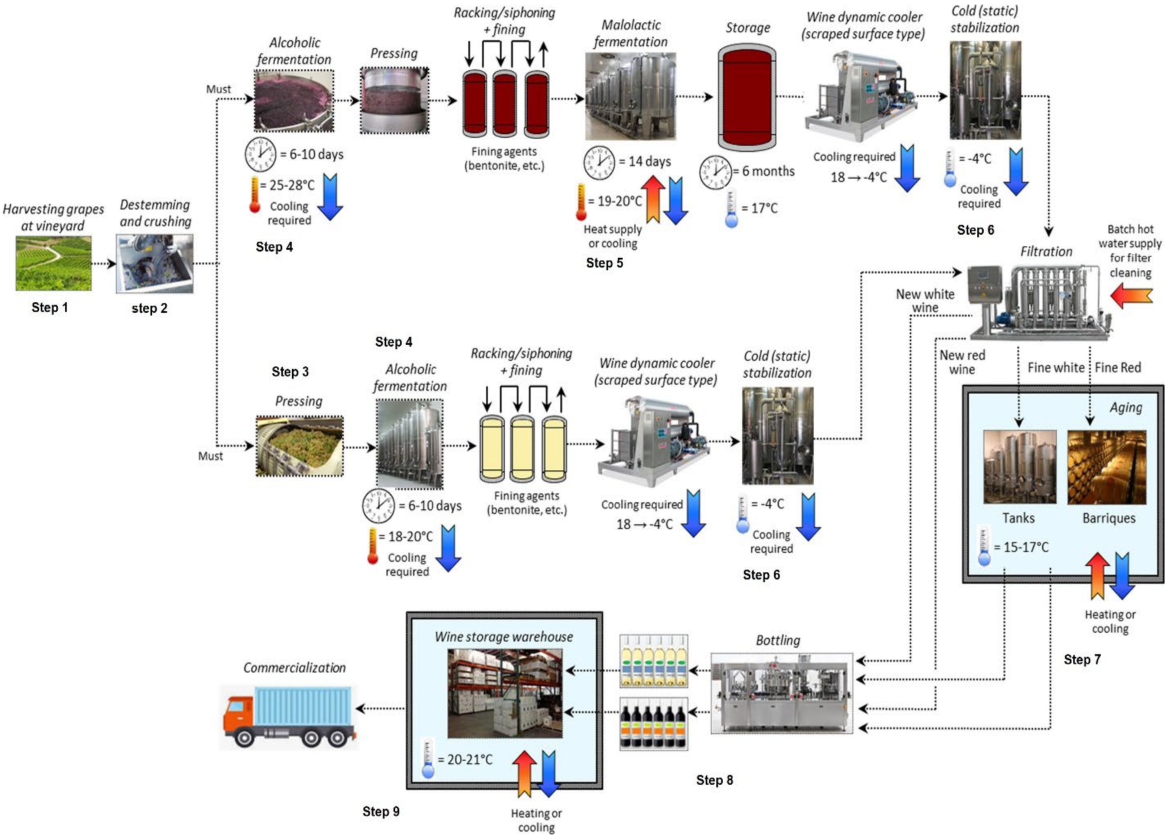

Figure 1 - Typical winery processes[2]

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[1] https://www.wineaustralia.com/market-insights/australian-wine-sector-at-a-glance

[2] P. Catrini et al , 2020' Characterization of cooling loads in the wine industry and novel seasonal indicator for reliable assessment of energy saving through retrofit of chillers", Applied Energy, 226 (2020) 114856

3.1 Grape Intake

Grapes are harvested in grape bins and loaded onto trucks. Fruit intake is closely managed to prevent picked grapes being exposed to the sun for prolonged periods. White grapes are typically harvested at night to improve quality outcomes and reduce the cooling requirement at the winery.

3.2 Crushing / Destemming / Initial Temperature Control

Fruit is destemmed and crushed during the fruit intake process, forming a mixture of grape skins, juice, seeds and pulp called 'must'. White fruit is cooled to under 5°C immediately after crushing and destemming to help prevent oxidation. This is a key early vintage cooling load. This typically happens as the must is being pumped to presses for the removal of skins and seeds from the juice.

White juice will then commonly undergo a 'cold settling' phase, where it is kept in tank close to 0°C for a few days, allowing solids to drop out of solution.

Wine style typically demands that red fruit is left in contact with skins throughout the fermentation process. Most often, red must will be sent to a fermentation vessel with no pre-cooling, at which point the temperature of the fermentation itself will be closely monitored and controlled.

In some circumstances red must will undergo 'cold soak' where it is kept between 4-10°c for specified periods to achieve certain stylistic outcomes, prior to progressing to the fermentation stage.

3.3 Primary Fermentation

Primary fermentation is the process of yeast converting sugars in wine grapes into alcohol and CO_2. Importantly, due to the intense metabolic activity at the time of fermentation, the process also produces significant amounts of heat. If not controlled, the heat from fermentation can seriously downgrade or destroy a wine in the space of a few hours. For red wines fermentation temperatures should be kept between 20°C - 28°C. For whites, between 16°C - 20°C. Controlling primary fermentation is the key vintage energy load.

3.4 Malolactic fermentation (Secondary fermentation)

Most red wines, and some white wines, undergo a secondary fermentation called malolactic fermentation. This converts malic acid to lactic acid, softening the wine. Malolactic fermentation is particularly temperature sensitive requiring temperatures of 18°C to 20°C.

3.5 Clarification and stabilisation

The clarification process is used to separate the wine from spent yeast and other residuals left from fermentation process. New wines undergo filtration or centrifuging and spend time in tank settling. Then, typically the wine is ready for cold stabilisation.

The process of cold stabilisation involves cooling wine down below -4°C, which causes tartaric acid to precipitate out of the wine. Cold stabilisation is extremely energy intensive.

3.6 Wine storage and maturation

Prior to bottling wine is stored in tanks and/or barrels. Temperature control is important for both types of storage preventing oxidation and helping ensure the wine matures appropriately.

Barrel cellars commonly have humidity and temperature control, keeping conditions between 15-17°C and relative humidity above 50%. This helps prevent excessive evaporation of product from barrel stores.

Many wines spend prolonged periods in stainless steel tanks fitted with cooling jackets and insulation. Bottle ready table wine is typically kept at 16°C.

3.7 Packaging

Wine ready for bottling is stored in tanks with temperature control. Wine is pumped through a filling carousel into bottles that have been cleaned with compressed air or nitrogen. From there the bottles are packed in cartons and stacked on wrapped pallets, ready for warehousing or shipping to market. Compared to the winery, energy use at a packaging center is a far more consistent load across the year, as they are able to govern their intake.

3.8 Warehousing

Packaged wine is stored in temperature-controlled warehouses between 18 - 20 °C. A key challenge for the industry is how to protect the wine from elevated temperatures during shipping, particularly wines for export. Work continues on various forms of insulation that may be incorporated successfully in a shipping container.

4 Understanding the Energy Balance

For a successful decarbonisation initiative, it is imperative to understand the winemaking process from an energy balance perspective. That is, understanding what the energy impact of each process is, as a percentage of site total energy use. This will allow a facility to target the opportunities of greatest magnitude first.

4.1 A ‘typical’ Australian winery

The energy use in an Australian winery will vary significantly depending on a wide array of factors, namely facility size and winery type. There are however there are some general energy characteristics that apply to most facilities:

- Electricity is the key energy fuel type, constituting 70-80% of site power. Most of this electricity is used for refrigeration. Refrigeration is the process of highest energy demand in most wineries, accounting for 40-60% of a facilities energy budget. Most of this refrigeration energy is spent controlling fermentation during the months of vintage. Another important use of refrigeration across the year at many wineries is Cold Stabilisation.
- Other fuel types include natural gas, LPG and diesel. Of these, natural gas and LPG are used in the production of hot water or steam for cleaning and sterilisation, or in some areas for heating coils used for product heating. At some wineries auxiliary diesel-powered cooling is hired during vintage to allow the winery to cope with the primary

fermentation load. This can amount to a significant use of diesel due to the lower performance of these units.

Figure 2 provides the proportion of electrical energy required for providing different energy services in the wine-making processes

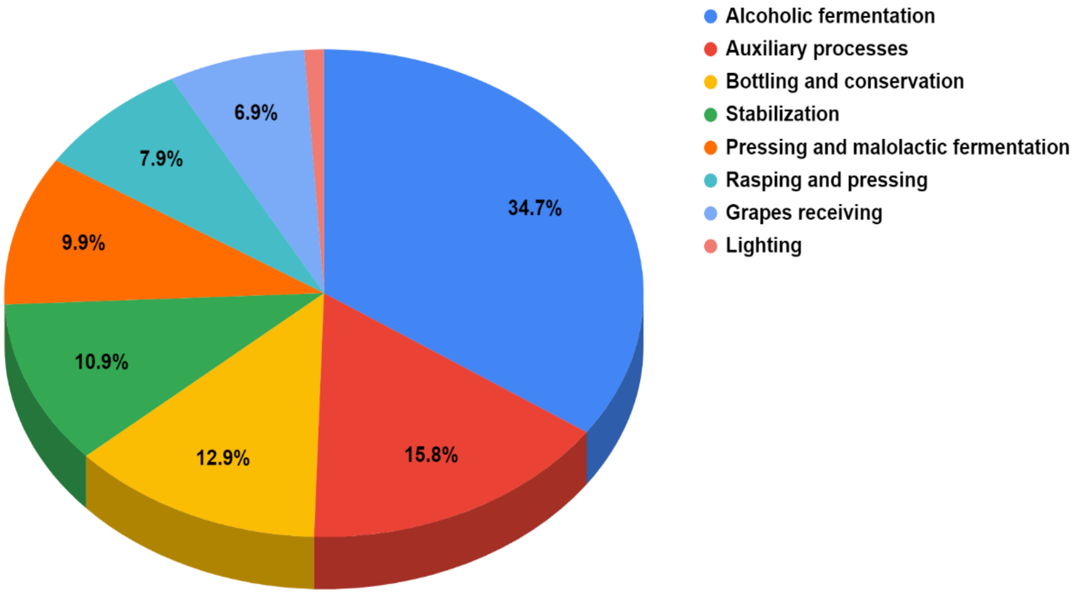

Figure 2 - Typical electricity energy consumption in the wine-making process[3]

5 The Transition to Renewables

Electricity is deeply linked to winery processes, particularly through their intense need for cooling. It follows that electricity from fossil fuel fired power generation has historically been the key source of CO_2 emissions associated with winery operations[4].

Direct fuel burning of LPG or natural gas for hot water, steam generation or mobile plant operation is a minor and diminishing activity in wineries. Availability of cheap renewable electricity has triggered the 'tipping point' for the electrification of heat, and business can see both environmental and economic incentives to move away from gas. Additionally, through partnerships such as Climate Active, Government and business are working together to encourage the setting of carbon neutrality goals across industry.

Many wineries in Australia and around the world have started installing Solar PV or purchasing green power. To date, three Australian wineries are certified carbon neutral for their

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[3] Pivetta, D., S. Rech, and A. Lazzaretto, Choice of the Optimal Design and Operation of Multi-Energy Conversion Systems in a Prosecco Wine Cellar. Energies, 2020. 13(23): p. 6252.

[4] South Australian Wine Industry Association, A guide to greenhouse gas reduction for South Australian grapegrowers & winemakers. 2010

sustainable Vineyard management and wine-making processes: Rose Hill Wines in Orange, NSW, Keith Tulloch Winery in Hunter Valley, NSW and Hither and Yon Winery in McLaren Vale, SA.

6 Why Thermal Energy Storage

6.1 Stand Alone Renewables

Installing large solar PV systems to drive winery cooling processes without some form of energy storage is problematic for several reasons:

- Winery processes, particularly during vintage, are 24/7 operations. Solar PV only provides intermittent power during daylight hours
- System size restrictions and export limits due to grid stability concerns, combined with a move towards separate network demand charges, make PV without storage less economically viable. Storage is needed to maximise renewable energy consumption.

6.2 Thermal Energy Storage vs Electrical Batteries

Thermal Energy Storage and Electrical Battery storage both have an important part to play in the transition to renewable energy and to ensure effective winery cooling and energy management operations. It is critical to understand the roles they each play are fundamentally different, and often complementary.

Many winery operators have investigated adding electrical battery storage in conjunction with solar PV but have found these forms of energy storage are not economically viable due to their high installed cost and relatively short life span. Electrical battery storage is not effective in bridging the gap between renewable energy and heating /cooling loads. For electrical battery power to service a cooling load it first needs to be converted to thermal energy using the power-hungry process of mechanical vapour compression. Further, an electrical battery would need to be physically large to hold the electrical energy required for a winery cooling load. Electrical batteries are simply not designed for the significant, repeated power draw of a refrigeration system. Electrical storage is, however, an excellent technology for maintaining electrical power to TES control systems and pumps during periods of power outage.

Unlike electrical battery storage, TES systems, as their name describes, capture, discharge and store thermal energy. This allows them to capture the resulting thermal energy from the conversion of electrical energy to mechanical energy done by vapour compression cycle, and store it for later, without having to run compressors again. TES systems are also energy 'dense' (technically they are very void of heat energy) as they leverage the energy storage potential of the latent transformation of heat. They form large heat sinks as energy is removed from the incorporated phase change material, changing it from liquid to solid state. For water the transition to ice means it has approximately 4 times less heat in it than when it was liquid. This in turn means TES is able to absorb 4 times more heat from winery processes than the same body of liquid water. This 'energy density' allows TES systems to provide a considerable amount of cooling for a relatively small physical footprint. These factors make the two technologies very different but very important parts of an off-grid or power limited TES installation.

6.3 Strategic Benefits of TES

6.3.1 Solving generation / use mismatch for renewable energy

A well understood limitation of renewable power such as solar PV and wind is its intermittency. Thermal Energy Storage can be used to store the energy when it is available, holding it for later use. This process requires some forecasting. That is, for the storage to store energy at the appropriate time, it needs to be sent a signal instructing it that there is renewable energy available now that should be captured.

6.3.2 Providing viable, cost-effective storage for otherwise wasted renewable energy

The renewable energy landscape in Australia is complex. In some jurisdictions, energy balance in the grid is achieved by curtailing renewable energy export, in some cases preventing export completely. This can have important implications for renewable asset owners, as it changes the return-on-investment parameters associated with uptake significantly. Thermal energy storage can ensure renewable energy that would otherwise be curtailed and wasted is instead stored and used. This 'flips' the problem, moving that energy from the 'generated as waste' category to the 'generated as the cheapest energy we use' category.

6.3.3 Enabling electricity wholesale market engagement and providing opportunity for arbitrage

With an energy grid supported by deployed renewables and growing electrical storage, the wholesale electricity market in Australia represents a significant opportunity for Australian energy users to redefine their energy use.

Thermal energy storage supported by the appropriate software, allows for important market interactions. Users generating surplus energy can choose to store it and use it instead of buying electricity at unfavorable price points. Previously stored thermal energy can also provide cooling at times of favorable renewable energy sale prices, allowing users to engage in arbitrage activities with site-generated electricity.

6.3.4 Enabling peak demand reduction when deployed strategically

Given the resource intense nature of vintage, with peaky but relatively short-lived energy use characteristics, wineries are often disadvantaged by Peak Demand arrangements with electricity service providers. That is, they can be subject to elevated peak demand charges set at their highest consumption point, even though it is not commensurate with typical and average demand. In these situations, TES can play a critically important demand-shifting role in allowing a facility to simply avoid the peaks by using stored cooling instead. Given these peaks are often occurring at the hottest most energy intense periods of the day with peak grid pricing, this peak lopping has significant positive implications for energy spend as well.

6.3.5 Additional to site capacity

TES, due to its ability to store energy during periods of downtime can in some instances bolster site cooling capacity. The stored cooling within the battery can be deployed at the same time as direct cooling from the refrigeration system. This can help a facility avoid the need to hire and operate supplemental diesel powered cooling or other ancillary services during peak production. Having a system supported by the appropriate optimisation software allows for these opportunities to be assessed and implemented.

6.3.6 Sector Integration

It is important to recognise that TES is a technology that delivers energy benefit in a number of different ways. From a winery perspective, the storage can be deployed to provide any or all of the advantages described above. As multiple facilities across electricity networks in Australia uptake TES technology, there will be an inevitable positive impact on national electricity grid stability through shaving peak power and promoting self-consumption. This will further opportunity for the uptake and optimised utilisation of renewable power.

7 Possible Deployments Thermal Energy Storage within the Wine Industry

The following case studies demonstrate the potential economic and operational benefits of integrating TES in businesses which have made serious commitments to transitioning to renewable energy.

7.1 De Bortoli Wines, Bilbul, New South Wales

In 2013, De Bortoli Wines installed a 230KW solar PV system at their winery in Bilbul, NSW. The system generates about 365 MWh per year, which accounts 5.5% of the total electrical consumption at the site. Their aim was to run most of the wine-making operations through the daytime to minimise the amount of electricity export to the grid. In the first year of its operation, the solar PV system exported only 1% of the electricity that it generated to the grid[5].

With renewable energy accounting for only 5.5% of site electricity the site needs a bigger solar PV system to further decarbonisation efforts. Just expanding the size of the renewable asset, however, will inevitably lead to more of that energy being exported to the grid. A TES system would allow excess solar to be stored rather than exported.

7.2 Cape Jaffa Wines, South Australia

Cape Jaffa Wines in South Australia is a completely off-grid site. Historically, the electricity demand was met mainly by diesel generators. In 2017, after conducting an energy audit with the support of a government grant, the winery installed 81 kW of solar PV and 460 kWh of lithium battery energy storage[6].

If Cape Jaffa wines wants to increase onsite solar electricity generation, storing excess electricity with a large TES unit is a sensible option to explore. A smaller electrical battery store could then provide the pumping power required to discharge the unit. At the time of this report, the

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[5] https://www.wineaustralia.com/getmedia/824b71af-93fc-469b-956a-38361305370e/CORD_Factsheets_WinerySavesSolarPanelInstall.pdf

[6] https://www.capejaffawines.com.au/index.cfm?method=blog.blogList&fromDate=01%2F12%2F2017&ToDate=31%2F12%2F2017

author was not able to get more information about the annual electricity energy consumption and the status of the installed solar PV and battery storage.

7.3 Mitchell Wines, Clare Valley, South Australia

In 2018-19, the electricity consumption of Mitchell Wines in the Clare Valley, South Australia was 158 MWh and threatening to trip the 'Large Business' tariff of 160 MWh use per annum. Once triggered, this change would represent an increase of 10.4% p.a. in large business tariffs with agreed demand, or 1.8% p.a. actual demand[7].

In a strategic decision Mitchell Wines installed 100 kW solar PV in 2020 and avoided the large business tariff. Although the new solar PV system reduced the electrical energy consumption ~20%, there is significant solar export to the grid. Mitchell Wines are not paid for this exported energy, so it represents asset utilisation without economic return.

Like other wineries, the majority of the facility's electricity consumption is attributed to cooling demand. This represents an opportunity to use TES and store the exported energy for use in cooling instead, further reducing grid demand. A good example of the ability of TES to 'rescue' stranded assets if deployed strategically within a system.

8 Actual Deployments of Thermal Energy Storage within the Wine Industry

Pernod Ricard's (PRW) Rowland Flat facility is located in the Barossa Valley, South Australia and has wine-making, wine storage and packaging capability. At the site refrigeration is supplied via four large ammonia refrigeration systems totaling $5MW_t$. The plant is sized to cope with the large refrigeration process loads during the vintage period from January to April. Outside of the vintage period refrigeration process loads reduce by around 70%.

The current annual electricity cost is in excess of $2M and this is a significant cost overhead that adds considerably to the average cost per litre of wine.

In order to reduce high electrical costs, PRW are implementing an ambitious energy management strategy. This energy resource consolidation strategy includes the installation of large-scale renewable assets aimed at reducing future energy bills. The company has installed 2.8MW of Solar PV at the Barossa facility, to cover around 20% of the site's existing electrical demand, with the remaining 80% (18MW) planned to be purchased through Power Purchasing Arrangements (PPA) for both wind and PV-generated energy.

For PRW, the installation of 2.6 MWh of TES forms a 'technical hedge' for managing electricity costs and cooling availability. As PRW currently participate in the wholesale electricity market, the TES with its smart control system provides the ability to arbitrage the energy price. PRW were interested in exploring TES technology as a demonstration project.

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[7] https://www.greenindustries.sa.gov.au/__media_downloads/202490/GISA_SAWIA_Mitchell.pdf?downloadable=1

Supported by the Australian Renewable Energy Agency's "Advancing Renewables" grant, Glaciem Cooling Technologies installed a Thermocold DYN 900 TES unit, integrating it into one of Rowland Flat's existing refrigeration plants. The system has been integrated with the site's Supervisory Control and Data Acquisition control system (SCADA) and Glaciem's cloud-based Advanced Control and Forecasting Algorithm (ACFA). This allows it to dynamically control the usage of the TES battery and optimise the storage and utilisation of solar generation (300 kW of PRW's 2.8MW total is connected to this system).

The data from this integrated system has been being monitored since its installation. The preliminary results shows that Glaciem's cloud-based Advanced Control and Forecasting Algorithm along with the TES were able to predict the high electricity price event and avoid grid demand and export solar.

One example of the operation of the system is from the evening of March 12, 2021. ACFA predicted a high price event with market energy prices as high as $16 / kWh for a period of up to 4 hours between 6:30 pm and 10:30 pm. The system worked to charge the store in time for this event in the two days leading up to it and there was a nearly full store at the time of the event, resulting in $2,300 of savings in energy costs over the resulting 6 hours of high prices.

The integrated ACFA, Solar PV and Glaciem's TES system has the following benefits:

- Management of the cooling loads at "Frig 9" in line with both other system requirements and wholesale market conditions via ACFA
- Contribution to management of site network tariffs through the application of ACFA integrated with PV and the TES system, as shown in Figure 3.

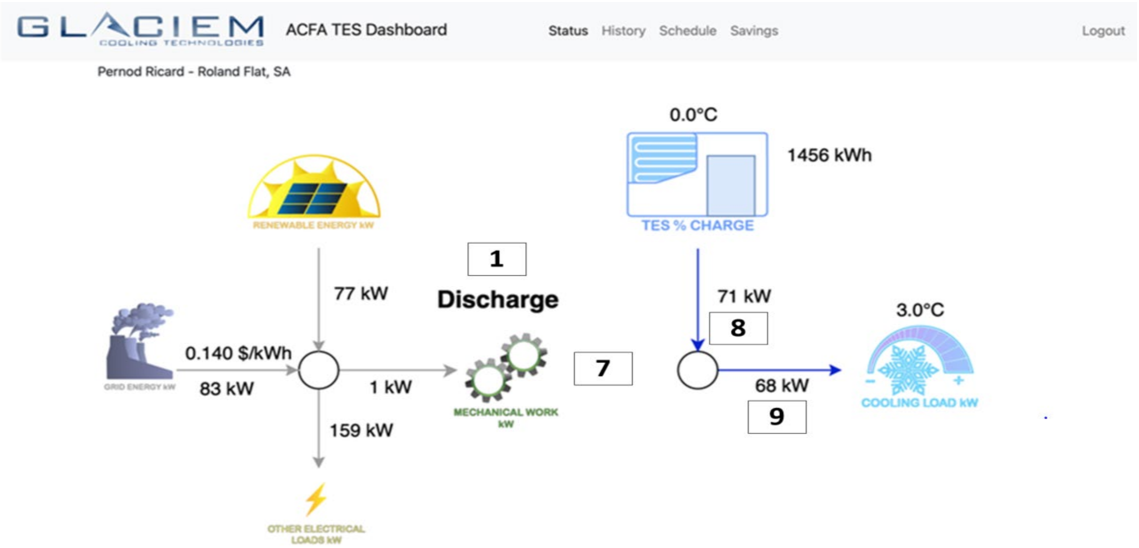

Figure 3 - ACFA TES Dashboard Status Screen Discharge Mode

Detailed analysis of the project can be found in the following case study "Advanced control and forecasting algorithm (ACFA) for thermal energy storage at a winery – Case Study" (24th March 2022) authored by The University of South Australia and Glaciem Cooling Technologies

9 Supporting the transition

The PRW example presented in this paper was made possible with external support. The reality is that businesses are at the beginning of a transition journey, and many are still grappling with decisions such as 'Which renewable power to acquire?.' Energy management technologies like TES are only just beginning to be understood with regards to their transformative nature in a hybrid renewable energy / cooling system. To this end, it is critical these technologies continue to attract support and continue to be deployed in industry relevant demonstration projects. Any technology capable of achieving step change in these systems, as is the case with TES, needs to be deployed within a strong policy framework. Australia has already committed publicly to the tenets of Net Zero by 2050. To honour these commitments, establishing optimised use of renewable energy is critical. This can only be achieved through appropriate support of the enabling technologies, of which TES is key.

Policy makers can implement a range of technology push and market pull settings to further increase uptake and stability. Using TES to leverage mechanisms such as time-of-use tariffs and demand-side flexibility incentives can provide economic benefit for users as well, further increasing renewable deployment. Policy-makers have the opportunity now to take a long term view on the development and deployment of TES, and providing incentives that de-risk such projects for investors.

The PRW project described above outlines one such mechanism in the Australian Renewable Energy Agency's support of Thermal Energy Deployment projects under their 'Advancing Renewables' grant program. This initiative funds demonstrations to help build market awareness, increase customer confidence and progress Technology Readiness Levels for developing solutions[8].

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[8] IRENA, Innovation Outlook: Thermal Energy Storage. 2020, International Renewable Energy Agency Abu Dhabi, United Arab Emirates

10 Conclusion

The transition to renewable energy is in full swing in the global wine industry. This will help the industry as it plays its part in decarbonisation efforts. Renewable energy deployment alone, however, will not be enough. The transition will need to be supported by appropriate energy management technologies. For electricity intensive cooling in wineries TES is this technology. TES is able to store cooling energy at high density and at temperatures well suited to common winery processes. TES removes the problem of intermittency associated with renewable energy and eliminates the need to use electrical batteries to run large refrigeration compressors.

The penetration of dedicated TES systems in the wine industry is in its infancy, and certainly lags well behind the proliferation of renewable energy deployment. It is expected that as winemakers and viticulturalists rely more heavily on renewable energy going forward, and as more seek an economic energy pathway through wholesale market interaction, TES will see far more uptake.

This uptake will hinge heavily on support through the right policy frameworks. Given the importance of the decarbonisation imperative, key outputs of any such legislation needs to be education, and financial support.