final report

Project code: V.SCS.0007

Prepared by: Max Barnes, Dr Gareth Forde, Mo Ahmadi
All Energy Pty Ltd

Date published: October 2018

PUBLISHED BY
Meat and Livestock Australia Limited
Locked Bag 1961
NORTH SYDNEY NSW 2059

Concentrated Solar Thermal and Concentrated Solar Power – Assessment for Australian Red Meat Industry

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

Abstract

Australian red meat producers and processors currently pay an estimated $1.5 billion per annum for heat and power, with the vast majority of this coming from fossil fuels or the electricity grid [1]. Concentrated Solar Power and Thermal (CST/CSP) technology concentrates the sun's rays to a focal point, intensifying and storing the generated heat for use in a process or for power generation, which provides an opportunity for renewable and lower cost energy. As the majority of the energy usage in the Australian red meat industry is supplied by the combustion of fossil fuels, solar thermal offers the opportunity to make greater inroads into reducing energy associated emissions compared to traditional solar Photo-Voltaic (PV) systems.

A number of vendors were identified, shortlisted and invited to submit budget quotations for a "typical" Australian processing facility (defined as 500-600 head per shift processing capacity, single shift per day, with on-site rendering and refrigeration). These submissions were then analysed in order to compare "like for like" and demonstrate the technical and commercial viability of implementing this technology in the Australian red meat supply chain.

The results of this analysis showed that concentrated solar can deliver power under a long-term power purchase agreement (PPA) for as little as 9 c/kWh, with no capital paid by the feedlot/processor. Similar term PPAs were proposed for hot water for sterilisation and hand washing at $9 / GJ and for steam at $12.6 / GJ. These values are significantly less than currently paid by the industry.

[1] All Energy Pty Ltd, 2017, MLA V.SCS.0003 – Review of Renewable Technology Adoption in the Australian Red Meat Industry

Executive summary

This report summarizes the findings of cost-benefit and sensitivity analysis of several CST/CSP technologies.

As part of Milestone 1, review of concentrated solar thermal and concentrated solar power technologies and how these technologies may be implemented at Australian feedlots and abattoirs was investigated. The following table summarizes the main technology classes.

Technology and commentary	Installations	Sample Image
Linear Fresnel. From 1 to 125 MW installations. Image source: Ausra.	14	
Parabolic Trough. Range of scales from 2 to 185 MW across a broad range of geographic locations. Image source: trec-uk.org.uk	99	
Power Tower. Suited to utility scale systems (> 50 MW). Largest at 392 MW (US) with Dubai planning a 5000 MW system. Image source: helio.scsp.com	35	
Dish. The two largest systems (both 1.5 MW in the US) are listed as being non-operational. Image Source: naturaecoenergy.com	4	
Actively cooled, high-efficiency photovoltaic modules. Highly space efficient, especially where suitable roof space for PV is not available. Thermal heating to 92 °C. Image source: raygen.com	3	

The literature review and weighted criteria assessment considered a range of companies offering systems of a suitable scale and have the capability to service the steam and power generation installations at feedlots and abattoirs (for grain steaming and rendering, respectively). Capital costs, previous commercial experience and technology offerings were also taken into account to develop a short list of vendors to approach for budget pricing as follows:

- Solar Reserve
- Impacts

- Aalborg
- RayGen
- Grupo Cobra

Further companies were not short listed due to a preference for utility scale facilities, tower based projects and/or limited evidence of a competitive price point. Of the listed companies above, proposals were received from Impacts, Aalborg, and RayGen.

The results of the cost-benefit analyses are as follows:

Vendor	**IES / AALBORG**	**Impacts**			**RayGen**
Tech Class	Complete solar system, parabolic trough AAlTrough in combination with a steam generator SGS3, steam turbine, and thermal energy storage (molten salt) covering 14 operational hours. CSP solar field size 45.6 MWt, equivalent to 63,404 MWht covering 66% of overall demand of steam and electricity.	Rendering heat 3.3 MWt (6 parallel strings of 550 kWt each) at 6 barg additional 1.1 MWt for 95 °C sterilisation water. Peflection Gen 7 collector, heat on "as-available" basis with limited thermal storage for buffering only			6 MW (1 MW elec, 5 MW th) PV Ultra Dual Tower system, including solar field(s), receiver(s), mast(s), cooling system(s) and power conditioning inverter and transformer
Delivery Model	15 yr PPA	Capital Turnkey Budget Price - Steam	Capital Turnkey Budget Price - Hot Water	BOOM	BOO - 15 yr PPA indexed to CPI
Further important info	Price held constant over term of PPA. Financing of PPA deal involves ARENA funding	Assumption that existing brownfield boiler retained and able to be turned down to 50%. Theoretical average steam 36.281 tpd, actual (accounting for clouds) forecasted 30.77 tpd; theoretical total annual energy 34,830 Gjpa, actual 29,537 Gjpa.	95 degC **hot water** load, 1.1 MWt, 9,846 Gjpa	Pre-approved financing. **Thermal supply as steam**. Assumptions apply as capital turnkey budget price proposal	Price before renewable subsidies, elec supply 22kV, **HW supply 95°C**, subject to approval by third party finance. $/GJ and $/kWh 1st yr saving (not factoring in escalation)
Capital $	$ -	$ 3,600,000	$ 990,000	$ -	$ -
$/GJ Steam/Hot Water	$ 21.47	$ 8.13	$ 6.70	$ 12.60	$ 9.00
$/kWh Power	$ 0.15	NA	NA	NA	$ 0.09
% Thermal Load Offset GJ pa basis	66%	30%	10%	30%	23%
% Electrical Load Offset kWh pa basis	66%	0%	0%	0%	13%
$ pa Saved	$ 292,894	$ 464,718	$ 168,908	$ 332,552	$ 469,407
% Energy Bill Saving	7%	11.4%	4.1%	8.1%	11.5%
Simple Payback Period	Instant	7.7	5.9	Instant	Instant
Comments on Submission	Very large portion of annual heat and power bill offset with concentrated solar. Main cost item is thermal energy, with subsequent power essentially "free issue", hence higher $/GJ cost. Thermal storage most capital intensive element No capital upfront, fairly modest savings. Prices held constant over 15 yr term, attractive considering multiple % point year on year growth of thermal fuel and electricity prices. Conditional upon availability of ARENA funding - unlikely to remain without	Approximate installed capital, factoring supply ex-works cost of $1,219,776 and contingency of 10%. Sensible solution to offset 30% of thermal load, prove the concept in an Australian abattoir, then scale up, include power generation, and storage if desired.	Designed for peak hot water loads of hand washing and sterilisation at beginning of shift, low cost alternative to HW from boiler.	No upfront capital cost. Quoted prices indexed by 2.5%, still likely to be lower than historic escalation observed with fuel prices. At end of 15 year period, contract price $17.8/GJ for steam, cheaper than current price for gas, without factoring efficiency of boiler. Expect prices to be slightly lower after detailed design.	Price is quoted before renewable subsidies, may be further improved by other funding assistance. No upfront capital cost. Quoted prices indexed by CPI (1.8%), much cheaper than year on year energy cost increases; at end of 15 yr period, prices $11.55/GJ and 11.55 c/kWh - significantly cheaper than projected energy prices. List price quotation, expect prices lower when better understand specific needs of customer.

Refer to the body of the report for a full discussion and interpretation of this cost benefit analysis, and its implications for the Australian Red Meat Industry (RMI).

The inclusion of extensive thermal storage significantly increases the capital cost of plant at the expense of overall economic viability. It is thus a recommendation of this report that when reliable heat and power options exist due to connection to the grid, lower cost fuel generators, or economical thermal fuel supply contracts, that concentrated solar heat and power be used on an "as available" basis, unless other strong external drivers exist such as carbon neutrality mandates, drastic changes in emissions and trading policy, and unavailability due to regional areas or prohibitive cost. As the technology further matures in the Australian market, the viability of extensive storage may be revisited.

The financial analysis above suggests that power purchase agreements (PPAs) may be the preferred model for implementing concentrated solar systems at Australian feedlots and processors, due to the capital cost (particularly high for systems with extensive storage) and relative lack of familiarity with the technology. It is then a wise choice to put the capital outlay and risk, and onus of operation and maintenance on the vendor and simply purchase steam, hot water, or power on a contract price basis.

Table of contents

1 Background

The Australian Red Meat Industry (RMI) spends an estimated $1.5 billion per annum on fossil fuel-derived heat and power[2], presenting a substantial operating cost to the industry and generating many thousands of tonnes of greenhouse gas emissions. Secondary threats related to energy security, availability, and year-on-year price increases leave the industry vulnerable by continuing to rely on fossil fuels. Concentrated solar thermal technology is one of a number of alternative energy technologies with the potential to make significant progress towards decoupling red meat production and fossil fuel use.

2 Project objectives

The following objectives were achieved in this project:

- Provide objective insight into available concentrated solar thermal and power technologies.
- Compare the suitability of each offering to the particular requirements of Australian feedlots and processors.
- Quantify the economic feasibility via a cost-benefit analysis with an associated comparison.

[2] All Energy Pty Ltd, 2017, MLA V.SCS.0003 – Review of Renewable Technology Adoption in the Australian Red Meat Industry

3 Results

3.1 Steam Applications

A summary of the steam applications along the red meat supply chain (primarily concentrated in feedlots and processing facilities) is shown below in Table 1.

Table 1 - Steam Applications, Process Temperature and Pressure Within Australian RMI

Application	Assumed target process heating temperature (steam pressure)	Note
Low temperature rendering for tallow production routinely at 88 °C (range: 70 to 100 °); meal drying at 100 °C.	120 °C (requires ~1 Barg)	To ensure high quality steam for most efficient heat transfer and/or for enhanced boiler efficiency, steam is normally generated at a higher pressure than required (e.g. 6 to 10 Barg). At 10 Bar, saturation temperature is approximately 180 °C
High temperature rendering at 130 °C (>100, often reaching 110 to 130 °C); meal drying at 100 °C.	150 °C (requires ~4 Barg)	
Steam flaking at 3 Barg (144 °C)	144 °C (3 Barg)	Steam is then passed through a pressure reducing valve (PRV) so that high quality steam is injected via the sparges into the steam chests.
Steam flaking at 7 Barg (170 °C)	170 °C (7 Barg)	
Power generation	High pressure supercritical turbine at > 220 Barg. Low pressure steam: routinely above 8 Barg.	

The fractional use of different energy sources at Australian RMI processing plants is presented in Figure 1 showing the high reliance on natural gas (37%), power from the grid (31%) and coal (18%).

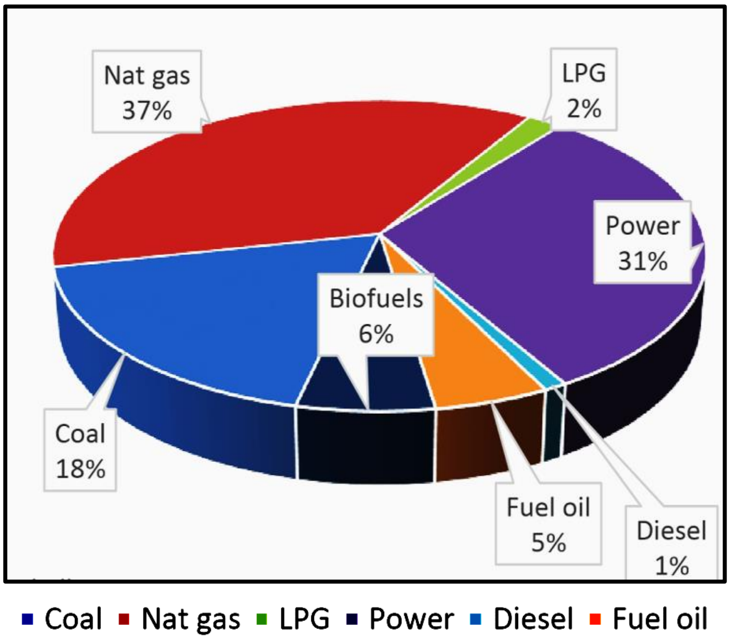


Figure 1: Breakdown of energy use at Australian red meat processing plants as a fraction of the estimated 15.81 GJ pa of thermal and electrical energy used in RMI processing plants. Source: MLA Project V.SCS.003.

A graph of GJ of thermal fossil fuel used and the estimated cost per annum for feedlots versus all red meat processors is shown in Figure 2 below, with the majority of fossil fuel use at feedlots for steam flaking of grain. The data presented is adapted from MLA V.SCS.003 *Review of Renewable Technology Adoption in the Australian Red Meat Industry* where it was assumed that the majority of feedlot fossil fuel use is LPG and diesel due to the regional / remote nature of feedlots (i.e. limited access to natural gas distribution).

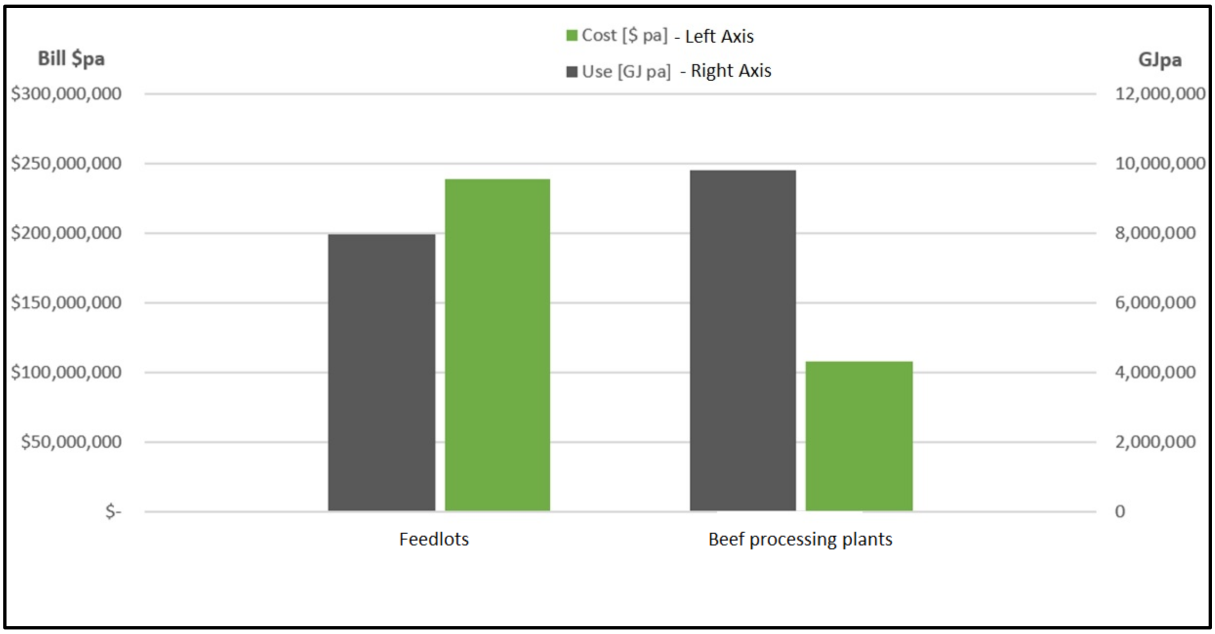


Figure 2 – Estimated Gigajoules of thermal energy per annum of fossil fuel consumed (GJ pa) and associated costs for Australian feedlotting operations (using predominantly LPG and diesel) versus beef processing plants (using predominantly natural gas and coal).

It can be observed from Figure 2 above that there is a very large economic driver for alternative and lower cost steam, particularly at feedlots where despite the lower GJ consumption compared to processors, limited energy options, rural areas and high fuel supply costs have resulted in a disproportionately high fossil fuel cost.

Table 2 – Indicative thermal energy costs accounting for supply, storage and combustion system to generate steam. Note that costs for fuels are highly location and time dependent and are impacted by wider market forces. Numbers presented are approximate for H1 2018 for 30,000 GJ pa consumption. For example, LNG storage and transport equipment is highly specialized hence use of higher amounts of LNG per annum reduce the storage and transport costs per annum.

Fuel [all estimates exclude GST]	LHV MJ/kg	$/GJ - calculated; fuel supply only	$/GJ – incl. fuel supply & storage 10 yrs.	Boiler eff.	$/GJ thermal energy fully costed 10 yrs
Waste heat recovery HX on diesel genset or boiler flue gas					4.50
Vacuum tubes – heating water from 21 to approx. 60 to 70 °C					6.09
Thermal Coal	25.9	5 - 7	6.84	75%	9 - 11
Grade 3 Recycled Wood Chip ~ 8% moisture; 160km delivery	17.5	3.60	3.60	75%	14
30% moisture pine chip (down to 28% moisture)	12.96	3 - 5	4.63	75%	13 - 15
Heavy fuel oil (i.e. recycled lube oil)	37.28	14.47	14.47	80%	17.46
Natural Gas	48.63	5 - 20	5.11	85%	8 – 23 plus pipeline tie-in / access costs
LNG (liquid natural gas)	49.10	10 to 16	24.26	85%	21 - 27
Diesel (accounting for ATO tax rebate for stationary energy / private road use)	42.61	27	27.37	80%	30
LPG (liquid petroleum gas)	46.61	25 to 30	27.12	85%	28 to 33

3.2 Case studies

3.2.1 Fuel use reduction via Direct Steam generation (DSG) from solar thermal heating

The “entry level” use for solar thermal heating is to off-set the use of fuel in an existing boiler; this method ensures the highest utilization of the solar collector system whilst reducing capital costs by making use of existing infrastructure. An excellent case study was completed in 2016 by the German company Industrial Solar GmbH[3]. Fresnel collectors (396 m^2; ~317 kWt @ 800) provided 6 Barg (166 °C) saturated steam directly to the steam network of an existing manufacturing facility via the use of a control valve for providing steam for drying product. Direct steam was created by the “recirculation concept” where the solar collectors were supplied with a surplus of feed water. As only a fraction of the water is evaporated, the collectors do not overheat. Steam is separated in a 2,000 L flash drum controlled at up to 14 Barg (when this pressure is exceeded, some mirrors are automatically turned out of focus to cease collecting solar energy). Water at an elevated temperature is recirculated around the system with make-up water provided from the existing feed water treatment plant. On clear days, the plant uses 100% solar thermal heating whilst during the evening the fossil fired boiler takes over automatically.

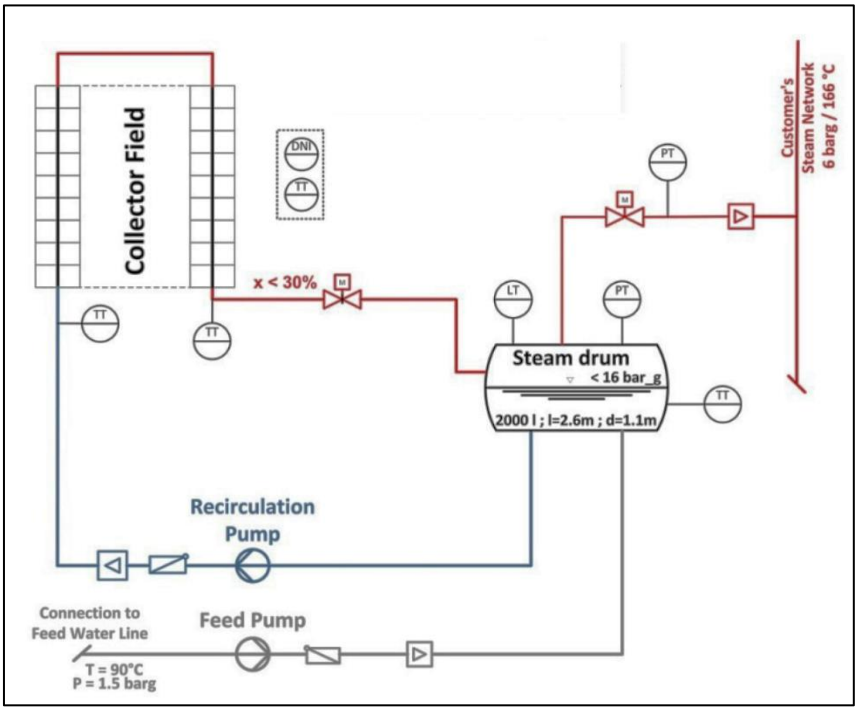


Figure 3: Simplified Process and Instrumentation Diagram of a Recirculation Solar Thermal Heating system. Source: Industrial Solar GmbH[3].

[3] https://doi.org/10.1063/1.4949189, accessed 20 May 2018.

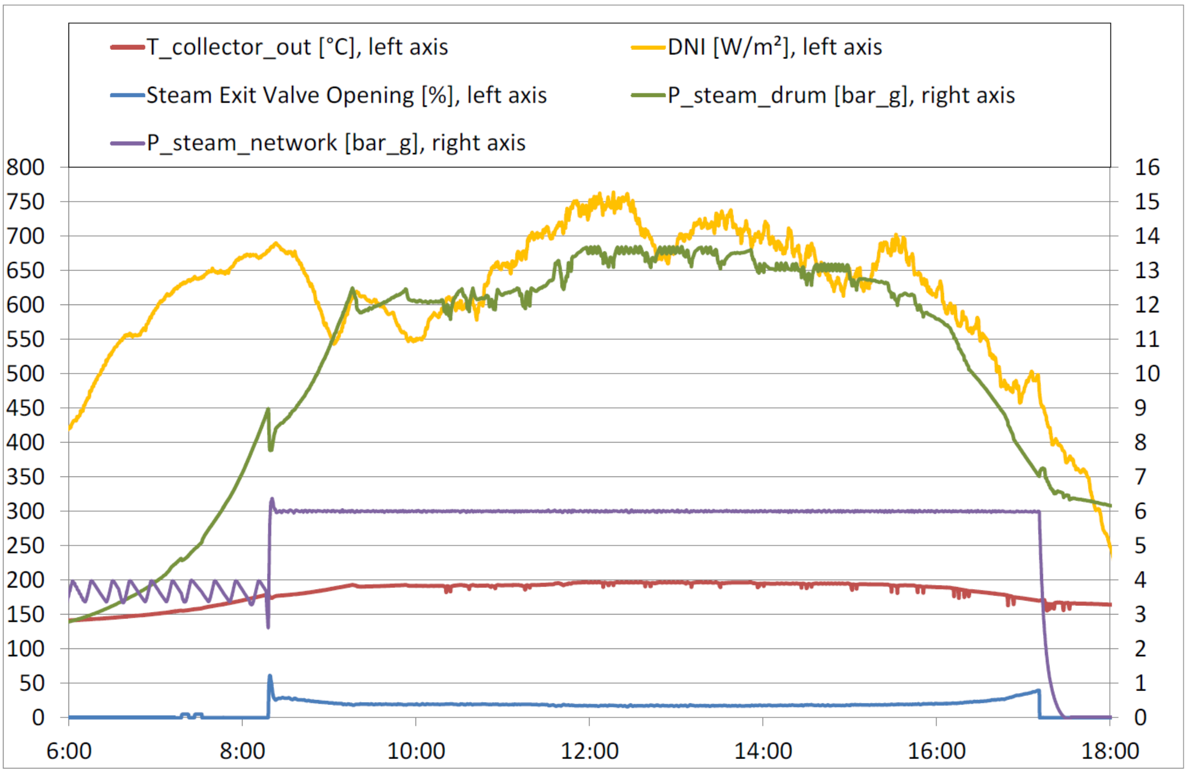


Figure 4: Sample operating day: in the early morning, steam is produced by the existing diesel fired steam boiler which runs at a set point of 3.5 – 4 Barg. At 08:15 a.m the solar system is at a sufficient pressure to commence providing process steam. The pressure in the flash drum fluctuates between 7 Barg and 13.5 Barg due to changes in steam requirements and solar collection. The pressure in the manufacturing site's steam network can be maintained at 5.95 to 6.05 Barg via the solar system pressure controller, five times more precise compared to the conventional boiler.

3.2.2 Complete use of solar thermal heating for process heat and power

Sundrop Farms in South Australia utilizes a blended industrial energy solution to produce tomatoes where thermal energy is used to desalinate sea water, produce electricity and for hydroponic heating and cooling. The facility is in Port Augusta and utilizes 23,000 mirrors to concentrate solar to a 115 m high tower generating 39 MWh per day. The full facility cost $200 mill (incl. a 20 Ha greenhouse) whilst generating $105 mill worth of truss tomatoes p.a. and employing some 220 people.

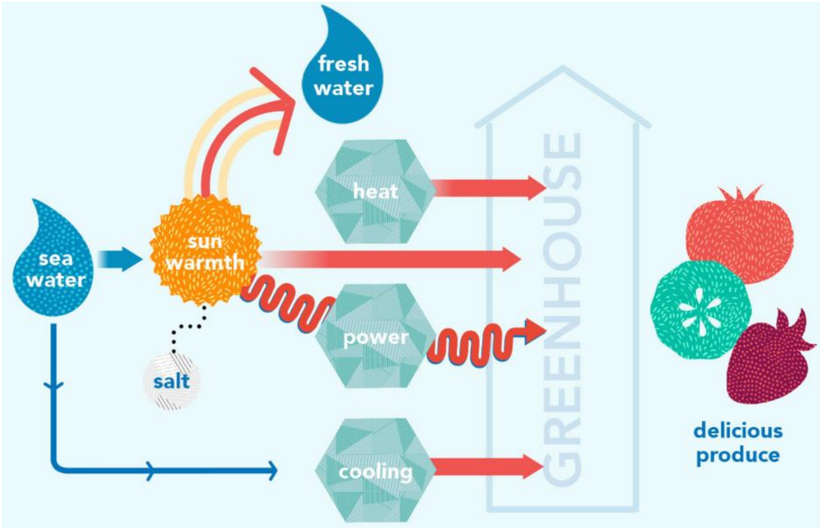


Figure 5: Simple flow diagram of materials and energy flows at Sundrop farms. Source: www.sundropfarms.com

Figure 6: Sundrop farms layout and facility Source: www.sundropfarms.com

3.3 Technology Review

3.3.1 Linear Fresnel System

The Linear Fresnel Reflector (LFR) focuses sunlight, using long, thin segments of mirrors, onto a stable absorber situated at a common focal point of the reflector. The Linear Fresnel mirrors focus the sun's energy to about 30 times the normal intensity. The concentrated thermal energy is transferred through the absorber into a specific thermal liquid, usually oil due to its liquid state retention at high temperatures. Finally, power is produced, from the transfer of the heat through the heat exchanger, for a steam generator.

In August 2012, a German based organisation, Novatec Solar, built a Fresnel solar power facility called Puerto Errado 2 (PE 2) Thermosolar Power Plant in Calasparra, Spain. The $150MW_{th}$ solar power plant uses a Linear Fresnel design and has an electricity capacity of $30MW_{e}$. The facility produces steam, through concentrated solar radiation of heating water up to 270°C. The steam is channelled to two turbines, both with a rated power of 15MW. The generators produce electricity, which is fed into the electricity grid. Annually, 49GWh of electricity is generated, equating to the annual reduction of 16,000 tons of carbon dioxide emissions. Hence, providing clean power to around 12,000 Spanish homes. The table, in section 2.1.6, provides a summary of Puerto Errado 2 (PE 2) Thermosolar Power Plant. A 5 MW Fresnel system was installed at Kimberlina, Bakersfield, California in 2008.

Figure 7 - Compact linear Fresnel. Source: Ausra.

3.3.2 Power Tower System

Solar Power Towers use heliostats, which are dual-axis, sun-tracking mirrors, to reflect the sunlight onto a single receiver point. Solar Power Towers' main benefits are the generation of more heat energy than other solar technologies and the integration of thermal storage.

In 2016, Aalborg CSP developed an Integrated Energy System, based on the Solar Power Tower technology, called the Sundrop Farms Project. The $36.6MW_{th}$ facility in Port Augusta reflects the sun's rays, using 23,000 heliostats, towards the 127m high tower. High temperatures are generated through the concentration of thermal energy, producing about 20,000MWh/year, to heat the greenhouses during the winter and cold summer nights and provide 250,000L/year of fresh water by desalinating seawater from the Spencer Gulf, which is about 5km from the site. The fresh water is channelled through a steam turbine (1.5MW_e), resulting in the generation of 1.7GWh of electricity per year.

Another primary case of a successful CSP technology, which is based on the Power Tower, is the Jemalong Solar Thermal Station Pilot by Vast Solar in 2017. The 6MW_{th} facility is Australia's first grid-connected CSP plant with thermal energy storage, with the primary focus of achieving high efficiency at the lowest cost. The research facility uses 3,500 heliostats, assembled into five modules that focus sunlight towards the 27m high tower. The five modules are connected to the thermal energy storage tank, where the thermal energy is distributed through a steam generator. The generator produces steam for the (1.1MW_e) turbine, resulting in the production of electricity.

A $650 million CSP project called the Aurora Solar Thermal Power Project, by SolarReserve, is planned for construction in 2018 and will be operational in 2020. The 150MW_e facility is expected to generate around 500GWh of electricity annually for 5% of South Australia's energy consumption. The expected electricity generation is equivalent to powering 90,000 homes day and night.

3.3.3 Parabolic Trough System

The Parabolic Trough Reflector is a CSP technology, used to capture and reflect sunlight at a concentrated focal point. It is essential for the reflectors to be designed in a way to reflect all sunlight at the same focal point; independent on the area the sunlight comes in contact with the reflector.

In 2013, Abengoa Solar developed the Solana Solar Power Generating Station, in Arizona, USA, for Arizona Public Service (APS). The 280MW_e facility is regarded as one of the largest CSP plants globally, which uses parabolic trough technology. The parabolic trough mirrors are used to reflect the sun's rays onto a pipe that contains petroleum-based heat-transfer fluid, Therminol VP-1 --- Xceltherm MK. The fluid is heated to temperatures of up to 393°C and is channelled to a heat exchanger, where water is heated, steam is produced and 724GWh of electricity is generated annually by the steam powered turbines.

Andasol 1, commissioned by Solar Millennium in 2009, is Europe's first parabolic trough facility. The 50MW_e facility generates about 165GWh of electricity annually, equivalent to supplying 200,000 homes.

3.3.4 Dish

The dish configuration of concentrated solar (also known as Dish Stirling) consists of a single parabolic reflector that tracks the sun's position over two axes to concentrate light onto a thermal fluid in a receiver located at the dish's focal point. The highly modular nature of dish systems provides good scalability, however marginal cost is higher than comparative systems.

An example of parabolic dish concentrators (the largest in Australia) is located at the Australian National University, with 380 mirrors of 100 kW rating. The peak sunlight concentration achieved by this plant is 14,000 suns, averaging at 2,000 suns. This energy heats water to 500 degrees Celsius and 5 MPa, generating power in a Stirling engine sufficient for powering 100 homes per annum. Configurations of this type appear to be limited to research operation. The largest current installation has a total power of 1.5 MW in Maricopa, Arizona (USA) with a 1 MW facility in the province of Cuenca in Spain[4].

Figure 8 - Solar Dish. Source: http://naturaecoenergy.com/product_solar_dish.html

3.3.5 Combined (Liquid Cooled PV Solar) System

Tracking lenses and reflectors may be used to concentrate sunlight onto conventional photovoltaic (PV) panels to boost generation potential by intensifying incident solar rays and extending the time these are present to the PV panel. The heat resultant from this presents an operational problem, in that elevated temperatures reduce electrical generation and transfer efficiency. Combined concentrated solar-PV systems thus utilise either passive heat sinks or active cooling. Traditional PV Solar is at such a low price point that "combined" PV systems cannot compete financially i.e. the added capex for cooling does not justify the efficiency gains. The high capital cost of combined systems means that there are currently no commercial plants of this type in Australia. Further, this technology has limited applicability for processors as it may only contribute towards 10 – 25% of energy offsetting for sterilization water, incoming water pre-heating and boiler make up water heating as it can only raise temperatures to 92 ^{o}C. At a feedlot water at this temperature could contribute to boiler water preheating which is approximately 10% of the energy use. An additional use for hot water at feedlots is elevated temperature wetting which has been shown to improve grain conversion efficiencies.

[4] http://naturaecoenergy.com/product_solar_dish.html

3.3.6 Technology Installations Comparison

The following Table 3 summarizes the number of commercial / pilot facility installations which is used as one guide in terms of the maturity / acceptance of each technology class.

Table 3 - Technology, Number of Installations Comparison

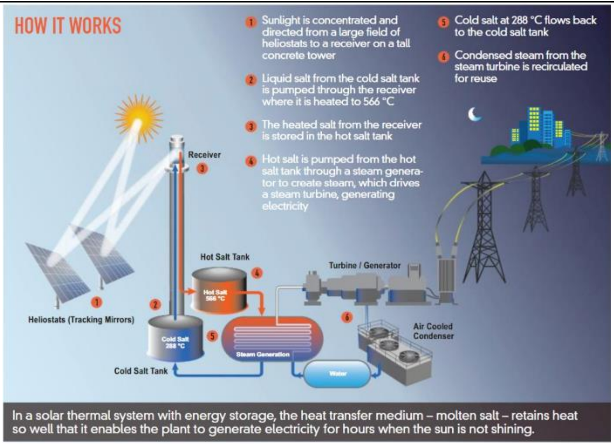
Technology	Installations	Notes
Linear Fresnel	14	Range of scales from 1 to 125 MW.
Parabolic Trough	99	Range of scales from 2 to 185 MW across a broad range of geographic locations.
Power Tower	35	Suited to utility scale systems (> 50 MW). Largest at 392 MW (US) with Dubai planning a 5000 MW system.
Dish	4	The two largest systems (both 1.5 MW in the US) are listed as being non-operational.

3.3.7 Summary of Vendor-Technology Combination Review

A review of example plant case studies, vendors, and operational data was done to demonstrate technical and commercial readiness of concentrated solar. Due to the relative youth of this technology, good long-term, steady-state operational data along with cost data is hard to come by; the results of this review are shown in Table 4.

Table 4 - Summary of Literature and Technology Review

Technology Review and Description	Example Image
Name: Sundrop Farms **(Aalborg)** **Technology:** Power Tower **Description:** * Uses 23,712 heliostats (Each heliostat is 2.2m²) * Heliostat manufacturer is eSolar (SCS5) * Avoids 16,000 tons/year of CO2. (400,000 tons/25 years of CO2) * Produces 250,000 million litres of water annually from desalinated seawater. * Generates 1.7GWh annually. * Integrated energy system area (CSP facility), 140,000m².	
Name: Jemalong Solar Thermal Station Pilot **(Vast Solar)** **Technology:** Power Tower **Descriptions:** * Uses 3,500 heliostats (Each heliostat is 4.3m²). * Receiver inlet and output temp., 270°C and 560°C. * Australia's first grid-connected CSP plant with thermal energy storage, designed to achieve efficiency at low cost. * Thermal energy storage system provides renewable energy, on-demand, day or night (2-tank direct [hot tank, 565°C and cool tank, over 200°C], 3 hour capacity, liquid sodium heat-transfer fluid). * Uses MACCSol air-cooled condenser (uses no water in the cooling cycle, specifically designed for CSP	

<table>
<tr><th>Technology Review and Description</th><th>Example Image</th></tr>
<tr><td>facilities and other thermal energy systems deployed in water-scarce locations.
* Enough to power 400 homes
* Facility area, 100,000m².</td><td></td></tr>
<tr><td>Name: Aurora Solar Energy (SolarReserve)
Technology: Power Tower
Descriptions:
* 495GWh annual net output (expected) (around 5% of South Australia's energy needs).
* Equivalent power generation of over 90,000 homes, day and night.
* Dry cooling (saves millions of litres of water pa)
* Displaces 200,000 t/year of CO2.
*No requirement for natural gas or oil back-up (completely emission free).
* 40 years storage with no degradation.
* 8 hours of full load storage (energy storage provides a firm, reliable electricity product on-demand, day and night).
* Targeting 60% of the value of sourcing (e.g. equipment) and services from SA during construction phase, allowing for entire new industry for SA.
* Supports Federal and State Renewable Energy Targets.</td><td>

In a solar thermal system with energy storage, the heat transfer medium – molten salt – retains heat so well that it enables the plant to generate electricity for hours when the sun is not shining.</td></tr>
<tr><td>Name: Solana Generating Station (Abengoa Solar)
Technology: Parabolic Trough
Descriptions:
* Uses 900,000 parabolic mirrors, with solar field aperture area of 2.2 million m² (Each mirror is 2.4m²).
* Solar field inlet and outlet temp., 293ºC and 393ºC respectively.
* Supplies electricity to 71,000 houses.
* Generates 724GWh annually.
* Avoids 430,000 t/year of CO2.
* Supplies (APS) with clean electricity.
* Generation of more than 2,000 jobs.
* 6 hour molten salt thermal energy storage.
* Consumes 75% less water.
* Use petroleum-based heat-transfer fluid, Therminol VP-1 --- Xceltherm MK</td><td>
The Solana solar power project will implement concentrating solar plant technology using parabolic trough mirrors.</td></tr>
<tr><td>Name: Andasol-1 (Solar Millennium)
Technology: Parabolic Trough
Descriptions:
* Supplies electricity to 200,000 houses.
* Generates 165GWh annually.
* Avoids 150,000 t/year of CO2.
* Estimated life span is at least 40 years.
* Uses 2-tank direct (28,500 tons of molten salt [60% sodium nitrate and 40% potassium nitrate) at storage capacity of 7.5 hours.
* Full load of storage holds 1,010MWh of heat.
* Solar-field inlet and outlet temp., 293°C and 393°C respectively.
* Solar-field aperture area is 510,120m².</td><td></td></tr>
</table>

<table>
<tr><th>Technology Review and Description</th><th>Example Image</th></tr>
<tr><td>Name: Puerto Errado 2 Thermosolar Power Plant (Novatec Solar)
Technology: Linear Fresnel
Descriptions:
* Site area is 600,000m².
* Generates 49GWh annually.
* Heat-Transfer Fluid: water.
* Avoids 16,000 t/year.
* Enough to power 12,000 houses
* Solar field area is 302,000m².
*28 rows of linear Fresnel collectors.
* Operating temp. Input and output, 140°C and 270°C respectively.
* Operating pressure 55 bar.
* Single-tank thermocline (Ruth's Tank) with storage capacity of 30mins.
* Solar to electricity efficiency is 18.6%.
* Operating lifetime about 30 years.</td><td></td></tr>
</table>

3.4 Weighted Criteria Matrix

3.4.1 Vendors

Due to the innovative nature of CSP/T resulting in information in the public domain being of limited detail, the weighted criteria matrix was unable to be completed to the originally-planned level of accuracy. When planning this milestone, the weighted criteria matrix was intended to compare technology classes on metrics of $/kWh LCoE and footprint m^2/kW, among others, but for this milestone will compare known vendors on their capabilities and experience. After higher-detail submissions from the market have been received, a revised weighted criteria matrix is presented in milestone 2.

Table 5 - Preliminary Weighted Criteria Matrix - Vendors

Metric	Weight	Aalborg	Industrial Solar	Abengoa	Vast Solar	Solar Reserve	Grupo Cobra	Novatec Solar	Impacts Solar
Correct Scale	2	Y	Y	N	Y	N	N	Y	Y
Thermal	2	Y	Y	Y	Y	Y	Y	Y	Y
Power	2	Y	N	Y	Y	Y	Y	Y	Y
Completed Australian Project	1	Y	N	N	Y	Y	N	N	N
Australian Presence	1	Y	N	Y	Y	Y	Y	N	Y
Total no. Worldwide Installations	5	15	23	27	2	10	9	3	0
Total MWe Installations	4	405	7590	1603	51.1	3910	480	31.4	0
Final Score		11.5	12.3	10.8	8.9	10.4	6.9	6.6	7
Tech Class		Trough and tower	Linear	Tower	Tower	Tower	Trough	Linear	Linear

A brief explanation on each metric is as follows:

Correct Scale

The correct scale for an Australian beef feedlot or processor is between 0.5 – 10 MWe, therefore if a vendor has previously installed a plant within this range, they were judged of the correct scale. Note that this was a binary (Y/N) value, with a weighting of 2 assigned.

Thermal/Power

Not all technologies have the capacity for producing power and steam/hot water; as these are both requirements at Australian beef facilities, this binary value was weighted by 2.

Completed an Australian Project/Australian Presence

There are many differences between Australia and Europe where many previous installations of concentrated solar have occurred, including planning and approvals, grants, credits, solar radiation intensity, geology etc. Vendors who had previously installed a plant in Australia, regardless of scale were favoured here with a weighting of 1.5. A weighted score of 1 was also given to vendors with an Australian office or other presence.

Total no. Installations/Total MWe Installations

Absolute number of installations worldwide by each vendor and their cumulative MWe rating were scored according to fraction of highest result. This means that for example, the highest number of installations was by Abengoa at 27, and the next highest score of 23 (Industrial Solar GmbH) accrued a score of 85% of total points. Absolute number of installations was weighted by 5, and cumulative MWe weighted by 4.

3.5 Technical Specifications – Representative Facility

A request for information was issued to interested feedlots and processors to submit their site data for use as a basis of design in this project. Required data included steam flows, temperature and pressure, fuel consumption, and cost data; this information is unlikely to be easily available at feedlots due to limited metering and control equipment, hence a processing facility was selected as the typical.

A ''typically'' processing facility was assumed as 500-600 head per shift processing capacity, single shift per day, with on-site rendering and refrigeration.

3.5.1 Power Requirements

Annual plant power consumption was calculated at 12,476 MWh, with the maximum load during the year observed at 2.688 MWe, averaging at 1.424 MWe. The daily demand profile (see Figure 9) shows that the baseline requirement for power, provided by the cooling and freezing duty is constant over the day, with single shift operation.

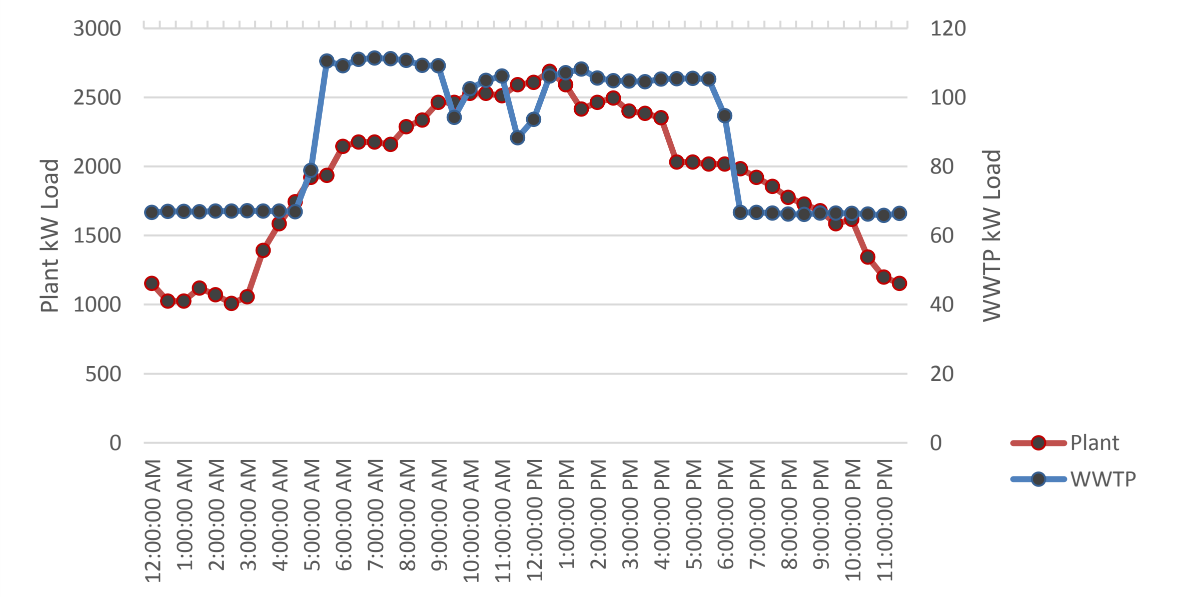


Figure 9 - Typical Plant kW Load over Day 19/12/2017

Statistics on the electricity account dataset are shown in Table 6.

Table 6 - 30-minute Power Dataset Statistics

	Wastewater Treatment Plant (WWTP)	Plant
Maximum kW Load Observed	149	2,688
Average kW Load	84	1,424
Average kWh/day	2,010	34,181
kWh/annum	733,653	12,476,004
Standard Deviation of kW load	21	563
Co-efficient of variation of kW load (ratio of SD to mean)	0.250 [less variable]	0.395 [more variable]
Range for kW load [difference between the largest and smallest values]	65	1264

3.5.2 Thermal Requirements

As frequently occurs with red meat industry technical specifications, the thermal data that was able to be obtained was of significantly less granularity than the electrical data. Based on advice on steam flows and generation pressure, the following was calculated.

Table 7 - Plant Thermal Loads and Steam Supply

	Boiler 1	Boiler 2	Combined
Steam Flow (tph)	4.32	3.71	8.03
Hours Operational per Day	10 - 12	17 - 19	NA
		Combined Power (MWt)	6.6

3.5.3 Cost Basis for Financial Analysis

Table 8 – Cost Figures of Test Site

Electricity Price	$ 0.1664	$/kWh
Electricity Usage Average per week	250,100	kWh
Estimated Annual Electricity Usage	12,476,000	kWh
Spend on Electricity	**$ 2,075,757**	**$pa**
Gas Price	20.28	$/GJ
Assumed 85% Natural Gas Boiler Efficiency	23.86	$/GJ steam or hot water
Gas Usage Average per week	1,980.00	GJ
Estimated Annual Gas Usage	99,000.00	GJ
Spend on Gas	**$ 2,007,720**	**$pa**

3.6 Vendor Proposals

3.6.1 IES[5]/Aalborg[6]

Aalborg proposed to deliver a complete solar system, including thermal, power, and storage. This would be achieved with a parabolic trough collector in combination with a steam generator, steam turbine, and molten salt thermal energy storage covering 14 hours of operation. The CSP field size proposed was 45.6 MWt, with an annual delivery equivalent to 63,404 MWht, covering 66% of the demand for steam and electricity at the basis of design plant.

Figure 10 below shows the modelled consumption of thermal and electrical energy from the concentrated solar field, and the residual continuing to be consumed from the grid and LPG over a typical year.

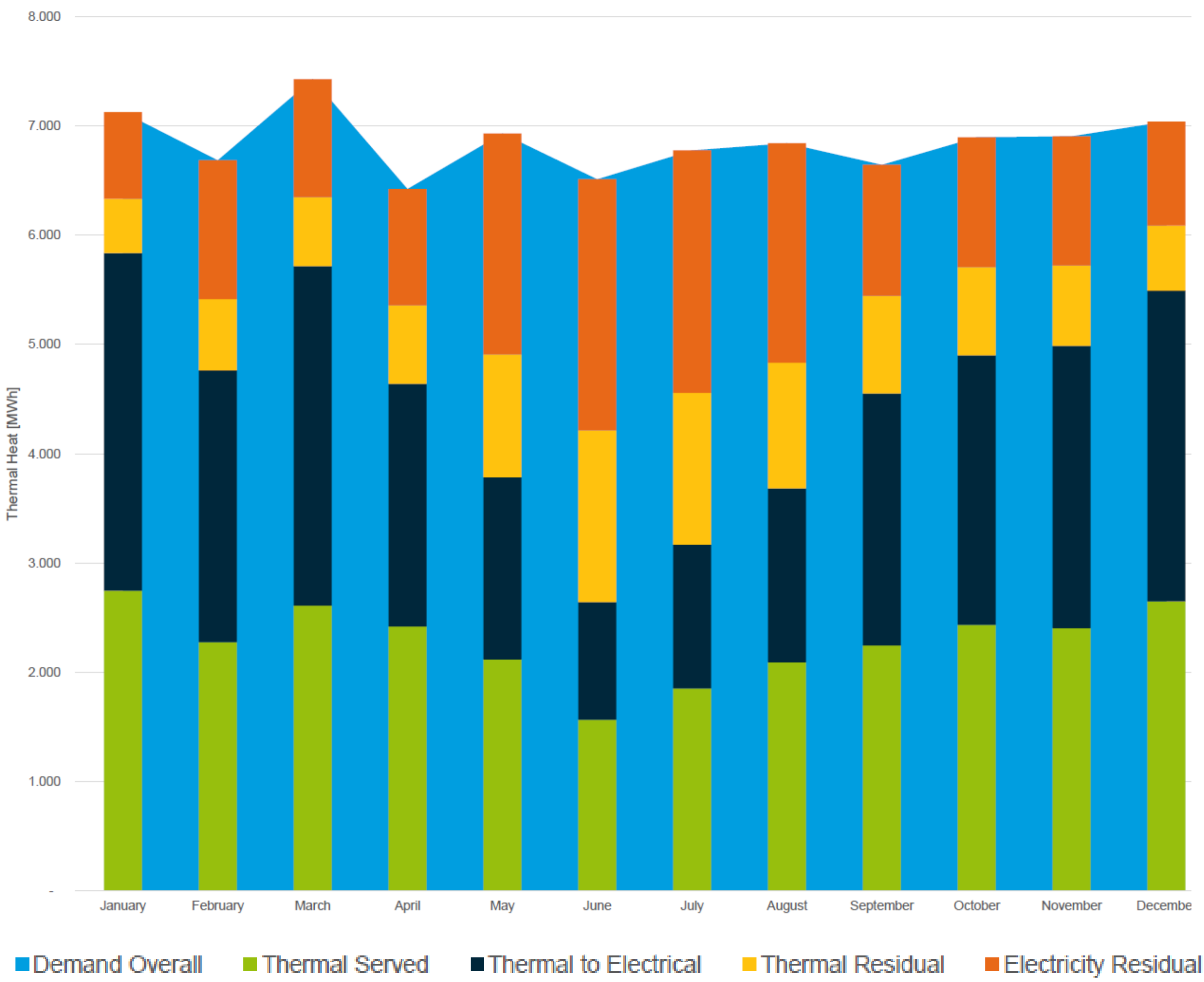


Figure 10: Monthly Distribution of Thermal and Electrical Energy

[5] http://iesaus.com.au/

[6] https://www.aalborgcsp.com/

Table 9: Aalborg System Specifications

System Specifications	
Heating System	AAL Trough
Steam Generation System	Aalborg CSP SGS3
Direct Normal Irradiance	1,978 kWh/m^2/year
Design Point Output	45.6 MWt
Net Annual Heat Utilisation	63,404 MWht
Net Annual Electricity Utilisation	8,028 MWhe
Length of Rows	168 m
Number of Rows	68
Space Between Rows	15 m
Aperture	64,070 m^2
Total Land Area	171,360 m^2
Solar Field Inlet Temperature	290 °C
Solar Field Outlet Temperature	390 °C
Azimuth Angle	8 °
Heat Transfer Fluid	Therminol VP1
Storage Capacity	131.4 MWh – 14 hours
Heat Storage Medium	Molten Salt 60 wt% $NaNO_3$ 40 wt% KNO_3

The Aalborg system was proposed under an outright capital purchase agreement, or a fifteen-year power purchase agreement (PPA) model.

3.6.2 Impacts Solar[7]

Impacts elected to propose a solution to address a portion of the thermal load at the base case facility, without electricity generation or extensive thermal storage, thus a low impact, low cost approach to demonstrate the technology and make considerable progress towards clean solar heat and steam.

Impacts designed a 3.3 MWt plant for 6 bar steam rendering, in a configuration of six parallel strings each of 550 kWt, with the potential for an additional 1.1 MWt of hot water at 95 °C by adding two additional strings and a heat exchanger. No thermal storage was proposed apart from for buffering (accommodate intermittent cloud cover and prevent unnecessary cycling) purposes only, thus heat supplied on an "as available" basis.

Table 10: Impacts System Specifications

System Specifications – Perflection Gen & - Industrial High Temperature Processes	
Effective Aperture Width	3,842 mm
Module Length	6,000 mm
Effective Aperture Reflector Area Per Module	23.052 m^2
Operating Temperature	Up to 400 °C
Heat Transfer Fluid	Propylene Glycol
Notional Design	3.3 MWt at 6 barg
Number of Strings	6
Modules per String	32
Total Modules	192
Effective Aperture Area	4,426 m^2
Parasitic Load	36 kWe
Site Area	5.2875 Ha
Theoretical Average Steam Generation per Day	36,281 kg/day
Forecast Actual Average Steam Generation per Day	30,770 kg/day
Theoretical Total Annual Energy Generated	34,830 GJ pa
Forecast Actual Total Energy Generated	29,537 GJ pa
Performance Uncertainty/Contingency	30%

Impacts proposed both an outright capital purchase of this plant, or a structured PPA for a fifteen-year term.

[7] https://impacts.com/

3.6.3 RayGen[8]

RayGen put forward a solution to address a sensible portion of both the steam and power load with a 6 MW (1 MWe and 5 MWt) PV Ultra Dual Tower system including solar field(s), receiver(s), mast(s), cooling system(s), and power conditioning inverter and transformer. Delivering 1,640 MWhe and 31,700 GJt annually, the proposed plant has capacity to offset 13% and 23% of the test site's electrical and gas demand, respectively. One days' thermal storage is included as part of this submission. Detailed design would need to consider the maximum thermal offset that could be achieved with 92 ^{o}C hot water (estimated at 10 to 25%, depending upon the heat integration and heat uses at a site).

The RayGen solution was proposed as both an outright capital purchase or a fifteen-year PPA.

[8] https://www.raygen.com/

3.7 Feasibility Analysis

The comparative feasibility of each technology and delivery model proposed by each vendor is shown in Table 11. Of note in the economic analysis are the rows highlighted in yellow, showing capital cost of each proposal and business model, levelized cost of energy (LCoE) or PPA price, annual saving, simple payback period, and fraction of total heat and power bill offset.

Table 11: Comparative Cost Benefit Analysis of Aalborg, Impacts, and RayGen proposal; Capital Turnkey and PPA Models

Vendor	IES / AALBORG	Impacts			RayGen
Tech Class	Complete solar system, parabolic trough AAlTrough in combination with a steam generator SGS3, steam turbine, and thermal energy storage (molten salt) covering 14 operational hours. CSP solar field size 45.6 MWt, equivalent to 63,404 MWht covering 66% of overall demand of steam and electricity.	Rendering heat 3.3 MWt (6 parallel strings of 550 kWt each) at 6 barg additional 1.1 MWt for 95 °C sterilisation water. Peflection Gen 7 collector, heat on "as-available" basis with limited thermal storage for buffering only			6 MW (1 MW elec, 5 MW th) PV Ultra Dual Tower system, including solar field(s), receiver(s), mast(s), cooling system(s) and power conditioning inverter and transformer
Delivery Model	15 yr PPA	Capital Turnkey Budget Price - Steam	Capital Turnkey Budget Price - Hot Water	BOOM	BOO - 15 yr PPA indexed to CPI
Further important info	Price held constant over term of PPA. Financing of PPA deal involves ARENA funding	Assumption that existing brownfield boiler retained and able to be turned down to 50%. Theoretical average steam 36.281 tpd, actual (accounting for clouds) forecasted 30.77 tpd; theoretical total annual energy 34,830 Gjpa, actual 29,537 Gjpa.	95 degC **hot water** load, 1.1 MWt, 9,846 Gjpa	Pre-approved financing. **Thermal supply as steam**. Assumptions apply as capital turnkey budget price proposal	Price before renewable subsidies, elec supply 22kV, **HW supply 95°C**, subject to approval by third party finance. $/GJ and $/kWh 1st yr saving (not factoring in escalation)
Capital $	$ -	$ 3,600,000	$ 990,000	$ -	$ -
$/GJ Steam/Hot Water	$ 21.47	$ 8.13	$ 6.70	$ 12.60	$ 9.00
$/kWh Power	$ 0.15	NA	NA	NA	$ 0.09
% Thermal Load Offset GJ pa basis	66%	30%	10%	30%	23%
% Electrical Load Offset kWh pa basis	66%	0%	0%	0%	13%
$ pa Saved	$ 292,894	$ 464,718	$ 168,908	$ 332,552	$ 469,407
% Energy Bill Saving	7%	11.4%	4.1%	8.1%	11.5%
Simple Payback Period	Instant	7.7	5.9	Instant	Instant
Comments on Submission	Very large portion of annual heat and power bill offset with concentrated solar. Main cost item is thermal energy, with subsequent power essentially "free issue", hence higher $/GJ cost. Thermal storage most capital intensive element No capital upfront, fairly modest savings. Prices held constant over 15 yr term, attractive considering multiple % point year on year growth of thermal fuel and electricity prices. Conditional upon availability of ARENA funding - unlikely to remain without	Approximate installed capital, factoring supply ex-works cost of $1,219,776 and contingency of 10%. Sensible solution to offset 30% of thermal load, prove the concept in an Australian abattoir, then scale up, include power generation, and storage if desired.	Designed for peak hot water loads of hand washing and sterilisation at beginning of shift, low cost alternative to HW from boiler.	No upfront capital cost. Quoted prices indexed by 2.5%, still likely to be lower than historic escalation observed with fuel prices. At end of 15 year period, contract price $17.8/GJ for steam, cheaper than current price for gas, without factoring efficiency of boiler. Expect prices to be slightly lower after detailed design.	Price is quoted before renewable subsidies, may be further improved by other funding assistance. No upfront capital cost. Quoted prices indexed by CPI (1.8%), much cheaper than year on year energy cost increases; at end of 15 yr period, prices $11.55/GJ and 11.55 c/kWh - significantly cheaper than projected energy prices. List price quotation, expect prices lower when better understand specific needs of customer.

The financial analysis above suggests that PPAs may be the preferred model for implementing concentrated solar systems at Australian feedlots and processors, due to the capital cost (particularly high for systems with extensive storage) and relative lack of familiarity with the technology. It is then a wise choice to put the capital outlay and risk, and onus of operation and maintenance on the vendor and simply purchase steam, hot water, or power on a contract price basis.

Both Impacts and RayGen proposed fifteen-year PPAs for purchasing thermal energy at approximately half that which is currently procured by the test site from pipeline natural gas. It is important to note that the Impacts proposal was for higher quality process steam up to 400 °C and RayGen for 95 °C hot water for hand washing/sterilisation. If desired, the smaller Impacts proposal for hot water may also be integrated into their proposed PPA. The RayGen proposal also proposed 13% of the site power demand at a very attractive 9 c/kWh.

A recommendation of this report is for processors with limited capital interested in offsetting a portion of their annual energy costs with concentrated solar to contact the above companies to discuss a more tailored plant design for their site.

For processors interested in offsetting a more significant portion of their site thermal and electrical load with concentrated solar, IES/Aalborg may be a suitable vendor as their proposal includes deliberate over-design of the concentrated solar array and extensive thermal storage. Conditional to the vendor securing third party funding assistance, this may be delivered under a PPA with a more modest annual saving, but with the more significant emissions offset (see below). In the future when there are more financial mechanisms of emissions reduction (including emissions pricing, compulsory reduction targets and trading schemes, and more definitive premiums on carbon neutral red meat), this should be re-investigated to determine the feasibility at the time.

4 Discussion

4.1 Comprehensive vs Cost Reduction Strategy

The inclusion of extensive thermal storage significantly increases the capital cost of plant at the expense of overall economic viability. It is thus a recommendation of this report that when reliable heat and power options exist due to connection to the grid, lower cost fuel generators, or economical thermal fuel supply contracts, that concentrated solar heat and power be used on an “as available” basis, unless other strong external drivers exist such as carbon neutrality mandates, drastic changes in emissions and trading policy, and unavailability due to regional areas or prohibitive cost. As the technology further matures in the Australian market, the viability of extensive storage may be revisited. Where a facility reduces operational hours (e.g. from 2 shifts to a single shift; long periods of scheduled maintenance) the need for storage of energy for long periods of time is reduced.

For processors where power can generally be sourced from the grid for less than 20 c/kWh (including the demand charge), concentrated solar power may not be as viable compared to feedlots where power is sourced from diesel generators or high regional area tariffs. However concentrated solar thermal may present a viable “green steam” option for all feedlots (e.g. running LPG boilers at 20-30 $/GJ) and processors running anything other than a bituminous coal-fired boiler. This may then be an attractive, modest CapEx, ‘cost reduction strategy’ to shift high cost, high emitting thermal fuel to nearly zero-emissions.

An extremely large advantage is deferred capital where a facility’s boiler house is running at capacity and/or the power reticulation system is running at capacity, hence a modular CST/CSP system could provide the additional energy required at a better net present value compared to a fossil fuel or grid solution.

4.2 Updated Weighted Criteria Matrix

Due to the unavailability of high detail information in the literature review done during milestone 1, the initial weighted criteria matrix was unable to compare vendors on finer points such as $/kW, $/GJ, and m^2/kWt. As part of the request for proposal process, vendors were requested to provide this information; the updated weighted criteria matrix is presented in Table 11. Note that only PPA proposals are compared under the assumption that this is the preferred business model for the Australian red meat industry. The weighting on each metric is designed such that the highest score is desirable.

Table 12: Updated Weighted Criteria Matrix

Vendor	Aalborg	Impacts	RayGen	
Business Model	PPA	PPA	PPA	Weighting
$/kWh	$ 0.15	$ 0.17	$ 0.09	2.5
$/GJ	$ 21.47	$ 12.60	$ 9.00	2.5
Annual Saving	$292,894	$332,552	$469,407	-3
m2/kWt	3.8	16.0	8.0	1
Maximum Temp °C	400	400	95	-2.5
Score	0.6	2.5	2.3	

4.3 Implications for Australian Feedlots

A scenario was run for a feedlot utilizing LPG at a cost of $28 / GJ (includes supply and storage) at a rate of 18,000 GJ pa for steam flaking of white grain for a 20,000 SCU feedlot. A high percentage of LPG offsetting was selected (66%) due to steam flaking occurring for a single shift per day during periods of high solar radiation. Hence, the CST system was sized to provide 11,880 GJ pa. A factorial multiplier was used to interpolate the Total Capital Investment for a smaller system of $2.084 mil. This equates to a fuel saving of $276,750 per annum or 41% of the total annual energy bill (boiler and gen set fuel). This equates to 7.5 years with no indexing.

For feedlots with steam flaking, towards three quarters of the energy bill can be attributed to boiler fuel costs plus feedlots tend to be located inland (higher solar radiation), have buffer zones (areas of land with low opportunity cost) and are run for single shifts (6 to 8 hours per day) as many days in the year as possible hence concentrated solar thermal is ideally suited to matching the thermal energy requirements of steam flaking.

Table 23: Impact of energy price increases on payback period for a CST system offsetting 66% of LPG usage

Price change in boiler fuel above base case (compounded, p.a.)	Simple payback period (years)
-10%	13.9
-5%	9.8
-1%	7.9
None	7.5
+1%	7.2
+5%	6.2
+10%	5.4
+20%	4.4
+50%	3.0
+100%	2.3

4.4 Emissions Reduction

Concentrated Solar Thermal and Power solutions have good potential to contribute towards the industry goal of carbon neutrality by 2030, as 100% of a site's power and thermal load can be sourced from the sun, greatly reducing Scope 2 and Scope 1 emissions, respectively. A summary of thermal and electrical usage (in emissions reporting terms of GJ rather than kWh) and emissions offset by vendor is shown in Table 14.

Table 14: Comparison of Reduction in Plant Emissions by Vendor

	Current	IES / Aalborg	Impacts	RayGen
Grid Electrical Consumption [GJ]	44,913	16,034	44,913	39,009
LPG Thermal Consumption [GJ]	99,000	33,660	69,463	75,839
Electrical Offset [%]	0%	64%	0%	13%
Thermal Offset [%]	0%	66%	30%	23%
Scope 1 Emissions [tCO2-e/yr]	5,089	1,730	3,570	3,898
Scope 2 Emissions [tCO2-e/yr]	4,042	1,443	4,042	3,511
Total Emissions [tCO2-e/yr]	9,131	3,173	7,613	7,409
% Reduction		65%	17%	19%

In the short term, and with the absence of a pricing mechanism on emissions, the benefits of reducing a facility's Scope 1 and Scope 2 emissions by as much as 65% (as seen in the comprehensive Aalborg proposal) are mostly limited to the non-monetary, including a clean and green image and social license to operate. In export markets, this may attract a further premium to the Australian provenance; market analysis is however excluded from the scope of this report. In the future, given changes in regulatory policy or emissions trading mechanisms, this has the potential for a monetary value to facilities.

4.5 Funding/Financing

A number of sources of potential funding and financing assistance exist for concentrated solar systems in the Australian market that can greatly improve project economics or streamline delivery. At the federal level, concentrated solar is likely to be sufficiently innovative to qualify for and potentially secure a grant from the Australian Renewable Energy Agency (ARENA), usually up to around 30% of capital.

In QLD, the June 2018 state government budget specified an allowance of $50 million capital grant to assist with concentrated solar thermal and storage projects[9]. Processors and feedlotters in QLD investing in CST/CSP should investigate this opportunity; others investigate availability of similar grants in their respective state.

In the financing space, operators may choose from standard debt funding; private equity where the equity group may only own a percentage of the special purpose vehicle (SPV) rather than the entirety; and operating leases or managed service agreements (MSAs). A comparison of the criteria of these is shown in Table 15.

Table 15: Comparison of Managed Service Agreement, Lease, and Loan

Criteria	Service Agreements	Lease	Loan
Security	Unsecured.	Unsecured.	Usually secured by main lender.
Service	No responsibility for the client. Fixed maintenance covered in MSA & OPA payments.	Responsibility of the client.	Responsibility of the client.
Operation	Not client's risk. MSA operator responsible. Errors and omissions insurance held by MSA operator.	Client risk, mitigated by supplier warranties.	Client risk, mitigated by supplier warranties.
Upfront Capital	None to client. No impact on bank limits and other financing sources given a service cost.	None to client. Usually no impact on bank limits and other financing sources.	None to client, but usually impacts bank limits and other funding sources.
Economic benefit	Structured to provide positive net cash flows from the start with no upfront capital expense.	Can be structured to provide positive net cash flows from the start with no upfront capital expense.	Unlikely to provide immediate positive net cash flows due to short term financing versus long-term payback.
Balance sheet	Off-balance sheet as a service OPEX cost; tax deductible.	Can be off-balance sheet as an OPEX cost; may be tax deductible.	On-balance sheet and depreciated.

[9] https://www.energetics.com.au/insights/thought-leadership/queensland-budget-2018-19-highlights-for-energy-and-climate-response/

4.6 Energy Pricing

4.6.1 Electricity and natural gas trends

The past decade of electricity pricing has seen a strong disconnect between the CPI and power costs for end users as shown in Figure 11 below. The plot also compares gas & other household fuels (blue), to Australian electricity (red), and the economy wide CPI trend (yellow) showing the dramatically stronger rise in energy costs for Australians especially from 2010 onwards. The ASX Energy Futures strip base swap from now through to Financial Year 2021 for NSW, Vic, Qld and South Aust is dropping, however due to the trend in the larger percentage of bills moving to capacity (kVA) based charges, whilst kWh charges may drop the overall power bill is not expected to drop in any dramatic form. Electricity has had a lot of attention, however natural gas and electricity pricing are now linked due to the importance of natural gas peaking plants hence natural gas is also following a trajectory higher than the CPI.

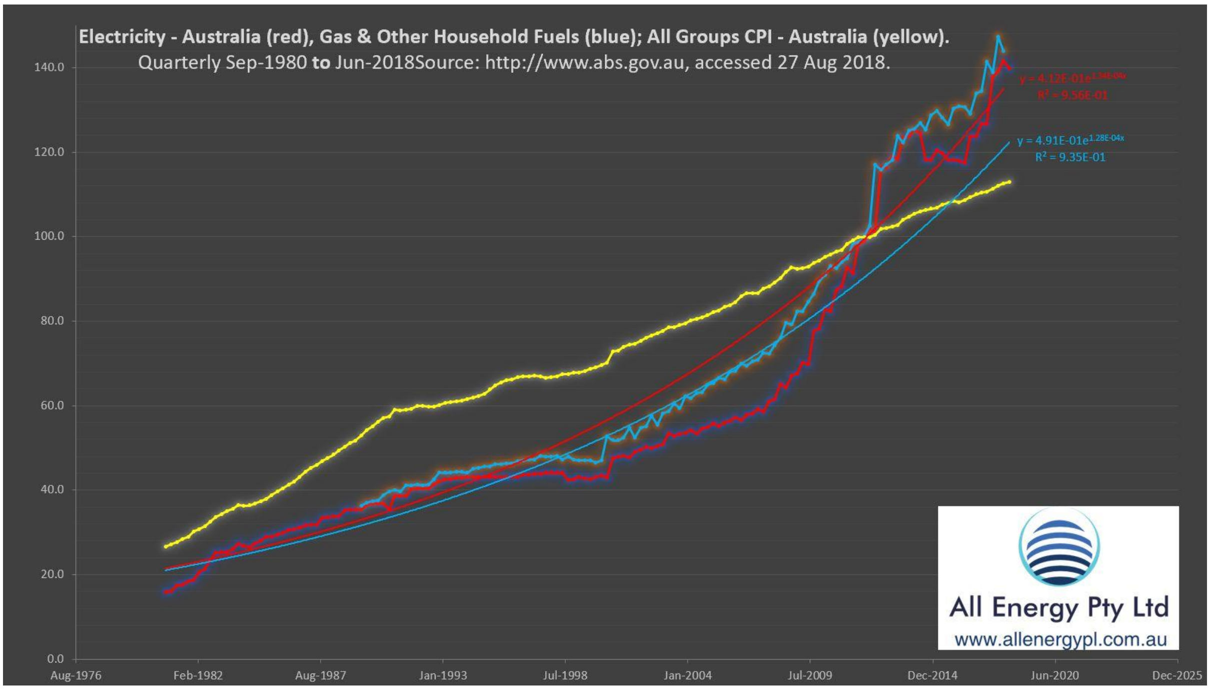


Figure 11: ***Energy price trends for Australia from Dec 1979 to June 2018 - Electricity (red), Gas & Other Household Fuels (blue); All Groups CPI - Australia (yellow).*** *Quarterly Australian Bureau of Statistics (ABS) Data, source: http://www.abs.gov.au, accessed 27 Aug 2018.*

4.6.2 Liquid Fuel Price Considerations – LPG and diesel

Global supply concerns and strong underlying demand will ensure that crude prices, and hence the related LPG and diesel prices, remain strong. The figure below shows that prices have been creeping upwards in the last 12 months; with Australia currently experiencing the highest liquid fuel prices for 4 years with little expectation of prices to drop. Hence, it is assumed that liquid fuel prices will not drop below current levels.

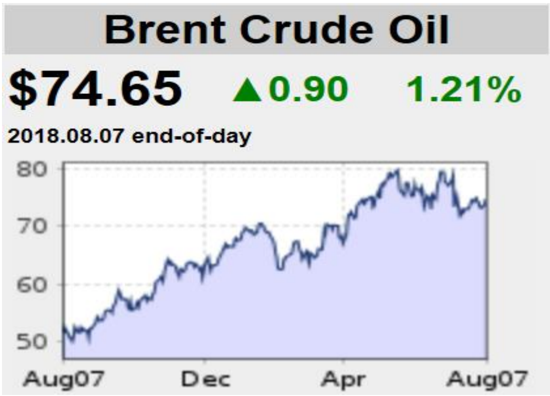


Figure 12: Brent Crude pricing for the 12 months to 7 August 2018.

5 Conclusions / recommendations

The modularization of concentrated solar has improved the economic viability for process thermal energy, with paybacks of towards 7 - 8 years now achievable for processing plants (excluding potential of improved paybacks by attracting third party funding). Power Purchase Agreement (PPA) and Build-Own-Operate-Maintain (BOOM) offerings are some of the options available to reduce energy costs by 10% with no capital outlay for 15 year agreements. The "sweet spot" for energy off-setting by solar thermal appears to be in the 20% to 66% range, as any smaller misses out on economy of scale whilst any larger the energy storage costs then erode the economics.

When considering a CST/CSP system the key considerations are:

- Whether to include thermal storage.
- The facility operating hours. For example, solar energy is better suited to a facility running 1 shift 7 days per week rather than a facility running 2 shifts for 5 days per week.
- Available surface area. Ground mounting is preferred.
- Storage of thermal and electrical energy is expensive hence commercially viable CST/CSP systems do not currently exhibit strong financials for providing 100% of the energy requirements. It is anticipated that into the future this will change rapidly.
- Detailed optimization considering:
    - Balance between economy of scale, acceptable risk profile (i.e. Total Capital Investment; continuing use for the energy), providing energy offset and cost reduction that is meaningful for the business and/or stake holders.
    - Whether thermal and/or power offsetting is required.
    - Analysis of cost reduction taking billing structure into account (i.e. kWh and kVA charges).
- Consider forward trends in energy pricing, in particular accounting for indexing of PPAs and BOOM.
- Configuration and available capacity / lifespan of exiting plant. For example:
    - Water treatment facility and capacity
    - Condensate return
    - Integration with existing facility as a fuel cost reduction strategy. With the two general options being:
        - Direct
        - Indirect (refer figures below).

Recommendations for future work:

- consider supporting commercial pilots of:
    - concentrated solar thermal direct system
    - concentrated solar thermal indirect system
- Maintain a watching brief on changes to pricing for modular power generation (which would reduce the capital outlay of CST) and thermal energy storage (which would increase the offset % and improve the economics of power production).

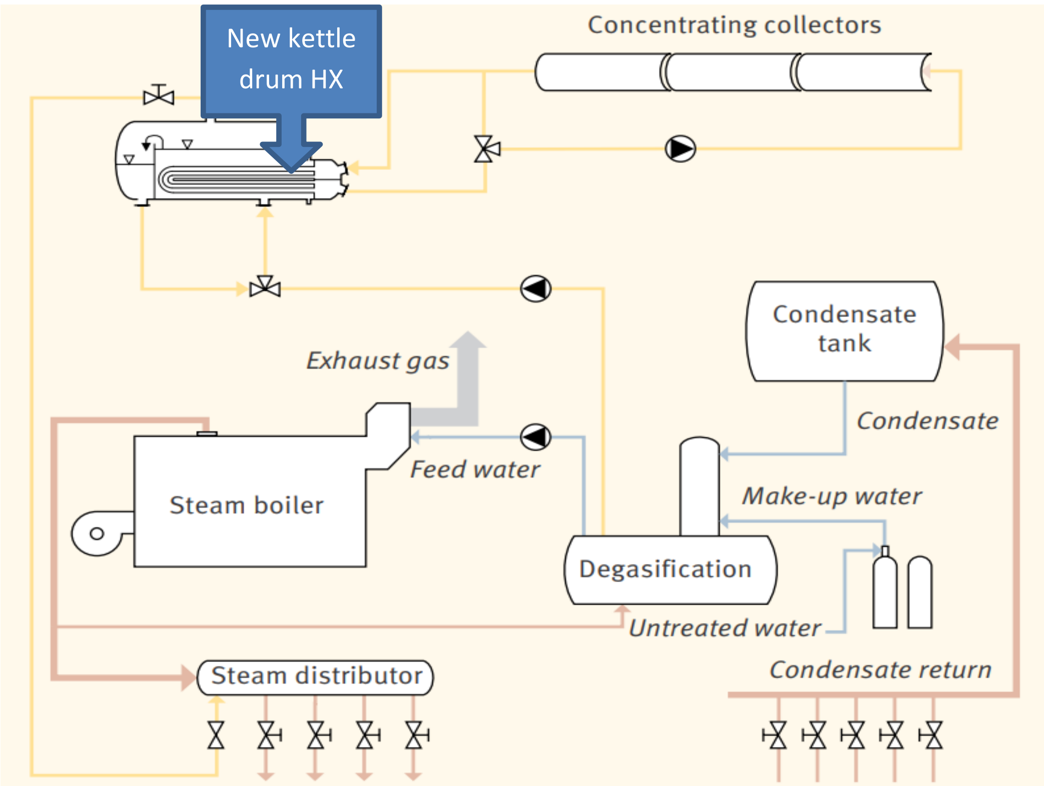
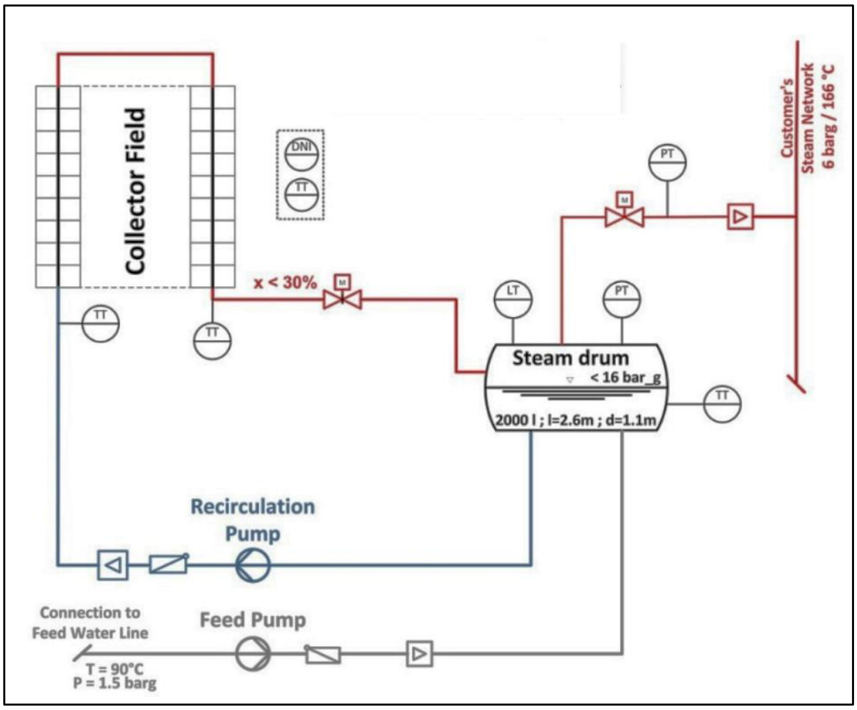


Figure 13: Indirect system - Integration of a solar collector with an existing boiler with the yellow lines being for the new solar installation and the orange lines the existing system. This is an indirect system where the process fluid (e.g. water) is kept separate from the solar thermal fluid (e.g. thermal oil) via the use of a kettle drum heat exchanger10.



[10] http://www.bine.info/fileadmin/content/Publikationen/Themen-Infos/II_2017/themen_0217_engl_internetx.pdf

Figure 14: Simplified Process and Instrumentation Diagram of a Recirculation Solar Thermal Heating system. Source: Industrial Solar GmbH[3].