AUSTRALIAN MEAT PROCESSOR CORPORATION

Renewable Energy Options for Off-Grid Red Meat Processing

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1.0 Executive Summary

The purpose of this report is to look at the economic and environmental benefits of renewable energy and storage systems that may be deployed in the meat processing industry, utilizing three desktop case studies as well as considering the regulatory hurdles that exist.

Looking at renewable energy technologies, with the exception of solar, bioenergy and wind, they are still in the early stages of the innovation curve and therefore would not be considered economic for commercial deployment. There has been much progress with battery storage over recent years and this is starting to become a viable option for coupling with renewable energy systems.

This report has focused on solar and bioenergy options as they currently are the most economical to deploy at scale within the Australian red meat processing industry. Specific technology choice, as highlighted in the desktop case studies, is site specific.

The regulatory rules are also very site specific with environmental regulation being controlled primarily by Local and State Government and the ability to connect renewable energy systems to existing infrastructure controlled by the local distribution entity. In a number of cases where new building owners have tried to generate their own power, the distribution companies are still requiring that there is the ability to service the building from the grid. The connection agreement is seen as a major obstacle in becoming independent of the grid.

Energy storage is also considered a major factor in being able to become grid independent and the market in Australia is still fairly week for energy storage technology. Many international companies are not willing to supply into a market that is still growing due to the need to have maintenance staff on ground. This does appear to be changing and it is expected there will be a full range of options within the next few years.

The planning process prior to any mobilization on site can take at least 12 months, so individual on-site case studies should be undertaken to look at viability from both technical and economic perspectives.

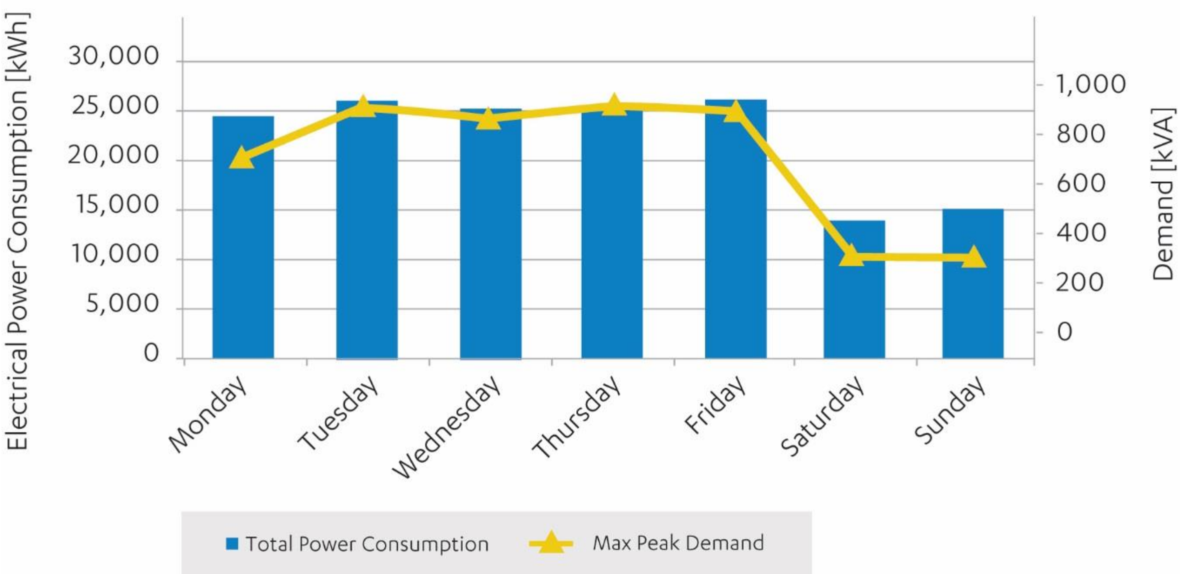
2.0 Background

There has been limited research into the potential for entirely off-grid red meat processing plants in Australia. Plant energy use can be broadly represented by the equation:

Energy use = Energy demanded from variable activities + Fixed energy use.

Fixed energy use can occur irrespective of the time of day or hours of operation and often includes steam and hot water generation, refrigeration and operation of security, cameras, lights and other essential 24/7 operations. By contrast variable energy demand changes based on inputs. **Error! Reference source not found.** demonstrates the impact of variable and static energy use by showing the electricity consumption profile of a non-rendering processor of approximately 12,000 tonnes of hot standard carcass weight (tHSCW) per annum of red meat comprising lamb, beef and pork. Generally, the more intensive the processing, the greater the energy requirements. Slaughter or boning facilities require less energy than facilities with more intensive value-adding activities like rendering AMPC (2013). The rendering process can account for over 70% of heat energy required for plants, while refrigeration can account for more than 50% of electricity use for plants with onsite or longer term freezing Hydro Tasmania (2008), Meat and Livestock Australia Ltd (2010)).

Figure 1: Weekly electricity consumption profile during July at a non-rendering processor of approximately 12,000 tHSCW per annum of lamb, beef and pork. Source: AMPC (2013)



Significant research has been conducted with respect to ways to increase energy efficiency and manage energy demand to reduce both the variable and fixed components of this equation. However, the research has focused on energy efficiency, or hybrid systems which require the meat processing plant to remain connected to conventional energy supply. The next step is to understand whether this requirement should remain, and what energy and electrification options exist for processors.

In its 2013 report, *Review of Renewable Energy and Energy Efficiency Options for the Australian Meat Processing Industry*, the AMPC reviewed the renewable and alternative electrification options for four sites across Queensland and New South Wales (3 cattle, 1 sheep) AMPC (2013). The technologies considered varied based on site characteristics but included, solar, wind, geothermal, biological (e.g. anaerobic digestion), effluent pond methane capture, manure biogas, combustion of tallow and paunch manure, and fuel cells. The focus of the review was on reducing energy use and identifying the most economic options. Across all plants examined, covering of effluent ponds for methane capture was identified as one of the most economic options with plants having other different types of technologies also identified as economic.

In its 2013 report, *Review of Energy Efficiency Utilisation Benchmarks & Technologies for Australian Red Meat Processing*, the AMPC undertook a more comprehensive analysis of energy challenges with a focus on strategies and technologies for increasing energy efficiency and the potential for alternative energy sources AMPC (2013). The report focused on small to medium red meat processors concluding that there were opportunities for processors to improve energy efficiency and consider alternative generation technologies. The report considered the potential for renewable technologies to reduce energy costs including solar PV, hot water (using solar thermal energy) and wind power noting that resource availability and capital costs were the drivers of financial feasibility. Biogas capture and reuse including capture, flaring or fuel replacement (e.g. LPG to biogas) were also considered noting that resource quality, capital and/or retrofitting existing equipment to handle biogas also drove financial feasibility though biogas capture and reuse was already occurring in some plants.

Other studies have considered ways to increase efficiency and use of renewable energy. Gas cogeneration was considered as a source of improving energy efficiency and achieving more environmentally sustainable outcomes MLA (2010). The use of paunch waste as a boiler fuel was found to be a feasible alternative to coal, particularly for boilers suitable for biomass firing MLA (2011). The potential for abattoirs to produce their own energy from paunch waste and DAF sludge was examined and found that even though (at the time of the report) waste pyrolysis was being used at commercial scale in Europe and Japan, it was not in Australia. The report concluded that pyrolysis of abattoir waste could be commercially attractive but pilot trialing was needed to confirm the finding MLA (2011). The use of abattoir waste heat for absorption refrigeration was considered and found that due to high capital and maintenance costs (at the time of the report), there were long payback periods, and biogas would be best directed to directly firing an existing gas-fired boiler primarily due to lower capital costs MLA (2010). The relevance of NSW and VIC government policies and programs to support resource and energy efficiency were considered and found to facilitate different types of changes, though it was concluded that large scale step-change projects may not be as good an investment as smaller incremental improvements in energy efficiency MLA (2011). The importance and benefits of energy management and efficiency for meat processors were identified and discussed. An energy management plan was said to help mitigate risks associated with rising energy costs, greenhouse gas emissions (GHGe) as well as consumer and community expectations about business environmental performance AMPC (2013).

3.0 Types of Electrification

Much of the literature has focused on managing energy demand, a necessary input into the energy equation, or alternatively on the development of hybrid systems that increase renewable energy use thereby reducing the amount of electricity sourced from the grid, or via natural gas (regarded as two of the most common sources of meat processing plant electricity) AMPC (2013). These types of systems can increase energy security by generating onsite and reducing vulnerability to input cost price changes (such as tariffs and natural gas prices), addressing environmental concerns, particularly relating to plant waste and GHG emissions and increasing overall plant efficiency. However, grid connected plants with hybrid systems possess one critical point of differentiation. They must remain interconnected to ensure electricity access. The grid remains a critical source of electricity and only the amount of electricity sourced from the grid changes. In renewable hybrid systems, or gas-grid hybrid systems, the non-grid generation options act as a cap, or cushion on the amount of electricity required from the network or from natural gas or LPG. If this cushion is deflated, then the plant can continue to operate by simply reverting to sourcing its electricity entirely from the grid (albeit generally at higher marginal energy costs).

In the off-grid context, this is not possible as by necessity the grid does not play a role in the generation mix. This means that electricity requirements must be satisfied entirely through the use of local distributed generators. This requires a generation mix that can satisfy peak loads, while retaining the capacity to provide energy 24/7 even during times when the plant is not operational. It must also contain sufficient redundancy to ensure all operational systems can be reliably powered and safety obligations can be satisfied.

Off-grid electrification (also known as distributed generation (“DG”)) is characterised by electricity generation located close to the demand. While the definition of DG is not settled and does not have to be exclusively off-grid, in the context of this report, references to DG are made in the off-grid context. DG systems can be incorporated into a larger electricity grid and still retain the ability to operate in isolation from that grid. Discussion and use of DG has occurred for decades Evans (1925) and has been met with mixed success. There is a plethora of literature that examines the use of DG. Barnett (1990) examined DG use in developing countries, Martinot (2001) in relation to World Bank projects, CSIRO (2009) with respect to the potential for high penetration of DG in Australia, and Zerriffi (2011) for a more general discussion. Much of the literature has focused on using DG in rural communities across different scales from household systems, community mini-grids and grid connected systems. This is likely a reflection of the reality of large centralised networks that service many urban areas.

The two types of DG most commonly used in regional and remote communities are individual household electrification (the most common method being solar home systems (SHS)) and mini/micro-grids. Mini-grids operate as a grid-type system within a community or area and function much the same as a large centralised grid, except electricity is generated locally and provided to the community (including businesses and other consumers). In contrast, individual household electrification is focused on providing electricity to individual households, and not to the community at large. Approximately 9% of Australian generation capacity is from distributed generation, of which approximately 32% is from renewable sources (mainly wind, bagasse and hydro) CSIRO (2009). For red meat processors, this presents two options, individual meat processing plant electrification, or a microgrid where meat processors incorporate the local community into their electrification plans. The differences are largely a question of scale, though the second option also requires significant administrative arrangements.

Following analysis of the impacts and utility of DG in the Australian context CSIRO (2009) concluded that DG had a number of advantages including:

- It could be an effective greenhouse gas mitigation option for Australia
- DG is more able to match growing demand by using smaller units, thereby reducing the impact of large stepwise additions to generation capacity associated with centralised technologies
- DG allows for reduced electrical losses from transmission and distribution by locating generation close to the point of use. These costs are incorporated into electricity tariffs
- DG is modular and can be tailored to end-user requirements.

Electricity requirements of meat processors are significant and similar to (or greater than) many remote isolated networks in Australia. For example, electricity generation required for electrification of remote communities on Horizon Power’s isolated networks ranged from 222,154 kWh per annum (Lake Argyle) to 130,238,468 kWh per annum (Broome) Horizon Power (2013). All of these communities are effectively micro-grids with electricity generated via diesel generators for the smaller communities and gas turbines (e.g. In Broome with limited renewable energy penetration, principally solar PV). Most meat processing facilities will fall within this range of electricity requirements and could operate off-grid using these established methods.

However, the marginal cost of electricity in remote isolated networks is generally high (particularly for diesel generation). Incorporating renewable energy can reduce risks associated with rising input (gas or diesel) costs. Distribution network operators such as Horizon Power have identified this and developed incentive schemes to encourage renewable energy penetration on their isolated networks to reduce the cost to supply. This is because the marginal cost of renewable energy, particularly solar and wind is very low. For meat processors the decision to go off grid is not simply a question of whether it is possible at any cost (which it clearly is) but whether an off-grid plant can be both off-grid and economically viable. The need for both function and economic feasibility requires consideration of alternative (generally renewable) generation options.

4.0 The Challenge of Off-Grid

Off-grid systems are still required to generate electricity 24 hours a day. Electricity networks to date have operated on the basis of ensuring sufficient electricity is available (i.e. matching generation with demand). In the absence of storage technologies, this poses challenges for off-grid renewable systems as generation can only occur when resources are available. For example, this means that solar systems cannot generate electricity when there is no sunlight. A further complication arises through intermittency of supply, which is unique to particular renewable technologies (such as solar and wind) where small changes in cloud cover can have an impact on the energy generated. Consequently, off-grid generators have traditionally adopted three approaches to managing this challenge. Firstly, the use of energy storage to manage intermittency and ensure supply – these occur in remote locations that lack access to the central grid including isolated properties, tourist accommodation, and communication facilities. Secondly, the use of different technologies that ensure generation 24 hours a day, though this generally requires that one of those generators to be able to cover intermittency in generation. Thirdly, some combination of the first and second approaches to ensure 24 hour reliable supply.

The requirement for storage has traditionally acted as an impediment to entirely renewable off-grid systems. While the cost competitiveness and efficiency and reliability of storage technologies continue to improve, they remain a challenge for off-grid cost competitiveness. Most off-grid systems that utilise renewable energy are hybrid systems that incorporate both renewable and non-renewable generators. Depending on the size of the network and available supply lines, the non-renewable generators are often gas turbines for larger electricity requirements (e.g. Remote mine operations, large regional towns) and diesel generators for smaller requirements (e.g. Isolated communities).

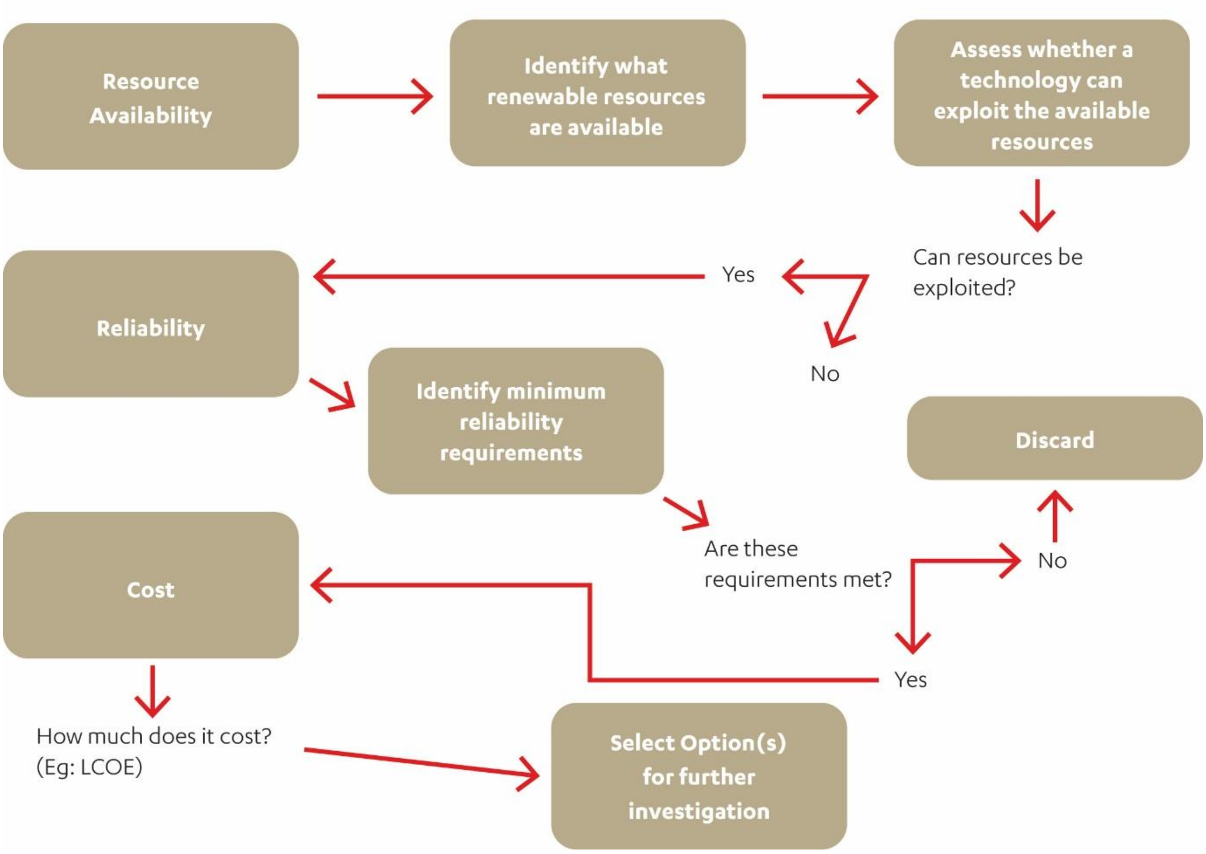
For an off-grid system to work effectively, it is necessary for processors to understand their electricity consumption profile at the time of installation as well as future requirements to ensure any growth in demand can be catered for. This is necessary because a system designed to cater for average consumption (without awareness of peak load) will mean that power quality will reduce significantly if peak load is above the average, which it inevitably will be. It provides an opportunity for processors to align energy and electricity intensive processing with periods of high generation (e.g. During peak sunlight hours if solar is installed). These types of demand management strategies can help minimise required system size (and thus cost). An advantage of many renewable technologies such as solar, wind is that they are scalable so systems can be adapted overtime if electricity or energy requirements increase. Nevertheless, because of the requirement for 24 hour electricity generation systems must be carefully designed to exploit available resources in a way that can ensure reliability of supply.

In addition, back-up or reserve generation can be required. In the off-grid fossil fuel powered context, an n + 1 approach is generally used. In this approach “n” equals the number of generators required to meet peak electricity demand and “+1” is the redundancy or reserve (i.e. one extra generator) in case there is a failure of one of the operating generators. In an off-grid context this back-up can take many forms that are ultimately dependent on corporate objectives, availability of resources and cost. Conventional diesel generation is used commonly in remote mining operations, communities and agricultural properties to supplement other forms of generation (such as gas or solar). Oversizing renewable systems and/or incorporating storage is also a common approach where the system is designed with excess capacity (generation and/or storage) to ensure that supply can be maintained if there is failure of components. Existing back-up generation used in the event of grid blackouts can also be used. Because the processor is off-grid it is important to ensure that some kind of redundancy exists to ensure system reliability.

5.0 Renewable Energy and Technology Choice

There are numerous renewable and storage technologies available all with different characteristics and levels of maturity. Ultimately the choice of technology is a function of the availability of resources, reliability and cost as depicted in **Error! Reference source not found.**.

Figure 2: Renewable energy and technology choice



The availability of resources refers to availability of energy inputs to the generator which in the meat processing context, provides an opportunity to utilise by-products for generation. It is important to identify not only whether resources are available at a particular point in time, but whether availability changes depending on the season or production processes undertaken. Processors in areas that experience extensive cloud cover during a period may find that solar technologies may need to be supplemented. Similarly, the availability of biological resources (e.g. for anaerobic digestion), effluent ponds for methane capture, manure for biogas, and tallow and paunch manure combustion may depend on the type of processing a plant does. Related to availability of the resource itself, is the need for sufficient space. Each technology will require different areas. This means that there must be sufficient space for the technology to be deployed. Solar PV is well suited to roof-top application and many processors have substantial roof space which can be exploited. All technologies will require some space (either land or rooftop) and this can be a constraint on resource availability and suitability. In addition, the space must be well suited to a particular technology uncleared land, or land that receives extensive shade cover throughout the day is likely to be less suitable for solar than cleared land. Effluent ponds, wind, and other renewable generators and feedstock will require space. The amount of space depends on the technology and how it is installed. Nevertheless, processors should be aware that the availability of suitable space constrains installation and technology choice.

Reliability has a number of different aspects including how reliable the technology is itself (is it prone to breaking down). This can be troublesome if it forms a key component of the generation mix. It also includes, its useful life and the ease of repairing and replacing components if they fail. The literature is replete with technological assessments of reliability. However, in a commercial situation, generally more mature technologies are regarded more favourably as they have a track-record. To this end, it is useful to consider the technologies that have achieved the greatest penetration in Australia and projects undertaken. This appears in Section **Error! Reference source not found.**.

Cost also has a number of aspects including the upfront capital and installation costs, and the ongoing maintenance, operational and decommissioning costs (included in levelised cost assessment). These are important to assess financial viability.

The challenge is leveraging available resources to ensure generation is matched to demand. This can be challenging particularly where generators with intermittent production are used.

6.0 Types of Renewable Energy

The process outlined above requires awareness of the different types of technologies available, and their relative maturity. Broadly, these technologies can be divided into six categories consisting of bioenergy, geothermal, solar, wind, hydro and marine energy. Across these categories there are a numerous technology types. Generally speaking, meat processors are most likely to be able to exploit bioenergy, solar and wind technologies due to their greater availability, though local environmental and locational conditions will determine this. In Australia, these technologies are generally more mature and have greater penetration. It is difficult to find a record of all renewable installations across Australia. The Clean Energy Council provide a map that shows the location and type of all renewable energy projects greater than 100 kW in capacity across Australia. It is apparent from that map that the most common technologies are onshore wind (especially across the southern part of the country), solar PV (especially in the northern part of the country), bagasse cogeneration (mainly in sugarcane growing areas in QLD and NSW), landfill gas (near urban centres) and hydro, primarily in NSW, VIC and TAS. Each of the 6 technology categories and their respective technology types are discussed below.

6.1 Solar

Devabhaktuni, Alam et al. (2013) consider the potential for solar energy to increase energy security and help satisfy the generation gap between rising electricity demand (globally) and limited growth in generation. They conclude that solar has the potential to be a primary, cost-effective power source that reduces environmental impacts and increases energy security. Different types of solar technologies are at varying stages of maturity, with photovoltaic panels achieving significant penetration globally. Solar thermal technologies while generally more efficient and inherently scalable are largely better suited to utility scale generation. There is very little solar thermal penetration in Australia, particularly in commercial applications.

Solar PV

There are many different types of photovoltaic (PV) technologies, with research and development continuing. Tyagi, Rahim et al. (2013) outline growth in PV technologies, efficiency, factors affecting the performance of PV module, and environmental impacts. El Chaar, Lamont et al. (2011) review the different types of PV technologies considering the four main types of PV technologies crystalline, thin film, compound and nanotechnology and noting that research is largely focused on improving efficiency while reducing cost. Parida, Iniyan et al. (2011) consider PV generating capability and its applications, performance and reliability evaluation models, sizing and control, grid connection and distribution. PV penetration globally is substantial. Germany (the largest installed PV market at present) has approximately 35.7 GW of installed capacity, primarily among residential customers and farmers, with the remainder largely divided between commercial enterprises, project planners and investment funds and rooftop and ground-mounted systems Wirth (2014). Australia has followed a similar trend with significant PV penetration estimated to be more than 3.42 GW APVI (2014) though this has been largely driven by small-scale residential rooftop installations. A range of policy and institutional challenges persist for PV technologies. There have also been limited solar installations in remote communities diesel powered distributed networks. These networks which are administered by state government owned utilities have used solar to offset the high marginal generation costs resulting from the use of diesel generation. Ergon Energy have a 130 kW concentrated solar PV installation in Windorah, a small town in South-

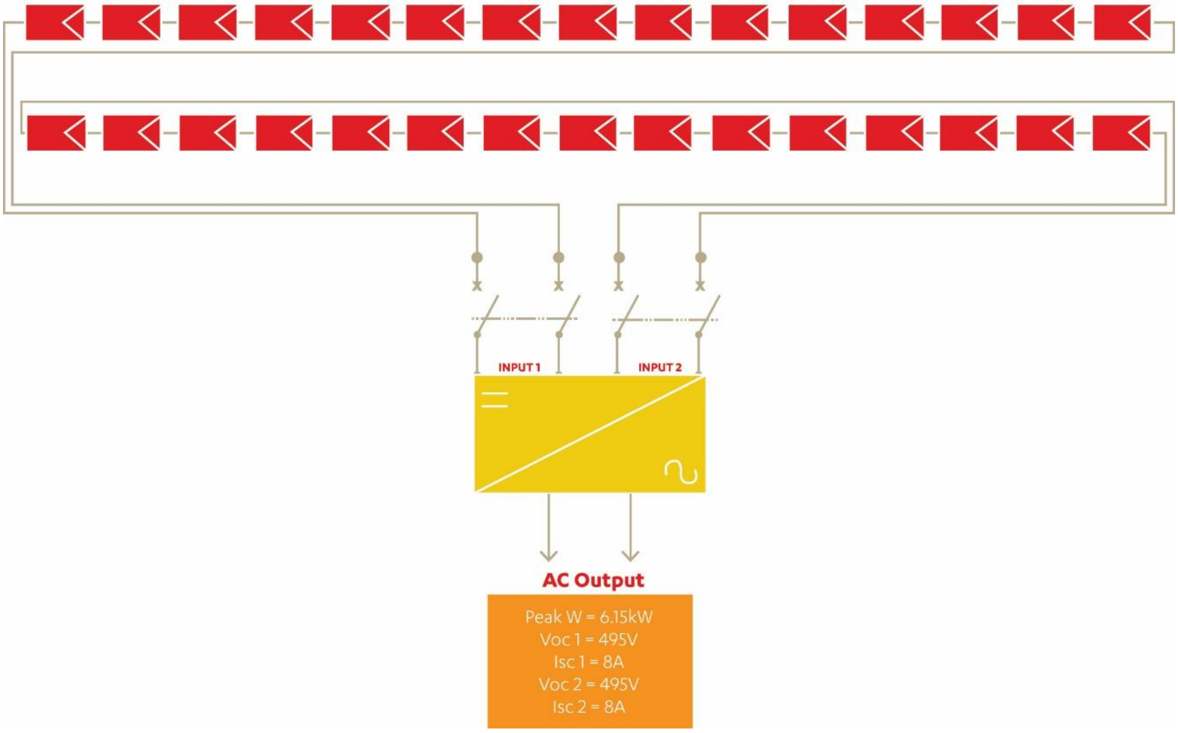
Western Queensland Ergon Energy (2014), and a 264 kW system in Doomadgee in far north Queensland RFI Solar (2014). Northern Territory Power and Water also have a number of hybrid installations across Hermannsburg, Yuendumu, Lajamanu, Bulman and Kings Canyon, with a combined capacity of more than one megawatt . Ntaria (Hermannsburg), Lajamanu and Yuendumu together contain 30 concentrated photovoltaic dishes with peak power of approximately 20 kW each while the others are flat panel PV systems. Horizon Power has also developed an incentive scheme designed to incentivise local renewable energy installation to reduce supply costs. The scheme offers a tariff that is reflective of local supply costs Horizon Power (2014). All of these installations are hybrid systems where the local distributed (or “off grid”) network is powered by a combination of diesel generation and solar power. Power supply and reliability concerns resulting from intermittent supply are addressed through a combination of limited ramp up/down capacity using capacitors or batteries and diesel generators which can “take up the slack”. PV could be a suitable technology for meat processors and can be deployed at various sites within the facility.

A PV system will consist of a number of components, as shown in Figure 3, based on a large-scale system including:

- photovoltaic (PV) modules
- inverters
- balance of system (BOS) components, which include the array framing, DC and AC wiring metering, circuit breakers and communication circuits
- storage options (optional).

Figure 3: Typical Array Design (Source: Aurora)

A PVI-6000 could be operated quite successfully with as little as 5 x 205W panels (!kW), then expanded out to 6.15kW using any odd or even number of panels up to 30. The absolute independence of each MPPT input together with an MPPT village range of 90Vdc to 580Vdc is what makes this possible.



Based upon a recent competitive tender for a large-scale PV array, the breakdown of tendered costs between the major array components is shown in Table 1.

Table 1: PV array system cost allocation (%)

ITEM	1	2	3	AVGE
PV Panels	48	60	47	52
Inverters	10	13	20	14
PV Panel Installation	6	2	4	4
Balance of Systems	36	25	29	30
	100	100	100	100

For the purpose of this report we will focus on the PV modules as that choice will determine what inverter is used and many of the BOS components. There is no standard pricing for PV systems and all are costed based on site specific details. Costs can vary in the range of $1.60 to $2.40 per watt.

It is possible to incorporate either single or dual-axis tracking systems, how these are generally land based and take up considerably more area than fixed systems and are therefore not considered suitable for the applications proposed.

There are a number of different PV technologies commercially available on the market, with many having characteristics that make them more suitable to different applications and environments. There are also a number of manufacturers selling into the market, primarily through installers, with options being site specific.

One of the major differences with the technologies is current cost, with this decreasing significantly in recent years as the rate of deployment has increased. Recent indications in competitive supply contracts are showing that the installed cost of a system is now below $2.40/W compared with $8.00/W three – four years ago. Some technologies have a lower cost structure than others, but also require a larger area (and possible larger BOS costs).

For the purpose of this report we have used a 2MW system, with the key details summarised in Table 2. One of the key advantages of PV arrays is that they are modular and can therefore be scaled to meet the current needs. The Annual Average Peak Sun Hours is site specific, with basic data available for most sites through the Bureau of Meteorology.

Table 2: Array output

DESCRIPTION		
Project Installed Capacity	2,000	kWp
Annual Average Peak Sun Hours	6.0	kWh / day
Efficiency of Array	80%	
Annual Average Daily Output	9,600	kWh / day
Annual Average Yearly Output	3,504	MWh

The scaling or staging of the array is important, as the size of this array could possibly meet the entire requirements of the site. However, this would be dependent upon the peak demand use of the facility and whether other possible generation sources such as cogeneration was incorporated into the system.

PV modules

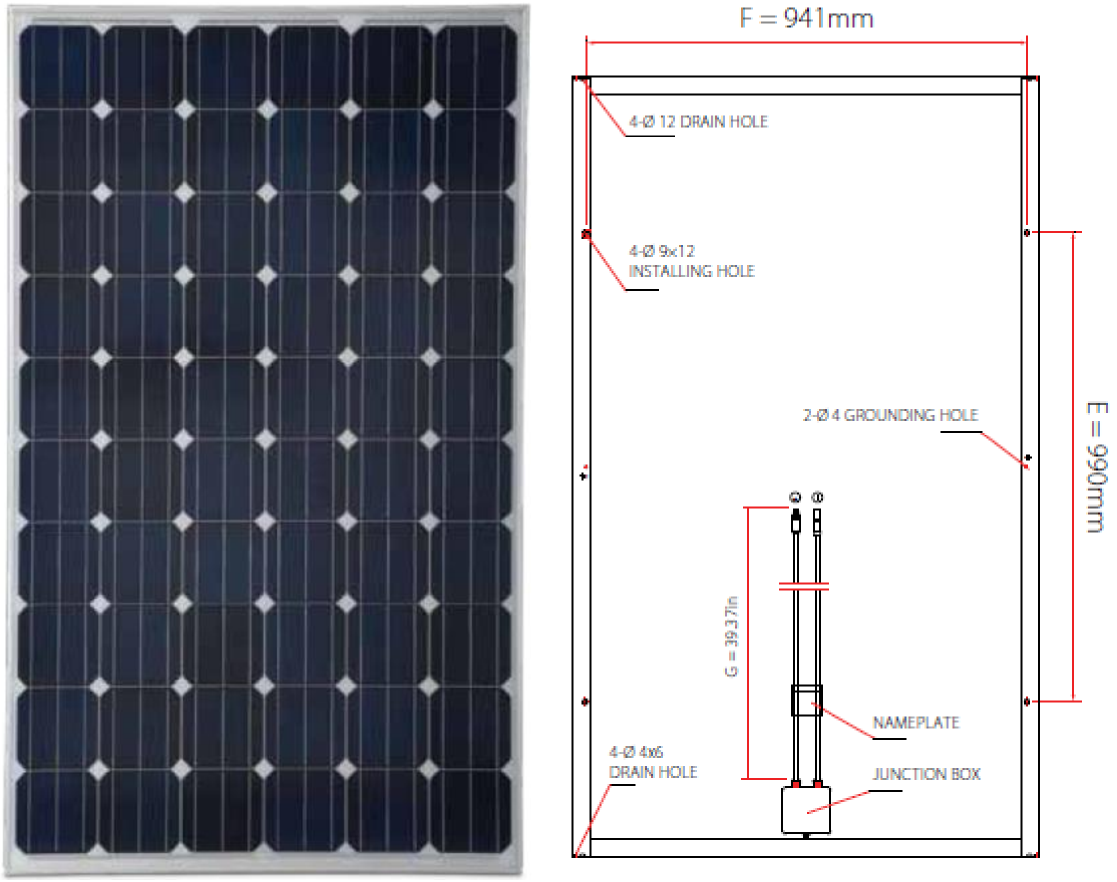
Monocrystalline and polycrystalline modules

These are the most common modules and have already been deployed extensively in all major arrays globally. The modules consist of monocrystalline or polycrystalline silicon cells encapsulated behind a sheet of toughened glass. Generally the appearance of the cells can range from blue to black, being dependent upon the manufacturer and technology being utilised.

The modules, like the colour, will vary in size dependent upon the manufacturer and the technology. Generally they are laid out in a 6 x 12 grid, with each module generating 5 Amps in full sun at a voltage of approximately 35V. The typical efficiency of monocrystalline or polycrystalline PV modules is currently about 15%, although some of the newer modules to be commercially released are showing test results of 18%.

The higher the efficiency, the more power that can be generated and these premium modules are being marketed at similar prices to existing products.

Figure 4: Monocrystalline and polycrystalline modules (Source: Trina Solar)



Historically there have been four major suppliers of this product, being Kyocera Solar, Trina Solar, Sunpower and Suntech, however a number of new manufacturers (particularly from China) are now entering the market, with the number more realistically being in excess of twenty.

Amorphous and thin film modules

The amorphous silicon modules are similar to the modules described above; however the amorphous silicon is deposited directly onto the rear-side of the glass. Whilst the modules above consist of a number of cells in the one panel, these are effectively one large single cell and undergo processes such as laser scribing to create the smaller interconnected cells. These cells are usually a reddish brown, but again this is dependent upon the manufacturer and the exact technology deployed.

These modules are currently less efficient than the more commonly deployed monocrystalline or polycrystalline panels and require a greater area to generate the same output.

An advantage of these cells, due to their size and layout, is that they tend to be more shade tolerant than the monocrystalline and polycrystalline cells, however this is not considered an issue based on the region being considered.

It is also important to note that this product will initially perform better than rated (by approximately 15%) in the initial period after installation. Once exposed to the sun there is a drop in performance, however all calculations and the quoted module rated power is based on the output after stabilisation.

Kaneka and Mitsubishi are the major suppliers of this panel.

Cadmium telluride (CdTe) modules

This module has the lowest cost per watt than any of the other technologies, but also has the lowest efficiency factor, therefore requiring a greater array size to produce similar generation to the technologies noted above. The cell efficiency is approximately 16.5%, with module efficiency around 9%, although the new product on the market is claiming much higher than this rate.

The major component of the cell, cadmium telluride, is a fairly toxic product and its use has been questioned by a number of environmentalists. The major company manufacturing this product, First Solar, has initiated a scheme whereby they are setting aside part of the module sale price into a fund to provide for collection and recycling of the product at the end of the module life.

Figure 1: Cadmium Telluride Modules (Source: First Solar)

First Solar is the major supplier of this product and has already undertaken a number of large projects within Australia including the 157MW Solar Flagships project supported by the Federal Government in Broken Hill and Nyngan currently under construction.

Other PV Technologies

The only other technology that is currently showing promise is the CIGS (Copper Indium Gallium Selenide) module, with a number of companies currently working with this technology. It is currently considered too immature to consider any possible large-scale deployment.

PV Inverters

The inverter is also a major part of the PV array and performs three main functions, being:

- accepts DC voltage from the array to extract the maximum power
- generates AC current to inject into the 240 V grid
- monitors the AC grid to ensure that it stays within the acceptable voltage and frequency windows.

Most inverters fall into two categories being either a single phase string inverter with a rated capacity of between 1 kW and 6kW or a central three phase inverter with ratings that can extend from 10 kW upwards. The single phase inverters are generally located on the AC grid side and are suitable for outdoor mounting whilst the three phase inverters are generally centrally located on the DC side in a plant room or similar.

Another key role of the inverter is the ability to provide detailed information in relation to the generation being obtained from the array.

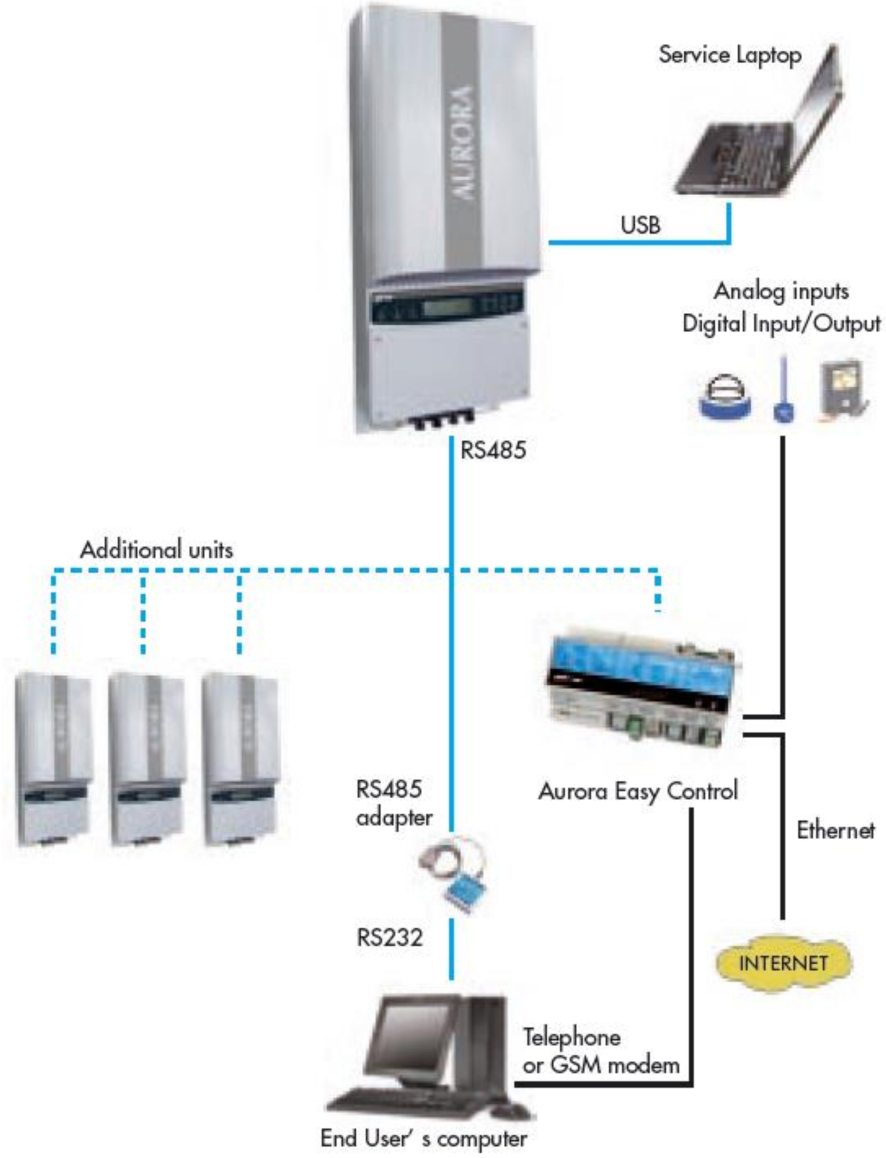


Figure 2: Inverter Data Supply (Source: Aurora)

There are two main suppliers of inverters being SMA and Aurora.

Balance of Systems (BOS)

What is usually referred to as the Balance of Systems (BOS) contains a number of essential infrastructure items that allows the system to be fully mounted and monitored, including:

- array structural framing,
- DC and AC wiring and earthing connections
- DC and AC switching and circuit protection
- metering and communications.

Much of the decision making in relation to these components will, like inverter selection, be based on the type of panel and panel supplier chosen. Most of the framing solutions today use solutions that do not involve any roof penetration, ensuring that that the external structure of the roof is not compromised by adding the array. Further details in relation to framing solutions are available; however a more detailed assessment of the roofing structure needs to be undertaken in conjunction with the preferred module choice.

The modules are usually mounted on racking prefabricated to ensure that the relevant tilt and orientation are achieved to ensure maximum generation capacity can be achieved.

It is important that any existing structures that are going to be retro-fitted have a full structural adequacy assessment to ensure that they are able to support the additional weight.

The suppliers of the BOS would be locally sourced and potential suppliers should be identified as part of the initial review process.

6.2 Solar Thermal

There are very few solar thermal installations in Australia. CSIRO has two research focused solar fields. The first field is used to run CSIRO's SolarGas reactor and has a 500kW capacity, while the second is the southern hemisphere's largest solar thermal field and has been designed as a test platform for solar thermal technologies, such as turbines, receivers and thermal storage prototypes[1]. Liddell coal power station utilises a 3-MWe solar thermal frisnel technology for pre-heating of feed water for the power station. Kogan Creek Power Station plans to utilise a 44-MWe solar thermal addition to produce more electricity with the same amount of coal[2]. The United States National Renewable Energy Agency provide a useful list of solar thermal projects – most of which are pilot or research focused[3]. Solar thermal energy has also been used for hot water – particularly in household systems. The Liddell coal power station provides a useful example of future applicability of solar thermal for water heating.

6.3 Wind

Wind technologies are much more location-specific than solar technologies. This is because wind generally requires a minimum wind speed for operation. Generally Vertical Axis Wind Turbines require wind speeds of greater than 2 metres per second (m/s) and up to 65 m/s, while Horizontal Axis Wind Turbines require wind speeds greater than 6m/s and less than 25m/s Islam, Mekhilef et al. (2013). Onshore wind has achieved significant penetration globally and the technology is arguably the most mature renewable technology, particularly for larger (MW+) scale installations. Islam, Mekhilef et al. (2013) provides a useful summary of the recent trends in wind energy noting that penetration is substantial and increasing, but due to the stochastic nature of wind some kind of energy storage system is likely to be needed. Wind energy is a technology that could be suitable to meat processors, but it requires sufficient available wind resources, the space for installation and a mechanism to manage the stochastic generation.

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[1] http://www.csiro.au/Outcomes/Energy/Renewables-and-Smart-Systems/Solar-Energy-Centre/Concentrated-solar-thermal.aspx
[2] http://www.areva.com/EN/operations-3642/areva-solar-projects.html
[3] http://www.nrel.gov/csp/solarpaces/by_project.cfm , http://www.nrel.gov/csp/solarpaces/by_country_detail.cfm/country=US%20(%22_self%22)

6.4 Bioenergy

Bioenergy is the most widely used renewable source of energy in the world A. Milbrandt and Uriarte (2012). Energy sources include forestry, crops and residues; by-products from food, feed, fibre, and materials processing plants; and post-consumer wastes such as municipal solid waste, wastewater, and landfill gas A. Milbrandt and Uriarte (2012). A variety of energy-conversion processes can be used to provide electricity, heat, steam, transportation fuels EPA and NREL (2009). Figure demonstrates the process of conversion of biological feed-stocks into bioenergy. In an off-grid application, processors are most likely to be interested in biopower, bioheat and biofuels.

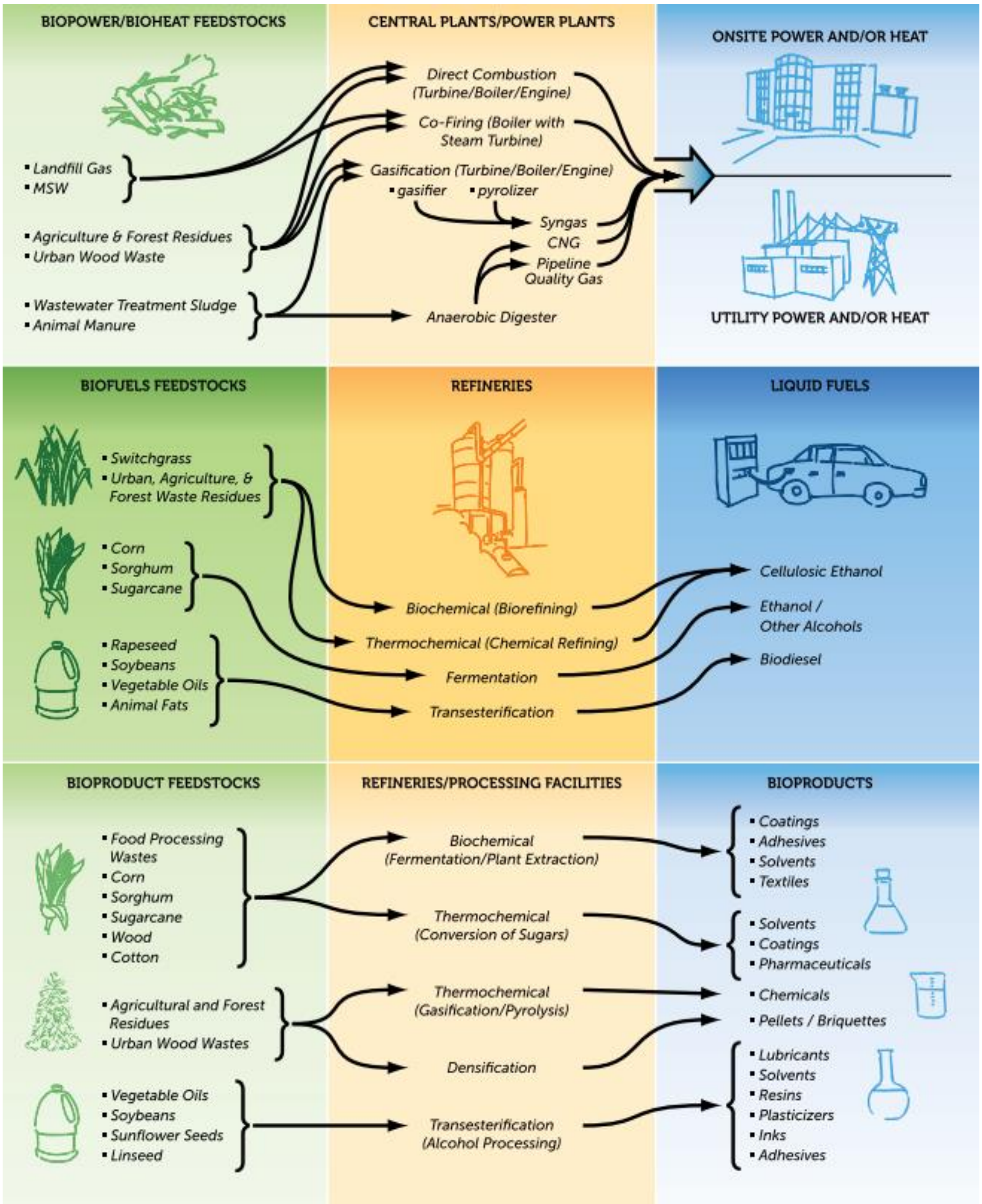

Figure 7: Conversion of biological feed-stocks into bioenergy (Source: EPA and NREL (2009))

Direct combustion technologies that can convert biomass into energy for heat, power, and CHP are widely utilized and commercially available for small- and medium-scale applications D. Peterson and Haase (2009). The maturity of solid-biomass gasification technology depends on how the system utilises the combustible gas produced. Systems that feed the gas directly into a boiler to produce steam for heat and power are generally viable and commercially available, but systems that require the gas to be cleaned and then used are less developed D. Peterson and Haase (2009).

Co-firing, landfill gas and anaerobic digestion systems (that decompose biological wastes by microorganisms which produces biogas) and anaerobic ponds are all commercially available, while meat processing residues are also used as a source of biogas used in practice EPA and NREL (2009).

Ultimately, from a bioenergy perspective, it is necessary to ascertain what resources are available and whether there are suitable available locations. This requires identifying what resources are theoretically available (e.g. manure, paunch waste, sludge). It is then necessary to consider what is technically available thereby limiting the theoretical potential by considering terrain limitations, land use and environmental considerations, collection inefficiencies, and social constraints A. Milbrandt and Uriarte (2012). Finally, economic conditions are applied which results in a subset of the technical potential accompanied by an estimate of the cost of biomass. This process is necessary for meat processors to undertake when considering what feedstock (and technologies) are appropriate.

6.5 Geothermal

Geothermal energy is highly location-specific requiring locally suitable environmental conditions. There are only two operating geothermal projects in Australia at present; a 1MWe pilot plant in the Cooper Basin in South Australia[4] and an 80 kW low temperature station in Birdsville in South West Queensland[5]. This is a developing technology, but for meat processors to consider it, there must be adequate local geothermal conditions that can be "tapped" into and sufficient available space for the generator to operate.

6.6 Hydro

Hydro is an established technology that also requires specific local conditions. Most suitable locations for large scale projects in Australia have been utilised though there is potential for smaller systems though they must compete for scarce water resources, and manage broader environmental factors GA and ABARES (2010). Pumped hydro storage is a potentially effective energy storage option for processors if local environmental conditions are suitable (e.g. 2 reservoirs, 1 at a higher altitude). Pumped storage can be used to run water back through turbines for generation. By using excess electricity generated when there is low demand to pump water into higher reservoirs, energy can be stored and released back into the lower storage in times of peak demand.

6.7 Marine Energy

This generally refers to wave and tidal power and are generally regarded as a developing technology with over 200 marine energy conversion devices proposed but only a few actually constructed and

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[4] http://www.geodynamics.com.au/Our-Projects/Innamincka-Deeps.aspx

[5] https://www.ergon.com.au/__data/assets/pdf_file/0008/4967/EGE0425-birdsville-geothermal-brochure-r3.pdf

suitable for demonstration or commercial testing in actual operating conditions CSIRO (2012). In any event, they are required to be located in the ocean and as such due to their location and limited development are unlikely to be suitable for meat processors, at least in the short term.

6.8 Storage

There are many different storage types which can be generally divided into the seven categories below.

1. Solar thermal – which refers to the storage of energy generated through the solar thermal process (i.e. solar thermal technologies). The cost of these types of technologies is inherently linked to the type of solar thermal technology because both share the heliostats, heat transfer fluid, generation unit and other shared components G. James and Hayward (2012).

2. Biomass storage - G. James and Hayward (2012) explain biomass storage as the ability to store various kinds of biomass (e.g. Crops, municipal solar waste, timber etc.) in solid form. However, they note that there is a difference between the use of biomass as a "tactical" storage source to meet the variable demands of an electricity system and the storage capacity necessary to ensure a continuous supply of feedstock to bioenergy generators.

3. Biogas storage – This is effectively storage of biogas (e.g. Methane) produced through either anaerobic digestion, or ponds (or similar), or through some kind of gasification, or methanation process commonly by converting biomass to a synthetic gas combining hydrogen and carbon monoxide, which is in turn converted to methane via a catalytic process G. James and Hayward (2012). Biogas storage tanks are commercially available.

4. Compressed air storage – this method stores pressurised air in containers (or vessels) and when released can be used to generate electricity via a turbine. Most existing storage systems of this type also combine the air with a gaseous fuel to assist with electricity generation G. James and Hayward (2012), though no-fuel alternatives also are being developed PNNL (2013). Compressed air has been contemplated in Australia and identified as a possible large scale network storage alternative, though it has limited deployment globally to date WorleyParsons and MMA (2011). It is commercially available Chen, Cong et al. (2009), but also a developing technology.

5. Batteries – There are many different types of batteries with varying levels of maturity. Nickel cadmium and lead acid batteries are both mature technologies, though technological improvements in efficiency continue (Chen, Cong et al. (2009), Koohi-Kamali, Tyagi et al. (2013)). **Error! Reference source not found.** shows the key benefits and limitations of the four main types of battery storage.

Table 3: Source: J.G. Levine and F.S. Barnes (2011)

	LEAD-ACID	NAS	LI ION	VANADIUM REDOX
CHEMISTRY:				
ANODE	Pb	Na	C	V2+ ⬄ V3+
CATHODE	PbO2	S	LiCoO2	V4+ ⬄ V5+
ELECTROLYTE	H2SO4	β-alumina	Organic solvent	H2SO4
CELL VOLTAGE:				
OPEN CIRCUIT	2.1	2.1	4.1	1.2
OPERATING	2.0 to 1.8	2.0 to 1.8	4.0 to 3.0	
SPECIFIC ENERGY AND ENERGY DENSITY:				
WH/KG	10 to 35	133 to 202	150	20 to 30
WH/L	50 to 90	285 to 345	400	30
DISCHARGE PROFILE	Flat	Flat	Sloping	Flat
SPECIFIC POWER (W/KG)	35 to 50	36 to 60	80 to 130	110
CYCLE LIFE (CYCLES)	200 to 700	2,500 to 4,500	1,000	12,000
ADVANTAGES	Low cost, good high rate	Potential low cost, high cycle life, high energy, good power density, high efficiency	High specific energy and energy density, low self-discharge, long cycle life	High energy, efficiency, and charge rate, low replacement cost
LIMITATIONS	Limited energy density, hydrogen evolution	Thermal management, safety, seal and freeze-thaw durabilities	Lower rate (compared to aqueous systems)	Cross mixing of electrolytes

Different sorts of batteries have different characteristics, and consequently, it is necessary to understand the type of use the storage system would be used for. Nevertheless, battery storage is increasing with a number of significant projects installations in Australia, including at The University of Queensland and in remote locations such as isolated cattle stations.

6. Fuel cells – This technology is in a development phase and is unlikely to be suitable for off-grid applications in the short term. Huang, Qi et al. (2011) note that the technology has now evolved to the pre-commercial stage with prototypes operating over 3000 h without significant voltage drop and costs being reduced to $700 per kW.

7. Flywheel storage – Flywheels are generally used in high power, short duration applications (e.g. 100s of kW/10 s of seconds) Díaz-González, Sumper et al. (2012). The most common application is to act as a smoother or bridge to shift from one power source to another and can be used in a hybrid configuration with stand-by generators such diesel generators Chen, Cong et al. (2009).

Energy storage is regarded as one of the potential solutions to challenges imposed by the use of variable renewable energy sources. Beaudin, Zareipour et al. (2010) reviewed technologies concluding that there was no single storage technology that would address the issue of variable generation, and that each challenge required consideration of the specific storage technologies' characteristics. Evans, Strezov et al. (2012) reviewed the potential for storage technologies in the utility context concluding that the choice of storage system depended on local requirements and that the best option may incorporate more than one storage system or technology. Mahlia, Saktisahdan et al. (2014) and Kousksou, Bruel et al. (2014) provide an assessment of the state of technology and installations for energy storage technologies. Energy storage provides an alternative to conventional supply backup, with the added potential of being able to smooth intermittent supply while enabling 24 hour electrification. The technologies exist, the challenges relate primarily to suitable control systems and cost, both of which are becoming more acceptable as technology maturity and deployment increases.

7.0 Renewable Energy in Context

In Australia, renewable energy has gained penetration across a range of technologies, particularly onshore wind (driven by large utility scale installations), solar PV (largely driven by solar home systems) and hydro (through many pre-existing projects). However, there is little domestic experience with off-grid systems powered entirely with renewable technologies, though there is limited (but increasing) experience with off-grid hybrid systems. The reasons for this are unclear, but appear to be a function of the historical cost and reliability of renewable and storage technologies for 24/7 electricity generation relative to their non-renewable counterparts, technological maturity, availability of commercial funding, and its relative "newness". Nevertheless, the technology does exist for entirely renewable off-grid systems.

A challenge for entirely renewable off-grid systems is that they remain relatively new, particularly in the commercial context. This can mean that commercial finance and funding can be expensive. Large scale renewable energy deployment that has occurred to date in Australia has generally received government support, with the exception of onshore wind installations. Islam, Mekhilef et al. (2013) noted (in the context of wind energy) that the adoption of new technologies starts slowly because they are usually expensive, unfamiliar and imperfect, then overtime the new technology becomes recognised as the superior one while the old technology becomes obsolete because of its inherent limitations. In the commercial off-grid context, this is doubly so as both the electrification model and the use of technology in that context is relatively new.

To date, most commercial renewable energy projects in Australia have benefited either directly or indirectly from some kind of government support or program. Overtime the level of support has been progressively reduced (or removed). While funding schemes remain at the State and Federal level the availability of government funds for off-grid renewable energy projects is increasingly limited. This is explored further in Section **Error! Reference source not found.**.

The technology for off-grid commercial businesses exists. Hybrid off-grid systems are reasonably established, though electronic control systems and hosting capacities continue to be developed. For example, Broome in Western Australia is a very large "off-grid" system in that it is not connected to a centralised electricity grid. The town is powered by gas turbines using LNG sourced via a virtual pipeline providing 61 MW of capacity increasing to 92 MW[6] over 20 years and also has PV installed, largely through small residential systems. Similarly, Thursday Island in Queensland is powered by a diesel-wind hybrid system with the wind turbines providing a combined annual output of up to 1.22 gigawatt hours depending on weather conditions (up to 10% of the total load)[7]. Many sugar mills across Australia (and globally) are off-grid during production season insofar as they use leftover cane pulp (bagasse) for electricity generation, for electricity generation and heating purposes. However, most mills export excess electricity to the grid and in that sense not off-grid. Further, they can only generate electricity during harvest season and consequently, tend to only generate electricity for up to 6 months of the year, with the remainder having to be sourced from the grid. Consequently, these mills cannot truly be regarded as "off-grid". Nevertheless, hybrid systems have been operating successfully for some time and reflect a compromise between off-setting relatively

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[6] http://www.energydevelopments.com.au/01_cms/details.asp?ID=92

[7] https://www.ergon.com.au/energy-conservation/what-are-we-doing/renewable-energy-sources

high local electricity costs and the need to provide reliable power 24/7.

The transition from a hybrid off-grid system to an entirely renewable system requires the replacement of the conventional base power source (generally gas or diesel) with renewable alternatives. Meat processors have an advantage over other commercial electricity consumers by being able to exploit processing by-product for generation purposes. This means that processors can reduce waste, increase business efficiency while simultaneously generating electricity. Previous analysis has shown that effluent ponds for methane capture is a feasible prospect and other waste (e.g. paunch waste) and by-product options may also be feasible depending on local characteristics (MLA (2011), AMPC (2013)). Waste water from meat processing has also been identified as an important potential source of energy Ombregt and Bambridge (2012). This in turn provides potential for a more diversified generation mix.

To date, most renewable off-grid systems are small having been developed for remote locations such as in the South Pacific. Apolima Island in Samoa is electrified via a 13.5kW solar PV system with no generator backup[8], two community mini-hydro schemes of 30 and 100 kW in Fiji[9] and others that have been met with mixed success throughout the pacific Dornan (2014). This mixed success has largely been a function of inadequate operation and maintenance (including battery replacement, and the capacity of rural communities to maintain off-grid systems, the migration of technicians away from rural communities (often to find employment using their new skills) Dornan (2014). Singh (2012) considered Pacific Island Nations and examined why the take up of renewables has been slow concluding that there was a need for effective institutional frameworks and available economic infrastructure. S. Bhattacharyya (2013) noted that in the South Asian off-grid (rural) context the most common renewable systems were micro-hydro and solar PV though biomass gasification has been used in India Ghosh, D Sagar et al. (2006) and Sri Lanka. Nepal also has significant renewable energy off-grid use, primarily micro-hydro and peltric sets (water powered turbine useful in mountainous areas) Yadoo, Gormally et al. (2011). In the rural context, even though different technologies have their advantages, the underlying principle for choice is predominantly motivated by adopting the least cost technology options and with minimum maintenance requirements as far as possible S. Bhattacharyya (2013). Battery storage has been found to be the technically weakest part in off-grid solar systems Ulsrud, Winther et al. (2011) and regarded as a creator of additional challenges for the operation of the solar mini-grids, including operational difficulties associated with proper battery use to maximise life S. Bhattacharyya (2013). (Deborah O'Connell, David Batten et al. (2007), Deborah O'Connell, Victoria Haritos et al. (2007)) examine biomass/biofuel research priorities for the Australian Rural Industries Research and Development Corporation and Rodriguez, May et al. (2011) conclude that biomass from agricultural residue is viable using feedstock with a plant gate cost of 46 Australian dollars per tonne under a renewable energy certificate price of $AUD 34 per MWh. CSIRO (2009) provides a comprehensive analysis of the potential for renewable distributed generation into the Australian electricity system concluding that there are both benefits and challenges likely to result. The Bushlight program articulated in Coull (2007) has been effective in developing and installing reliable solar PV with storage off-grid systems for remote indigenous communities.

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[8] http://www.mof.gov.ws/Portals/195/Energy/Samoa%20Energy%20Review%202011%20-%20Nov%2012.pdf

[9] http://www.fdoe.gov.fj/images/NEPReviewWorkPlan/fiji_se4all_report.pdf

There is significant evidence that renewable off-grid electrification is possible and achievable. The approach adopted by meat processors is likely to be similar in nature, though different in scale to rural experience. The technology exists, and as maturity increases costs will reduce and reliability increase. Many of the challenges associated with operation and maintenance in the remote community context are unlikely to be as significant due to experience operate complex machinery and processes and availability of skilled labour. The choice of technology in the rural off-grid literature has largely been a function of the availability of resources, cost and reliability. These are likely to remain key drivers of decisions for processors.

8.0 Government Policy

A challenge for entirely renewable off-grid systems is that they remain relatively new, particularly in the commercial context. This can mean that commercial finance and funding can be expensive. Large scale renewable energy deployment that has occurred to date in Australia has generally received government support, with the exception of onshore wind installations.

Renewable energy policy prior to the current federal government is discussed in (Byrnes, Brown et al. (2013)). Many of the key measures designed to incentivise renewable energy deployment, including the Carbon Pollution Reduction Scheme, the Australian Renewable Energy Agency and the Clean Energy Finance Corporation have an uncertain future given the federal government's apparent commitment to their disbandment and the need for political deals with cross-benchers. The Clean Technology Food and Foundries Investment Program, a potential grant source directly relevant to processors has been closed. The closure of the CEFC may make sourcing funding for off-grid renewables more difficult as it has played a role in helping to familiarise traditional lenders with renewables projects. In addition, the renewable energy target is currently under review. This is an important policy scheme from a deployment perspective as it provides incentives via tradeable certificates for renewable energy deployed. It is unclear what the future of the scheme will be, but its closure or restructure has the potential to increase project costs not insignificantly. A new Energy White Paper is being prepared which will outline the current federal government's view of the future of Energy in Australia. In the absence of this document it is difficult to identify whether processors considering off-grid deployment will receive any support at the Commonwealth level. At best, the future of government support is uncertain.

While funding schemes remain at the State and Federal level the availability of government funds for off-grid renewable energy projects is increasingly limited. Consequently, the prospect of government assistance is uncertain and the schemes that have previously driven renewable energy deployment in the commercial context are declining, or being wound up. Conversely, assistance remains for some non-renewable generators (such as diesel generators in remote locations benefiting from excise exemptions). Nevertheless, it does provide a major advantage over non-renewable sources in that it exploits available resources (including waste) while helping to insulate processors from electricity tariff and/or generation input cost variability.

Methods for recovering energy from abattoir and slaughterhouse waste streams

In broad terms, the subject of recovery of energy from organic solids and wastewater treatment has been quite well researched. In regard to the research relating directly to the more specific area relating to the recovery of energy from abattoir wastes, this literature is considerably scarcer. There are several reviews of the literature relating to various technologies used for waste to energy (WtE) systems. The reader is directed to several reviews for more detailed information relating to these technologies:

- Direct combustion (Abuelnuor et al. 2014, Van Caneghem et al. 2012),
- Co-firing with a second substrate (e.g. pulverized coal)(Tchapda and Pisupati 2014),
- Gasification (i.e. gasifier or pyrolysis)(Stafford et al. 2013),
- Anaerobic Digestion (Balat 2008).

The opportunities in regard to abattoir wastes are limited to those technologies where the substrates fit the requirements of the technology. As with any industrial process the characteristics of the waste stream must be taken into account when assessing the most appropriate technology for the waste. There are a range of factors that need to be considered in regard to process selection. These include:

- Moisture content of the waste substrate (% Total solids)
- Heating value (MJ/kg)
- Temporal regularity of supply (per day/month/season)
- Fuel feed handling characteristics (solid/liquid/granular/fibrous)
- Solid wastes and toxic off-gas management.

Selecting the WtE process suited for abattoir wastes is best done via a high level overview of those technologies and their substrate requirements and then comparing these to the characteristics of the available waste substrate streams. Table and

Table present these high level overviews of the WtE technologies and the wastes under assessment.

Table 4: Waste to energy processes and the characteristics generally required from the substrate wastes being processed (Van Caneghem et al. 2012, Tchapda and Pisupati 2014, Stafford et al. 2013, Tumuluru et al. 2011, Kumar et al. 2009, McCabe et al. 2014).

TECHNOLOGY TYPE	EFFICIENCY (%)	DEGREE OF WASTE REDUCTION	OUTPUTS REQUIRING FURTHER MANAGEMENT	NOTES
Direct Combustion (Incineration)	15-35% (Electricity only) 85% (Elec. and heat)	95-96%	Ash	Emits toxic gases that need managing/scrubbing. Requires low moisture content feed.
Co-firing	18 - 22%		Ash, Tar	Requires a second substrate, coal, methane, natural gas. Biomass moisture content should be less than 50% to increase energy efficiency.
Gasification	25 - 35 %	85-92%	Ash, hydrocarbon oils and char	First step is dehydration of substrate, preferably substrates less than 10% moisture. Emits many toxic gases that need managing/scrubbing
Anaerobic Digestion	30 - 85% degradation to CH4. Electricity generation	40 - 100%	Anaerobic sludge, leachate (high in nutrient)	Moisture content of feed is not an issue. Least toxic off-gasses. Nutrient reclamation possible.

	dependent upon generator			

The gasification technology is a multi-step process that can utilise a range of different biomass substrates (Figure 8).

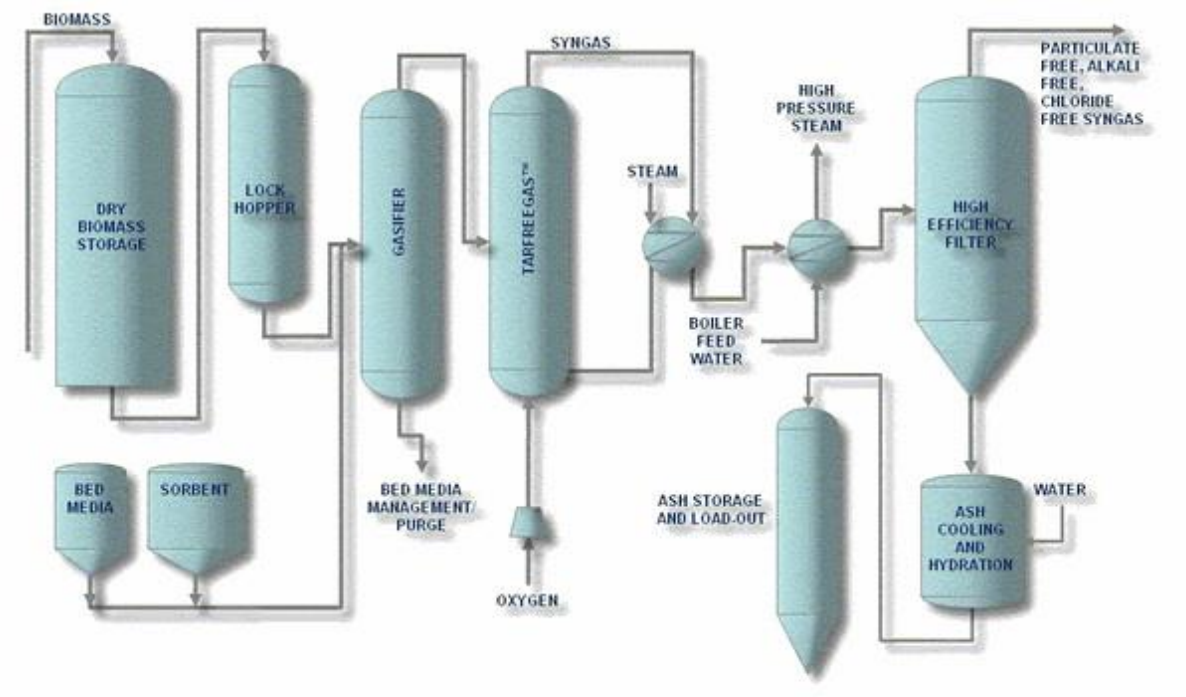

Figure 8: A process flow diagram for a gasification system. (Frontline BioEnergy LLC 2014)

Table 5: The characteristics of the organic waste streams of an abattoir (Hofmeier 2007, Johns 2011, AMPC 2014)

	TYPICAL QUANTITY (KG/T HSCW)	RANGE (KG/T HSCW)	WASTE STREAM STRENGTH (TCOD1 - MG/L)	SOURCE
Manure (cattle)	10/day	4 - 13	--	Cattle yards
Manure (sheep)	9/day	5 - 12	--	Sheep pens
Manure (lambs)	5/day	3 - 7	--	Lamb pens
Manure (Truck wash)		1 - 5	1,880	Truck wash
Paunch contents	45	25 - 70	55,000	Paunch emptying and washing
Gut Contents		15 - 30	6,500	Mechanical gut cutting
Solids from Primary Treatment		150 - 300	9,245	Screening, DAF float, bottom solids
Biological sludge from wastewater treatment	135	70 - 200		Waste activated sludge (10 - 15 % solids)
Wastewater (untreated)	10,400 L/ t HSCW			Abattoir site

[1] - TCOD = Total Chemical Oxygen Demand

Taking into consideration the state of the commercially viable waste to energy technologies, and the fact that three of them require waste streams with a high solid content/ low moisture content, the most suitable technology for the treatment of abattoir/slaughterhouse facility wastes is anaerobic digestion. This is clearly recognised to date by the industry itself as the most cost effective method for reducing organics and solids in the wastewater stream. Although treatment with anaerobic digestion is well recognised, the use of WtE systems using biogas from this process is less recognised and needs further validation (AMPC 2014).

8.1 Recovering Energy from Organic Solids and Wastewater via Anaerobic Digestion

Treating of wastewaters from abattoirs and slaughterhouses has previously been discussed by various authors, highlighting the need for treatment units such as facultative and polishing ponds, and in the instance where solids content is high, the waste stream should have primary treatment in an anaerobic pond (Green 1992, Husband 1992, Masse and Masse 2000, Lopez-Lopez et al. 2010). The advantages and disadvantages related to anaerobic digestion are presented in Table .

Table 6: The advantages and disadvantages relating to the use of an anaerobic step in the treatment of wastewater (Tchobanoglous et al. 2004, Tritt and Schuchardt 1992)

ADVANTAGES	• Lower requirement for energy to treat wastewater/solids • Reduced production of biological sludge • Nutrient addition reduced • Production of biogas cf. methane (CH_4) • Volume of reactor is smaller • Over time most organics can be transformed • Responds quickly to new influent after extended periods of non-feeding • Nutrient release
DISADVANTAGES	• Biomass growth is slow and start-up time can be extended. Inoculation from another reactor/pond can overcome this • pH control and alkalinity addition can be necessary • Aerobic polishing is necessary to meet discharge requirements • Biological nutrient removal must occur in a subsequent step • Performance is poor during low temperatures • Presence of toxic substances can be problematic • Odours and corrosive gases can be problematic depending on site and waste influent

Anaerobic digestion is considered to be a non-thermal WtE system that is ideally suited to treating wastewater streams with high organic loads, high water volumes and also allows for nutrient recovery options during downstream processing. The major benefit, relevant to this review, of treating wastewater anaerobically is that the biological processes involved in breaking down the solid and dissolved carbon wastes release biogas during the process.

The simplified equation is:

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$$

This biogas contains between 60 - 70% CH_4 and 30 - 40% CO_2. The captured methane can be utilised to generate heat, steam, electricity or a combination of these.

The other notable benefit related to this process is that due to the breakdown of the solid matter, the downstream energy requirements for final treatment of the wastewater before they are released are greatly reduced. Whilst noting that anaerobic digestion is described as a non-thermal process, the performance of the process is enhanced through the use of reactor heating from ambient temperatures up to mesophilic (30 to 38 °C) or thermophilic temperatures (49 to 57 °C) (McCarty 1964). The benefits gained from having a higher temperature for anaerobic digestion can be facilitated through the use of heat produced during the generation of electricity using a combined heat and power (CHP) generation system that returns some of the heat produced back to the digestion reactors. There are also small gains to be made from the hot effluent stream of an abattoir wastewater as this is, in contrast to many other types of waste streams, often received into the anaerobic digestor at a temperature around 35 to 37 °C (Pittaway 2011).

8.1.1 Covered Anaerobic Lagoons

The design and operation parameters for an anaerobic lagoon or pond in an abattoir have previously been specified as:

- Organics loading rate (50 to 80 g BOD5/m^3/day)
- Hydraulic Retention Time - (HRT - 20 - 40 days)
- Sludge (Solids) Residence Time (SRT - 20 - 50 days)
- Length to breadth ratio - 3 : 1
- Depth – 3.0 – 5.0 metres
- Minimum free board - 0.5 metres
- Internal slope - 2:1 - 3:1 (soil type dependent)
- Some mixing within the pond, lagoon or anaerobic tank is preferable
- Temperature (> 15°C - 65°C)
- pH (6.0 - 7.5).

To facilitate the recovery and utilisation of energy, from biogas, an anaerobic pond should be covered, and this is often referred to as a Covered Anaerobic Pond (CAP) or Covered Anaerobic Lagoon (CAL). As well as ensuring the energy recovery, the cover provides the added benefit of odour reduction. The operation of the CAL can be simplistic, involving no stirring (Figure 9), or higher throughput and improved treatment is attainable with a stirred system (Figure 10).

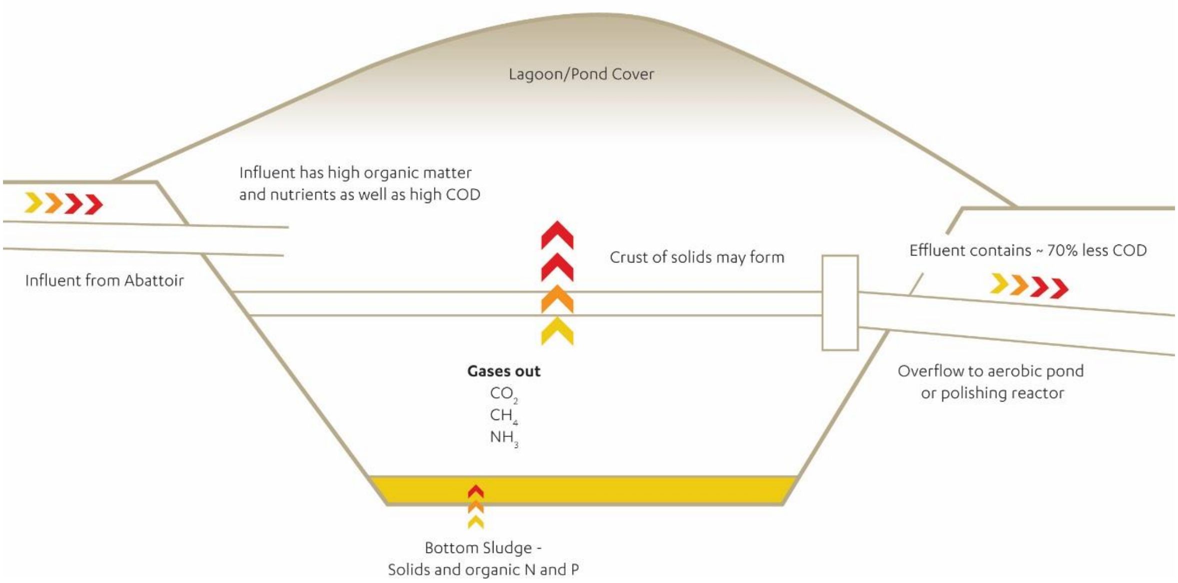

Figure 9: Schematic of a covered anaerobic lagoon process without stirring

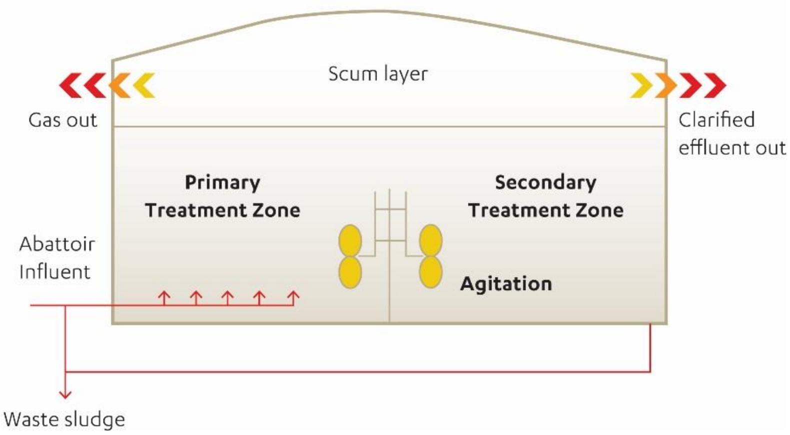

Figure 10: Schematic of a covered anaerobic lagoon process with the facility for stirring and improved treatment

In terms of scale, the CAL can be quite large (60 - 100 m long), where management of the biogas inventory is necessary to ensure the mass storage of biogas on site does not become a safety issue (Figure).

Figure 11: An example of a covered anaerobic pond (Anonymous 2010)

Good design and management of the CAL is important as performance and gas production can be variable and the anaerobic processes can under -perform from the expected levels. For example, in a five pond system at the Churchill Abattoir in Queensland, treating abattoir wastewater with an influent strength of 7,442 mg COD/L and a flow rate of 503 m3/day, the total COD removal from the system was between 72 and 83% efficient. These researchers used BioWin (a Windows based simulation programme) to simulate the performance of the lagoon system. By adjusting the layout of the ponds and adding an effluent clarification step, where clarifier sludge was returned to the inlet of the system, the BioWin programme estimated a >74% improvement in biogas productivity (McCabe et al. 2014).

8.1.2 Anaerobic Reactor Systems

Other researchers have investigated the options for improving the productivity of anaerobic digestion of slaughterhouse waste. The pre-treatment of solid organic waste was tested prior to using a two-stage anaerobic digestion system. The options trialed were:

- Mechanical pre-treatment. Consisting of grinding (disintegrating) solid particles in the substrates, as this process releases the cell compounds, resulting in the specific surface area of the particles increasing and means that anaerobic bacteria and archaea have a better contact with the substrate.

- Thermal pre-treatment. Considered as either low (i.e. < 110 °C) or high (i.e. > 110 °C) thermal treatment, can improve biogas productivity by disrupting cell membranes, resulting in solubilisation of cellular organic compounds. The literature suggests that low temperature pre-treatment has a range of benefits, including pathogen reduction, whereas high temperature pre-treatment can reduce biogas production due to formation of undesirable compounds (e.g. melanoidins (Liu et al. 2012)

- Chemical pre-treatment. Can be in the form of an acid, alkali or oxidative treatment. Alkali methods are generally preferred leading up to anaerobic digestion processes (Li et al. 2012), but do have the disadvantage of requiring additional chemical use.
- Biological pre-treatment. The options available include added anaerobic steps, aerobic treatment, and the use of specific enzymes such as peptidase, lipase or carbohydrolase. The addition of such enzymes will add costs to the treatment process. Added anaerobic treatment can be considered to be a pre-treatment, or equally can be argued to be part of the anaerobic digestion process (Ariunbaatar et al. 2014, Ge et al. 2010).

Determining which of the pre-treatment methods improved biogas productivity has not been done in a step-wise study, comparing all pre-treatment options on the same waste stream, but via a review of literature and the results presented, Ariunbataatar et al. (2014) considered that thermal treatment at low (i.e. < 110 °C) temperatures in association with a two-stage anaerobic digestion system resulted in the most cost-effective process, and there are also opportunities for nutrient recovery (Carrère et al. 2010).

As mentioned above, the two-stage anaerobic digestion process can arguably be considered as a pre-treatment or two separate processes of the anaerobic digestion system. Whilst there has previously been considerable research on the different arrangements of two stage anaerobic digestion, the system in most common use is an arrangement where the first stage has reactor has a smaller volume than the second reactor, and therefore a lower hydraulic residence time (HRT). The first reactor is also operated within the thermophilic range and acts as an acidogenic/acetogenic reactor enhancing the hydrolysis of the substrates, and the second reactor is operated in the mesophilic range and operates as a methanogenic reactor for the production of methane (Ariunbaatar et al. 2014, Ge et al. 2010, Park et al. 2008, Houbron et al. 2003). Figure 12 is a simplified schematic of the two stage anaerobic digestion system.

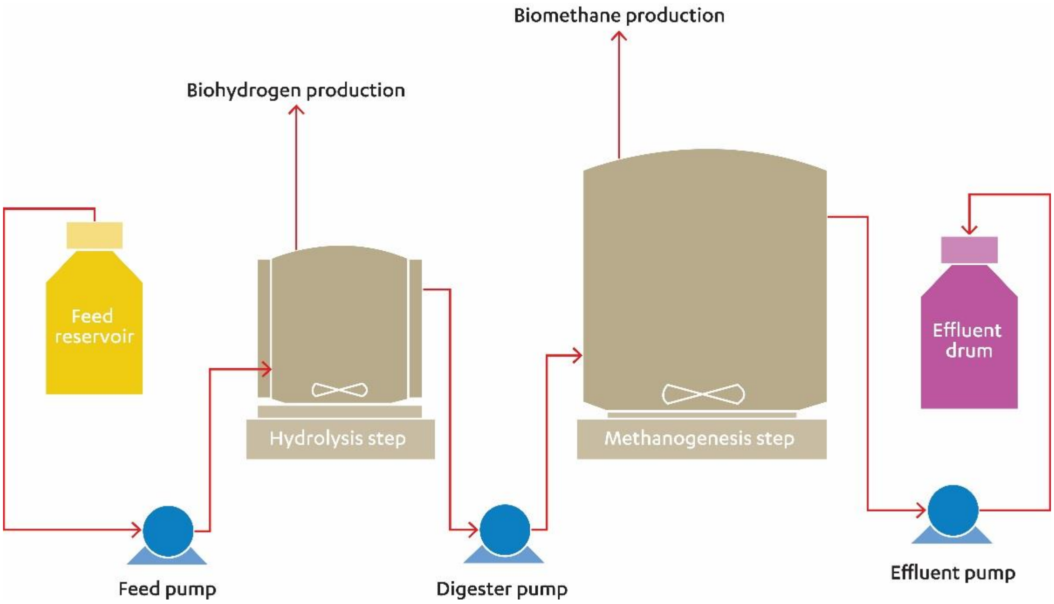

Figure 12: A simplified schematic of the two stage anaerobic digestion process. Adapted from Ge et al. (2010).

A recent study has added another option to the pre-treatment train process. One of the conventional methodologies for treatment of abattoir wastewater is for there to be a long sludge retention time (SRT) in the activated sludge reactor which aerobically treats wastewater (Sampson et al. 2005, Mittal 2006). As a function of this design, the footprint and energy demand of such a system is large due to the volumes of wastewater being managed. In a novel set up, influent wastewater was treated in a high-rate sequencing batch reactor (SBR) with both a short HRT and short SRT. Whilst this process reduced the COD concentration of the effluent by >80%, the majority (70 - 80%) of the COD was not oxidised, instead being assimilated or accumulated in the activated sludge biomass. The anaerobic degradability of the waste activated sludge with a long SRT is usually poor (Gossett and Belser 1982). This occurrence was also demonstrated in the research with the high-rate SBR, where degradability reduced with sludge age - 85% at 2 days SRT, 73% at 3 days and 63% at 4 days, showing a decrease in degradability of about 10% per day of SRT. Despite this being the case, the degree of degradability in the high-rate SBR was far better than from reactors with a longer sludge age. The high-rate SBR system offers multiple benefits that make it well worth considering in a scenario where energy savings and recovery are being considered. Firstly there is the large energy savings achieved through the size reduction of the reactor for the high-rate SBR process. There is also the retention of the COD present in the wastewater as biomass, rather than having this COD oxidised. The final recognisable benefits are the higher degree of anaerobic degradability and therefore increased methane production. Overall it is likely that such a system will improve the net energy production of an abattoir wastewater treatment process (Ge et al. 2013).

The next step in an analysis of the potential for recovering energy from a waste stream, using anaerobic digestion, is to consider the degree to which a wastewater stream can be transformed into methane. The literature is limited in regard to the number of studies completed upon abattoir wastewater, but there are sufficient to allow for informed calculations to be made. Table 6 presents a collation of results from anaerobic digestion literature, treating an abattoir wastewater or solid waste. This data can be utilised to estimate the methane productivity when utilising a covered anaerobic lagoon/pond or an anaerobic reactor similar to the types described above. Methane productivity is most usually presented as the volume of methane produced per mass of volatile solids digested. The units for this are mL CH_4 /g VS or the equivalent measure (L CH_4 /kg VS, m^3 CH_4 /t VS).

Table 7: Summary of results from literature in regard to the methane production from different abattoir waste streams and types of treatment.

WASTEWATER TYPE	CONCENTRATION /LOADING RATE	TREATMENT TYPE	METHANE YIELD	SOURCE
Cattle wash		BMP[1] (160 mL bottles)	199 - 283 (m3 CH4/t VS)	(Jensen and Batstone 2012)
Paunch Liquid			244 - 586 (m3 CH4/t VS)	
Paunch, Tripe, Green Wash			430 - 542 (m3 CH4/t VS)	
Kill Floor			470 - 476 (m3 CH4/t VS)	
Tripe Wash			718 - 858 (m3 CH4/t VS)	
Saveall Effluent			547 - 832 (m3 CH4/t VS)	
New Render			652 - 834 (m3 CH4/t VS)	
Total Effluent Cold			702 (m3 CH4/t VS)	
Total Effluent Hot			733 (m3 CH4/t VS)	
Total Wastewater			657 (m3 CH4/t VS)	
Paunch Solids			253 - 325 (m3 CH4/t VS)	
Cattle manure	3 g VS /L/day	68 °C then 55 °C (Lab scale)	260 (mL CH4/g VS)	(Nielsen et al. 2004)
Unscreened dairy manure	5 g VS/L/day	Two stage anaerobic digestion (Lab scale)	149 (mL CH4/g VS)	(Demirer and Chen 2005)
Mixed abattoir waste	3.6 kg TS/m3/day	Two stage anaerobic digestion	270 (L CH4/kg TS)	(Banks and Wang 1999)
Fresh cattle manure (feedlot)		BMP[1] (160 mL bottles)	350 (mL CH4/g VS)	(Gopalan et al. 2013)
Slaughterhouse wastewater	16.5 kg COD/m3/day	Anaerobic Filter	411 (mL CH4/g COD)	(Lopez-Lopez et al. 2010)

[1] Data from biochemical methane potential (BMP) tests.

Methods for Calculation of Resources

From the results presented above, an analysis of different wastewater and solid waste streams can be achieved to calculate the available energy. An additional consideration required in such an analysis is to state the parameters to be used for calculations in regard to the conversion of biogas, containing methane, and the types of energy (heat, electricity) that can be recovered, and at what efficiencies. Methane has an energy content of 37 MJ/m^3 (Green and Ackers 2008), whilst noting that biogas usually has a methane content of 50 - 65%, the analysis being presented in this report is only considering the direct use of the methane. In regard to the calculation of the volumes of methane produced, the findings from the report produced by Jensen *et al.* (2012) will be used. The justification is that the data for this report was generated from slaughterhouses in Australia, and the report was published by Meat & Livestock Australia. For this reason it is considered to be the most applicable to the forward projections in the current report. An assessment of the data presented in the above report has provided average values for methane production per kilolitre of wastewater and tonne of paunch solid. These values are 6.43 m^3 CH_4/kL and 35.13 m^3 CH_4/tonne, respectively. The conversion of energy from megajoules to kilowatt hours is the standard value of 1 kWh = 3.6 MJ, or alternatively = 0.2778 kWh/MJ. The efficiency of a generator system has been assumed to be 35%, with 50% of the energy recoverable as heat (de Mes et al. 2003).

Assessment of Three Sites for Energy Recovery Potential

A summary of the relevant raw data to be analysed for this report in regard to wastewater and solid waste (paunch waste and manure) requiring treatment is presented in Table 8. The three AMPC member sites who provided at the data have been classed as 'Small', 'Medium' and 'Large'.

Table 8: A summary of the raw data to be analysed in regard to operational timeframes and wastewater and solid waste loadings for three abattoirs.

	SMALL	MEDIUM		LARGE
		ABATTOIR	FEEDLOT	
Variable	tHSCW processed per year			
Beef (tHSCW/yr)	1,620	43,965	53,3331	94,000
Sheep (tHSCW/yr)	3,800			
Pig (tHSCW/yr)	960			
	Operating Hours			
Hours/day	9	20	24	16
Days/week	4	7	7	5
Weeks/year	50	48	48	48
Operating (d/year)	200	240	336	240
	Wastewater generated			
Wastewater (ML/yr)	1.6	917.6		554.4
Water Efficiency (kL/tHSCW)	0.25	20.87	-	5.90
	Paunch Waste generated			
Cattle (t/yr)	28.7	3,480		4,230

Sheep (t/yr)	7			
Pigs (t/yr)	4.7			
Manure (t/yr)			100,564	

[1] - The number of head held in the feedlot at any one time.

There is generally a high degree of variability in regard to the mass flow (kL/hr) and the concentration of pollutants/contamination (mg/L) in wastewater streams, both within an abattoir site and between sites as well. The reader is directed to the reports of Johns (2011) and Jensen et al. (2012) for further reading and consideration in this regard. Taking this into consideration there is recognised value in undertaking an assessment of any specific site being considered for a WtE installation, as the type, scale and efficacy of an anaerobic digestion installation will be directly related to which waste streams are to be treated. Without this in-depth information being available for the current report, the calculated values are derived from the data presented in the reports previously cited. An example of how a more in-depth site analysis can benefit the overall design is presented in Figure 9 where the various waste streams had been assessed for mass flow and pollutant concentration before being assigned to a specific treatment process.

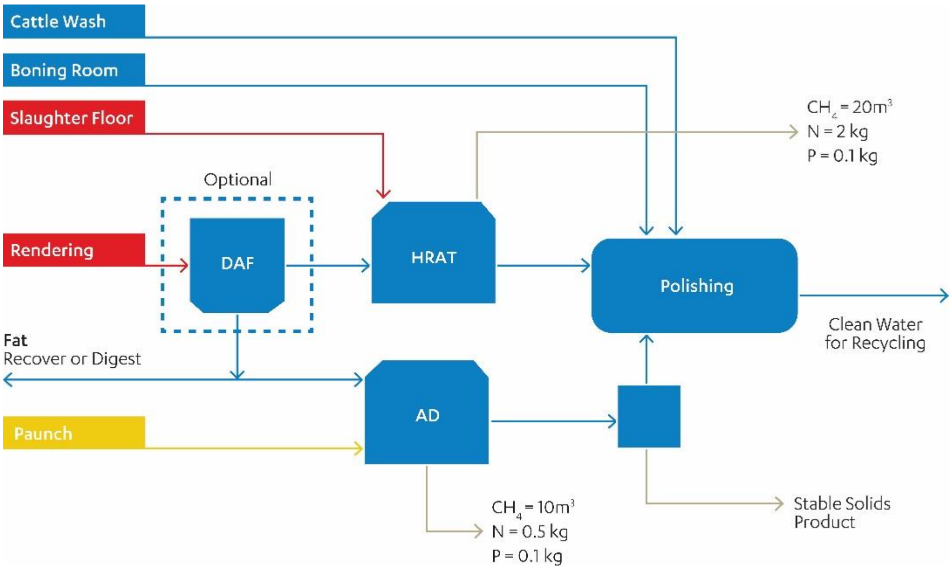

Figure 13: A proposed treatment train for the potential recovery of energy and nutrients (Jensen and Batstone 2012)

Assessing the data presented in Table 8 for its waste to energy conversion potential and incorporating the conversion factors presented in

Table , the potential energy recovery values are presented in

Table . As well as presenting the WtE values from the abattoir waste streams, being the wastewater and paunch waste solids, the WtE opportunity of the manure stream from the feedlot has been assessed.

Table 9: Summary of the potentially recoverable energy from the waste streams at three abattoirs and a feedlot.

	SMALL	MEDIUM		LARGE
	ABATTOIR	ABATTOIR	FEEDLOT	ABATTOIR
Wastewater Generated (ML/yr)	1.6	917.6		554.4
Paunch Generated (t/yr)	40	3,480		4,230
Manure Generated in pens (t/yr)	55	440	37,763	940
Wastewater (kL/day)	8	3,823		1,650
Paunch solids (kg/day)	202	14,500		12,589
Manure in yards (kg/day)	276	1,832	112,390	2,798
Methane from Wastewater (m3 CH4/day)	27	12,753		5,504
Methane from Paunch solids (m3 CH4/day)	6.4	459		398
Methane from manure in yards (m3 CH4/day)	83	550	33,717	839
Total methane produced (m3 CH4/day)	116	13,761	33,717	6,741
	Recoverable Energy as Electricity and Heat			
Energy available from methane (MJ/day)	4,302	509,158	1,247,526	249,419
Electricity Produced (MWh/day)	0.42	50	121	24
Heat Energy Produced from methane (MWh/day)	0.5975	71	173	35

These results are in reasonable agreement with previous assessments into recoverable energy opportunities at abattoirs. In an assessment of three abattoirs that had wastewater flows of 2,423 kL/day, 3,153 kL/day and 2,115 kL/day, the potential energy production from wastewater for these sites were reported as 42, 37 and 20 MWh/day respectively (Jensen and Batstone 2012).

The notable variances in the values presented in this report relate to the following data. For the feedlot associated with the medium abattoir, a value of 44,427 t/yr was provided for solid waste from the feedlot and the abattoir, an assumption was provided that 10% (4,427 t/yr) of this value was paunch waste (abattoir), 5% (2,213 t/yr) was 'downers' and 85% (37,762 t/yr) was the manure produced in the feedlot. Separate to the value of 4,427 t/yr for paunch waste, a separate value of 3,480 t/yr was also provided for paunch waste for the medium abattoir and this is the value that was used, but it does give reason to have caution over the mass balances for this site as some values conflict. No values were provided for the manure from the pens at the abattoirs, so these were estimated based on the tHSCW/yr data provided and the literature available (Sampson et al. 2005).

Additional data was provided in regard to the manure from the feedlot, identifying that there was also a stream of feedlot manure that was composted - 100,564 t/yr. This manure was not included in the tabulated calculations, as it was stated that the stream was composted. If however this manure was collected and anaerobically digested then this concentrated waste stream constitutes a considerable opportunity to recover more energy, particularly if the manure is recovered and digested within a short period (up to 3 weeks), rather than stockpiling the manure to be treated (up to 8 weeks or more), because the greatest methane potential is lost in instances where long storage occurs (Gopalan et al. 2013). This feedlot manure was assessed to have an electricity production potential of 323 MWh/day and a further 460 MWh/day of heat energy if collection and anaerobic digestion occurred without storage.

The levels of efficiency in regard to water usage are noticeably variable, although both sites are within the industry values previously reported (5.6 - 22 kL/tHSCW) (Johns 2011, Tritt and Schuchardt 1992, Mittal 2004). The "Medium" site used, on average, 21 kL/tHSCW, whilst the "Large" abattoir was more economical, at 6 kL/tHSCW. These differences in wastewater production are a good example of why caution is needed in interpreting recoverable energy potential for a site. The recoverable energy potential is calculated from several values, including one derived from the volume of wastewater production on site, along with values from literature in regard to the volume of methane produced per kilolitre of wastewater. Therefore, the final results for volume of methane produced do relate to the volume of wastewater. Equally, it is logical to assume that a site that processes more Head per year will have a greater mass of solid waste to treat and the recoverable energy will be greater. If however the water efficiencies of the two sites are different, then the final calculated values will be different, as is the case in this report, and for this reason some degree of caution is warranted in regard to the WtE potentials.

Summary of Available Energy Resources through the use of Anaerobic Digestion

Anaerobic digestion has been identified as the most suitable waste to energy technology available for both an abattoir and a feedlot system. The main reasoning behind this is the high moisture content of the waste streams, as well as the pragmatism of utilising one technology for the entire site, thereby reducing the complexity of the energy recovery and conversion systems that would be installed on a site.

From the data provided for the three abattoirs, of differing sizes, and the one feedlot, the potential for recoverable energy was found to have a wide range. The "Small" site was assessed to have the potential to produce one MWh/day, but caution is needed in regard to this value as the greater number of Head processed at this site are sheep and pigs, which will have an effect on the mass of solid waste per tHSCW. The "Medium" abattoir and feedlot are estimated to have a WtE value of 415 MWh/day for the combined waste streams. If the extra feedlot manure that is currently composted was digested as well this would add a further 783 MWh/day to the "Medium" site.

The "Large" site was assessed to have a recoverable energy potential of 59 MWh/day. This value is obviously at considerable variance to the value for the "Medium" site, but for the reasons given above in regard to wastewater production, this result will have been skewed downward, and so a more specific site assessment will elucidate a more accurate value.

The potential electricity produced at each site makes up 42% of the recoverable energy, with the remainder being recovered as heat, assuming a combined heat and power (CHP) system is utilised for burning the methane.

Without a detailed and site specific analysis of the various waste streams of any individual site, the values presented for each of the sites reviewed are indicative only, but do demonstrate that a valuable opportunity does exist to recover energy at each site.

9.0 Regulation

The regulatory environment governing renewable energy industry in Australia has primarily been left to Local and State Government on environmental matters and to distribution companies on electricity generation matters.

The major regulatory hurdle with renewable energy systems is getting a connection agreement with the local distribution company. There is no regulatory system in place and the agreements will vary between distribution companies as well as location within a given distribution company's area. Dependent on the technology employed additional requirements may be required to ensure that voltage stability is maintained within the network – irrespective of whether there is the possibility of export or not.

Whilst some distribution companies have been privatised, the majority are still State Government owned. Distribution companies still have major concerns with intermittent renewable energy technologies and in some instances have required that the ability to take a customer's full peak load from the grid be maintained, ignoring any on-site generation. As noted above, this process will be by negotiation with the relevant distribution company and there are currently no national rules, however will impact on the ability to take a processing facility off-grid.

10.0 Conclusion

Whilst it is technically possible to taking a red meat processing facility off-grid, there are a number of site specific variables that need to be considered. This study provides a number of options which should be considered, with all, reducing the amount of reliance upon traditional fossil fuel based energy supplies. It should also be noted that all systems are designed site specific, utilising those resources that are most economically available for that site. Whilst some estimates have been provided for solar PV systems, other systems that may be utilized have not reached deployment levels to provide sound financial estimates.

It is recommended that further studies be considered using actual case studies which would look into actual land available, electricity and energy needs based upon time-of use and other opportunity's that may flow from anaerobic reactors (such as growing algae). This would also provide the opportunity in conjunction with equipment manufacturers to undertake economic feasibility studies on small, medium and large systems.

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