A Bio-energy Roadmap for South Australia

RENEWABLES SA

Jacobs Report

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Contents

Abbreviations **4**
Executive Summary **6**
1. The Current Landscape **10**
1.1 Introduction 10
1.2 Solid Biomass 10
1.2.1 Common Solid Biomass Feedstocks 10
1.2.2 Utilisation of Solid Biomass 11
1.3 Gaseous Bio-fuels 21
1.3.1 Common Gaseous Bio-fuel Feedstocks 21
1.3.2 Utilisation of Gaseous Bio-fuels 22
1.4 Liquid Bio-fuels 28
1.4.1 Common Liquid Bio-fuels 28
1.4.2 Utilisation of Liquid Bio-fuels 29
1.5 Global Bio-energy Landscape 35
1.6 Australian and South Australian Bio-energy Landscape 35
1.6.1 South Australian Bio-energy Political Landscape 35
2. Bio-energy Material Sources in South Australia **37**
2.1 Relevant Materials 37
2.1.1 Existing Feedstocks 37
2.1.2 Purpose Grown Biomass Feedstocks 41
2.2 Quantities and Geographical Origins 47
3. Bio-energy Demand Sources in South Australia **57**
4. Logistical Factors Influencing Bio-energy Projects in South Australia **68**
5. Technological Factors Influencing Bio-energy Projects in South Australia **69**
5.1 Introduction 69
5.2 Council Green Waste 69
5.3 Residual Municipal Solid Waste 71
5.4 Forestry and Sawmill Residues Project 73
5.5 High Moisture Content Organic Feedstock Project 74
5.6 Straw Feedstock Project 76
5.7 Indicative Small Scale Heating Project 78
5.8 Indicative Bio-methane Upgrading Project 80
5.9 Algae Production for Bio-fuels 81
6. Areas of Opportunity for South Australia **83**
6.1 Existing Feedstocks 83
6.2 Purpose Grown Biomass Crops 88
7. Conclusions and Recommendations **92**

Appendix A. GIS User Guide

Appendix B. References

B.1 GIS Maps

B.2 Report

Abbreviations

Abbreviation	Full name
A$	Australian dollars
AD	Anaerobic digestion
Bn	Billion
Bxx	Xx% blend of biodiesel and mineral diesel
C&I	Commercial and industrial
CAPEX	Capital expenditure
CGGW	Council generated green waste
CH_4	Methane
CHP	Combine heat and power
CNG	Compressed natural gas
CO_2	Carbon dioxide
COD	Chemical oxygen demand
Cogen	Cogeneration
EfW	Energy from waste
EPC	Engineer, procure, construct contract
EU	European Union
Exx	Xx% blend of ethanol and petrol
GJ	Gigajoule
GWh	Gigawatt hours
h	Hour
HHV	Higher heating value
Jacobs	Jacobs Group (Australia) Ltd
k	Kilo
Kraft	Kraft pulping process
kT	Kilo tonnes
kW	Kilowatt
kWh	Kilowatt hours
L	Litre
LHV	Lower heating value
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas

Abbreviation	Full name
m^3	Cubic metre
M	Million
MBT	Mechanical biological treatment
MJ/kg	Megajoules per kilogram
MJ/Nm^3	Megajoules per normalise cubic metre
ML	Megalitre
MSW	Municipal solid waste
MW, MWe, MWth	Megawatt, megawatt electrical, megawatt thermal
NG	Natural gas
Nm^3/h	Normalised cubic meter per hour
NSW	New South Wales
º C	Degree Celsius
OPEX	Operational expenditure
ORC	Organic Rankine cycle
QLD	Queensland
RDF	Refuse derived fuel
RE	Renewable energy
RET	Renewable energy target
SA	South Australia
SRF	Solid recovered fuel
t	Tonne
Tas	Tasmania
tpa	Tonnes per annum
tph	Tonnes per hour
Vic	Victoria
WA	Western Australia
y	Year

Executive Summary

Objective

South Australia is actively seeking ways to reduce its greenhouse gas emissions and dependence on fossil fuels. It is widely seen that achieving this will require exploitation of a diverse range of technologies and fuels, rather than relying on one or two technologies such as wind and solar. Although wind and solar already make a significant contribution to achieving these goals, it is likely that further contributions will be limited by their intermittency (unless storage becomes commercially viable).

Bio-energy could play a significant role in coming years by supplying a dispatchable source of energy from localised and regional waste resource streams and purpose grown feedstock's. Bio-energy enables a supply of energy in circumstances when solar or wind relies on energy storage during low input periods making it less reliable during peak demands.

The rapid expansion of bio-energy systems in Europe and may other parts of the world provides an insight into the potential for exploiting local possibilities.

Energy cost (electricity and gas) in South Australia have continued to rise over the past 10 years making local industry, processing and manufacturing more uncompetitive. There is good potential for greater use of existing and new feedstock's and technologies, which could lead to an increased contribution from bio-energy across energy generation, industry, transport, utility and domestic energy sectors. This improved uptake will allow bio-energy to make a more valuable contribution to South Australia’s low carbon future and localised energy demands.

In early 2015, Renewables SA commissioned Jacobs Group (Australia) Ltd (Jacobs) to undertake targeted research and the initial stages of development of a ‘roadmap’ to identify and support viable opportunities to further develop the bio-energy industry in SA.

Bio-energy

Biomass resources are a sustainable and environmentally friendly feedstock that can contribute significantly to a diverse energy portfolio. Electricity, transportation fuels, chemicals, and materials currently produced from petroleum and natural gas can instead be produced from biomass.

Bio-energy can be produced from organic matter derived from plants, animals or manufactured food waste. Specific types of organic matter that are used to produce bio-energy are called biomass or bio-fuel feedstocks.

Bio-energy feedstocks and fuel products can be stored and are transportable allowing provision of a controllable supply of energy. Bio-energy systems often use organic material that would have otherwise been disposed in landfill, burnt without energy recovery or left to decay in situ adding to greenhouse gas emissions however they can also be produced by purpose grown energy crops, as is now the practice in many overseas countries.

The supporting technologies are generally well established, and there are already numerous ways of converting biomass into bio-energy on a commercial basis. These technologies are often referred to as “mature” technologies. Additionally, new forms of the technology are being investigated that make better use of ‘residue’ materials from other agricultural or industrial processes. These emerging second or third generation technologies are progressing through pilot and demonstration phases and may present future opportunities for Australian businesses. In the Australian context, some of the mature technologies have not reached their resource potential due to commercial and other market barriers. In that sense they are technologically mature but commercially emerging.

Bio-energy is produced by a range of processes including combustion, pyrolysis, anaerobic digestion, gasification, esterification, fermentation and other microbial process which is the subject of considerable interest and research activity globally, and in Australia.

There are a number of key drivers for the increased usage of bio-energy feedstocks:

- Utilisation of waste streams (avoiding the cost of disposing of those waste streams);
- A reduction in CO2 emissions due to the substitution of fossil fuels and avoidance of methane emissions;
- Enhancing energy security through the development of low cost alternative energy supplies;
- Provision of dispatchable power to complement wind and solar technologies;
- Securing regional development and employment through new industry activity, and
- Environmental improvement.

The industry is currently worth approximately $0.5B to Australia; and the potential to grow this contribution significantly is considered high.

The current state of play

There is considerable investment in bio-energy plants worldwide. In essence these form a number of major streams including:

- Combustion of waste crop material (eg straw) to produce heat and electricity
- Combustion of purpose grown crop material (eg coppiced wood) to produce heat and electricity
- Combustion of municipal and commercial wastes to produce heat and electricity
- Digestion of wastes to produce gas for heating, conversion to electricity or injection into gas reticulation systems
- Conversion of biomass to produce bio-fuels; and
- Capture of gas from decomposing wastes (landfill gas) to convert to electricity.

In Australia the capture of gas from decomposing wastes and the combustion of waste crop material are the more typical applications.

Within SA bio-energy plants have been installed at;

- SA Water – various Adelaide wastewater treatment plants anaerobic digestion for power generation
- Landfill gas – various small scale electricity generation facilities
- Thomas Food International - Murray Bridge anaerobic digestion
- Tarac Technologies – Nuriootpa anaerobic digestion
- AR Fuels – Largs Bay
- Forestry processing - Mt Gambier heat and power generation
- Swimming pool heating - Mt Gambier
- Sita-Resource Co. – Wingfield anaerobic digestion

South Australia maintains excellent engineering skills and the practical bio-energy consulting services required to implement bio-energy opportunities.

South Australian supply and demand

Local investigations indicate numerous potential supply and demand opportunities, mostly revolving around localised waste materials available and "end of line" demands. In addition too existing biomass potential supplies there is opportunity to grow alternative vegetative crops. Whilst requiring additional research this approach appears to be promising and could provide a good use of non-productive cleared landscapes.

There is a regional demand for and potential to supply additional energy. Industries that could benefit or expand from the opportunity include:

- Horticulture - heating
- Intensive industries (e.g. chickens and pigs) - process heating and electricity generation
- Processing plants - heating and power generation
- Processing hubs –heating
- Forestry processing –heating and power generation

Technologies, logistics and costs

Australian made versions of anaerobic digestion and pyrolysis technologies already exist as do suppliers of technology who represent international suppliers.

As in all countries, the need to capture local waste streams or grow complementary plants species locally is an advantage to delivering cheap energy alternatives.

Logistically the shorter the collection and delivery distances of waste streams or purpose grown crops to the energy plant the lower the costs of the energy produced. As a typical rule a production distance of no more than 40 - 50km radius from the energy plant is preferred.

Typical investment costs (excluding the costs of supplying biomass) have been derived for some of the more promising fuel sources.

Opportunities for further investigation

Our investigation has shown that there are both untapped existing and potential sources of biomass. These sources have been identified on a geographic basis that has led to the identification of potential bio-energy nodes across SA.

The feasibility of utilising these sources has not been investigated and further work including consultation with stakeholders is a logical next step to determine:

- If the sources have been adequately characterised – and do, in fact, exist
- The barriers to use of the sources
- What other uses of the land / products would be displaced if the biomass was produced and used for bio-energy
- The environmental and social impacts of growing and utilising these sources
- The economics of bio-energy projects including the value of the unconverted biomass and hence the likelihood of landowners using their land to grow additional biomass or to divert wastes from existing uses.

Important note about your report

The sole purpose of this report and the associated services performed by Jacobs is to investigate and collate in a GIS database available data and knowledge and report this to help initiate the development of a roadmap to support improved bio-energy industry development in South Australia, in accordance with the scope of services set out in the contract between Jacobs and the Client. That scope of services, as described in this report, was developed with the Client.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client and/or from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

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While Jacobs has been provided access to several SA Government databases it has not consulted with other stakeholders. The report should be considered in the context of the limited time available and budget.

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1. The Current Landscape

1.1 Introduction

This chapter of the report provides an initial broad and high level review of the current state of play within the bio-energy industry nationally and worldwide. In particular the chapter addresses the following key points as per Jacobs's proposal scope for this task:

- Establish what technologies and project types are in operation or near to market development in Australia
- Establish what technologies and project types are in operation or near to market development globally, with an emphasis on regions with similar climatic conditions to South Australia
- Compare with the situation in SA.

This section of the report is broken down into the three main broad categories of bio-energy as follows:

- Solid biomass
- Gaseous bio-fuels
- Liquid bio-fuels.

1.2 Solid Biomass

1.2.1 Common Solid Biomass Feedstocks

Solid biomass is material originally produced from biogenic matter of recent origin. The source of the biomass may encompass many forms including the following categories, for which in some cases there is a degree of overlap from one category to the next:

Woody Biomass – A well-established form of biomass proven for energy applications, usually utilised in log, chip or pellet form, and which may include:

- Forestry or timber product residues or bi-products such as sawmill residues or forestry/arboriculture arisings and brash. These are generally sourced as a by-product from an existing supply chain of forestry production primarily for timber production
- Purpose grown woody energy crops such as short rotation coppice or tree plant woody crops (e.g. fast growing species such as eucalyptus, acacia, casuarina or leucena)
- Waste wood material such as recycled wood from municipal waste, commercial waste (e.g. pallets) and construction and demolition sources.

Agricultural Biomass – An area of biomass production which is established and proven in some overseas countries but which in some agricultural sectors in Australia may be considered as having potential for increased utilisation:

- Straws from cereals such as wheat, corn, rice
- Bagasse which is the organic residual fibre following extraction of sugar from sugar cane
- Seeds, husks, skins, pulp, shells and pits such as oil seeds, rice, almond, olive or grape marc, generated as bi-products during the processing of agricultural products
- Purpose grown whole crops for bio-energy purposes such as miscanthus, energy cane, king grass, switch grass and arundo donax native reeds and mallee. However some of these

crops e.g. energy cane, king grass, switch grass require higher rainfall and are not suitable for the South Australian climate

Waste Derived Biomass – produced and potentially segregated as organic rich wastes from municipal, commercial and industrial sources:

- Green waste (e.g. kitchen and garden waste, or council generated green waste (CGGW))
- Biomass derived from municipal solid waste (MSW) or municipal like commercial and industrial (C&I) waste (e.g. derived from some sort of source segregation or post collection mechanical, heat or biological treatment process). Sometimes waste derived fuel products produced from these sources are called refuse derived fuel (RDF) or solid recovered fuel (SRF)
- Paper waste (recycled from municipal or commercial collections or sludge from paper recycling processes)
- Sewage sludge (also a feedstock for the production of bio-gas) either from municipal or food processing plant waste water treatment processes
- Animal waste (chicken litter, animal carcasses, or meat and bone meal)
- Woody perennial weeds.

1.2.2 Utilisation of Solid Biomass

Solid biomass can be used for power and heating applications from domestic scale up, for industrial applications and up to power utility scale. The following technologies are considered to be those most commonly currently applied to biomass for useful energy production.

Biomass combustion - the most common form of biomass conversion technology is combustion with heat recovery in a boiler. Boiler types depend on the fuel combusted and scale but can often be grates or bubbling fluidised bed boilers. The boiler can be used to produce hot water or steam, with larger scale boilers producing high pressure and temperature steam being suitable for the generation of power in a steam turbine. Boilers with thermal oil as the working fluid are also common in some industries like timber processing and fibreboard production although using hydrocarbon working fluids introduces some risks relating to safety with boiler tube failures. The heat from such boilers can also sometimes be used in smaller scale power applications coupled with organic Rankine cycles (ORC), which can deliver higher electrical efficiencies than steam turbines when the gross power output is less than around 2 MWe. Combined heat and power or cogeneration is possible with either steam or ORCs with a range of possible methods of delivering heat for an industrial or community energy demand.

Gasification of solid biomass feedstocks is the thermal degradation of the biomass to a gas called syngas or, in some countries, producer gas in a process where there is insufficient oxygen present for complete combustion of the material (sub stoichiometric conditions), but enough oxygen to generate a heat of combustion from biomass carbon to keep the process self-sustaining. The temperature can vary from process to process (600 to 1,300 ºC) depending on the feedstock and the desired end use application of the syngas and by-products such as char and ash. The syngas produced is a mixture of the combustible elements carbon monoxide, hydrogen and methane, and non-combustible carbon dioxide, water and nitrogen. The syngas also contains other trace undesirable components like tars but can generally be reliably used for direct combustion in an industrial application or in a boiler. When applying the gas to potentially higher conversion efficiency applications like gas engines or gas turbines, there are some technical challenges remaining to be resolved in delivering high quality syngas following gas treatment that can be used without operational and maintenance issues.

Gasification variants include **plasma gasification** and **oxygen blown gasification** which are sometimes applied to waste derived biomass feedstocks that present challenges to achieving a quality gas and ash products using more standard gasification means. Plasma gasification involves the exposure of the syngas produced in the gasifier to a very high temperature plasma arc for a short period of time, which helps to convert tars and other problematic volatile organic compounds to safer inert gas compounds, making the gas cleaner for downstream energy conversion technologies. The plasma can also be used to melt ashes to form when cooled a slag or frit which is a more inert form of ash for disposal or reuse from waste feedstocks that might contain undesirable constituents. Oxygen blown gasification works on a principle similar to a blast furnace to achieve high temperatures in the gasifier. This produces both a cleaner gas product and a molten ash which forms an inert slag when cooled. Both these methods have considerable electricity demands for either plasma torches or for air separation into oxygen.

Pyrolysis of biomass is another thermal degradation technology, but which is undertaken in the absence of or with low levels of oxygen, and as such requires an external heat source to be self-sustaining. Pyrolysis of biomass produces a bio-oil, char and syngas. There are two main types of pyrolysis, fast and slow processes, with the relative proportions of the liquid, solid and gas products changing considerably depending on the rate of heating. A fast or flash pyrolysis process will produce more oil product and a slow process more gas and solid char. As with gasification, there can be technical challenges with gas quality for its use in high conversion efficiency electrical generation applications, and it is often instead consumed for raising process heat.

Torrefaction is another technology emerging commercially with the capability of producing a coal-like solid fuel from biomass. The torrified wood product has a low moisture and high calorific value and can be stored, transported and used directly in coal fuel applications. The production process involves slow heating to around 280 ºC to drive off moisture and volatiles and to transform the residual carbon molecular structure to a more coal like matrix.

Some solid biomass feed stocks can also be considered as having potential for feed stocks for second and third generation conversion technologies for the production of liquid or gaseous bio-fuels which are covered in Sections 1.3 and 1.4 below.

The following tables list and comment on various solid bio-fuel technology types which are considered commercially mature or are near to commercial deployment. One table presents international technologies whilst the other focuses on specific national and South Australian projects. The two tables present commentary on a range of high level considerations including:

- Feedstock types applicable with reference to the above list of biomass types
- Status of technology, whether the technology is considered fully commercial or more of an emerging technology
- Typical ranges in scale of the technology in terms of energy output or tonnes of feedstock input
- Indicative capital costs per unit of energy produced, where this can be provided
- Key conversion factors or thermal efficiencies of the technologies
- Any by-products produced and comments on their use or disposal requirements.

Table 1.1: International solid biomass technologies considered commercially mature or nearing commercial deployment

Technology	Application	Feedstocks	Technology Status	Scale	Capex	Conv. Factor	Bi-products
Biomass combustion	Domestic heating to industrial scale heating	Wood logs, chips and pellets and some selected agricultural residues	Mature and common place	5 kW to 50 MW thermal	0.5-1 MWth => ~$550/kW	80-90 % thermal	Boiler ash which, depending on fuel types can be of benefit as a soil improver due to Nitrogen, Phosphorus and Potassium content
Biomass combustion with steam boiler and steam turbine for power or combined heat and power (CHP)	Industrial or utility scale power or cogeneration	Woody biomass of all types, many varieties of agricultural residues (with straws being the most common form), many varieties of waste derived biomass although these feedstocks are more challenging technically	Mature and common place, however more care is needed for the design and equipment selection for agricultural residues and waste derived biomass fuels due to their specific physical and chemical properties	500 kW to 300 MW electrical	10 MWth => ~$200/kW	10-35 % electrical. An overall CHP efficiency up to 70 to 80 % is possible	Boiler ash which, depending on fuel types can be of benefit as a soil improver due to Nitrogen, Phosphorus and Potassium content
Biomass combustion with organic fluid boiler for power and combined heat and power (CHP) by ORC	Industrial or community scale heat and power provision	Woody biomass of all types, not recommended for some waste or agricultural residues due to tube failure risk	Commercially proven for clean wood chip type fuels. Higher technical risk for agricultural and waste fuels	50 kW to 5 MW electrical		15 to 20 % electrical. An overall CHP efficiency up to 70 to 80% is possible	Boiler ash which, depending on fuel types can be of benefit as a soil improver due to Nitrogen, Phosphorus and Potassium content
Biomass co-firing using	Industrial scale	Woody biomass co firing e.g. food	Commercially proven for clean wood chip	0 – 10 MW	No information available	No information available	No information available

Technology	Application	Feedstocks	Technology Status	Scale	Capex	Conv. Factor	Bi-products
bubbling fluidised bed boilers for process heat		processing plant wastewater treatment sludge, coffee production waste	type fuels and meat processing wastewater sludge				
Biomass co-firing or conversion of utility scale coal fired power plants	Utility scale power generation, and in some cases also with heat output if a significant demand exists	Most commonly use wood pellets although other pellet types can be used. Wood chip input is limited by capability of mills to pulverise biomass	Commercially proven, although issues around economic and safe handling of wood pellets are the subject of current focus for large scale projects	100 to 1000 MW electrical. Co-firing conversion percentages from 5-100% possible	Costs vary significantly from project to project and depending on co-firing percentage	33 to 40%	Depends on current practice with coal ash if co-firing with coal as it will be a mixed ash. If 100 % conversion, then as above applies
Gasification for heating	Industrial process heating	Less challenging for clean wood chips	Some limited and specific examples exist	100 kW to 20 MW thermal	Limited data	Circa 80%	For gasification with lower oxygen levels, as well as ash, a char is produced that has potential for some higher value applications such as activated carbon or catalytic media
Gasification for power generation using gas engines	Community to industrial scale power and heat applications	Woody and agricultural residue feedstocks are most common	Many commercial installations worldwide, but also many of those have suffered reliability problems with engines due to poor quality	10kW to 20 MWe, however facilities < 1 MWe are most common	~$7,500 per kW electrical for a 500 kW unit.	18-25% electrical efficiency. An overall CHP efficiency up to 70 to 80% is possible	For gasification with lower oxygen levels, as well as ash a char is produced that has potential for some higher value applications such

Technology	Application	Feedstocks	Technology Status	Scale	Capex	Conv. Factor	Bi-products
			gas				as activated carbon or catalytic media
Plasma gasification with syngas cleaned and used in gas engines or gas turbines	Industrial scale	Generally applied to waste derived fuels	A very limited number of demonstration type plants are operating, but it is not considered well proven technology	Circa 100 to 1,000[1,2] tonnes per day of waste feedstock	$0.22-0.29 million AUD$/TPD[2]	Some report around 30% gross electric efficiency[3,4]. Note that parasitic demand is high due to plasma torches (20-25%)	Produces fused slag from solidification of molten ash. Has some potential for use as a construction material
Oxygen blown gasification (blast furnace type)	Industrial Scale	Generally applied to process waste derived fuels	Some examples operating commercially in markets with very high waste disposal gate fees e.g. Japan, which can justify it economically	50,000 -100,000 tonnes per annum waste feedstock	Little published data, expected to be high	Little published data, expected to have high parasitic loads to run process	Produces fused slag from solidification of molten ash. Has some potential for use as a construction material
Pyrolysis for heating	Small to medium industrial heating applications	All feedstocks are possible in theory, but this technology in practice is often applied to waste derived fuels	Limited number of examples known where this has been proven as successful	40,000 -100,000 tonnes per annum waste feedstock	Little published data	Circa 80% on heat output	Depending on feedstock types and process type, process can produce a coke or oil which may have some potential for higher value applications

Technology	Application	Feedstocks	Technology Status	Scale	Capex	Conv. Factor	Bi-products
Pyrolysis for power generation with a gas engine or boiler and steam turbine	Community to industrial scale for power generation	All feedstocks are possible in theory, but this technology in practice is often applied to waste derived fuels	Few well proven examples with engines running successfully due to gas quality issues. Some commercial examples exist where pyrolysis gas is burnt in a steam boiler feeding a steam turbine	500 kW to 20 MW electrical	~$5,000 / kWe @ 10 MWe scale	9 - 26%	Depending on feedstock types and process type, process can produce a coke or oil which may have some potential for higher value applications
Torrefaction (low temperature heating to dry and devolatilise solid biomass)	Production of a dry low volatile bio-coal type high calorific value (e.g. ~20-21 MJ/kg) and energy density transportable fuel product that can replace coal	Wood chips have been the main fuel attempted to date. In theory, agricultural residues may also be possible feedstocks	Some pilot scale and commercial demonstration facilities exist for this technology	20,0005 to 60,0006 tonnes per annum of bio-coal product (current plants), 250,000 tpa marketed by vendors	~$400 per annual tonne of product[7]	94 to 96% of original biomass energy content is retained.	A volatile combustible gas is produced during torrefaction which is used as an energy source to heat the torrefaction process to around 2800 ºC

Table 1.2: Examples of Australian and South Australian solid biomass projects that are commercial installations or demonstrated in deployment

Project / Location	Tech. / Application	Feedstocks	Technology Status	Scale	Capex	Conv. Factor	Bi-products
Various NSW and QLD sugar industry biomass cogeneration projects: e.g. Mackay (38 MW), Broadwater	Cogeneration with steam boiler and turbine for industrial process heat, and site and	Bagasse (sometimes with secondary fuel for the non-crush season, such as	Mature with at least 4 30MW or greater projects operating, and a number of smaller scale cogen	500kW to 40 MW electrical	Most recent Racecourse Cogen, Mackay is $120 M[8] for 38 MW in 2013	20-25%	Bagasse ash is generally returned to cane fields for use as a soil improver

Project / Location	Tech. / Application	Feedstocks	Technology Status	Scale	Capex	Conv. Factor	Bi-products
(30 MW), Condong (30 MW) and Rocky Point (30 MW)	export power	green waste or wood chips)	projects at various sugar mills				
Project Harvest Biomass Plant, Carwarp, Victoria	Combustion with steam turbine for power generation for grid export and food industry use (almond processing plant)	Almond shells and spent grape mark	The technology is well proven but this would be the first use with these particular feedstocks. This project is at an advanced stage of development	35 MWe gross	Approx. $140 M[9]	Circa 27%	The ash product is proposed to be used as a compost additive due to valuable nutrient content
Phoenix Energy Waste to Energy Plant Kwinana, WA	Martin stoker grate combustion system with a steam turbine for power generation	Municipal solid waste (MSW) including some commercial and industrial feedstocks	Mature, hundreds of this type of facility operating worldwide. This project is currently at the planning stage	400,000 tonnes per annum. 32 MW electricity export capacity[10]	$380 M[11]	Sufficient to be deemed a recovery operation under the EU R1 efficiency criteria	Bottom ash has some potential for re-use as construction aggregate
New Energy East Rockingham and Pilbara Waste to Energy Projects, WA	Entech low temperature gasification with syngas burner, boiler and steam turbine	Residual municipal solid waste after a front end treatment process	A number of reference plants for the Entech technology are claimed (46 in total)[12]	Each project is up to 130,000 tonnes of post treatment SRF, up to 18 MWe	Approx. $200 M for East Rockingham[13]	Not stated	It is understood that ashes from the process will be inert and landfilled[12]
Select Harvest, Robinvale, Vic	Boiler / Steam Turbine	Almond shell and hull	Contract placed with Vyncke	2.5 MWe, and supplying 700 kW heat to almond dryer	$12.9 M EPC price	Not stated	It is understood ash will be returned to the almond orchards
Western Australian	Boiler / steam	Saw mill waste	Development	40 MWe	$150 M	23%	Ash

Project / Location	Tech. / Application	Feedstocks	Technology Status	Scale	Capex	Conv. Factor	Bi-products
Biomass, Manjimup WA	turbine	and forest residuals	consent approved, but awaiting RET certainty				
Carter Holt Sawmill, Mt Gambier, SA	Boiler / steam turbine	Wood waste	In operation since 1995	10MWe	Not known	Expected to be cica 22%	Ash
Regen Australia, various states	Boiler / steam turbine	Waste wood fired	Various projects under development	10 - 15 MWe	$50 M	22%	Ash
Southwood Huon Valley, Tas	Boiler / steam turbine	Forest residue	In development	30 - 50 MWe	Not stated	25%	Ash
South East Fibre Exports, Eden, NSW	Boiler / steam turbine	Sawmill residues	In development	5 MWe	$20 M	23%	Ash
Dial A Dump Industries Waste to Energy, Eastern Creek, NSW	Moving grate boiler and steam turbine	Municipal waste	In development	140 MWe, 1.2 million tonnes per year of waste	$800 M	Not stated	Bottom ash has some potential for re-use as construction aggregate
Select Harvest Robinvale, Vic	Boiler / Steam Turbine	Almond shell and hull	Contract placed with Vyncke	2.5 MWe, and supplying 700 kW heat to almond dryer	$12.9 M EPC price	Not stated	It is understood ash will be returned to the almond orchards
Visy, Tumut, NSW[14]	No information available	Degraded paper fibre from a paper / cardboard recycling plant	Operating	No information available.	No information available	No information available	No information available
Visy, Campbellfield, Vic[15]	No information available	Degraded paper fibre from a	Operating	30 MWth and 3 MWe	$50 M	No information available	No information available

Project / Location	Tech. / Application	Feedstocks	Technology Status	Scale	Capex	Conv. Factor	Bi-products
		paper / cardboard recycling plant					
Visy, Gibson Island, QLD[16]			Operating				
Visy Waste to Energy, NSW[17]	Mechanical biological treatment (MBT) facility for fuel production	Municipal waste converted to refuse derived fuel	In development	75 MW	$100 M for the MBT facility, and $200 M for the power plant	No information available.	No information available
Carter Holt Harvey, Morwell, Vic[18]		Woody biomass waste	Operating	20 MWth			
Nestle, Gympie, QLD[19]	Bubbling fluidised bed boiler	Woody biomass (saw dust), coffee production waste	Operating	16 MW	$10 M	75%	
Australian Tartaric, Mildura, Vic	Thermal Energy	Grape marc & other leftovers from tarac acid production	Operating since 2013	400 kW electricity	$7.5 M	12 tph steam, no longer uses fossil fuels, reduced LPG use reduced by 69%, reduces costs by 1.52 M / year	
Suncoast Gold Macadamias, Gympie, QLD	Steam boiler	5000 tonne nutshell	Operating since 2003	9.5 GWh/y	$3 M		1.4GWh to the electricity grid
Reid Brothers Sawmill, Yarra Junction, Vic	Wood burning	Waste timber	Operating since 2005		$360,000	Save dumping fees $14000 / y,	Nothing goes to landfill

Project / Location	Tech. / Application	Feedstocks	Technology Status	Scale	Capex	Conv. Factor	Bi-products
						save LPG $270,000 / y	
Gelliondale Nursery, Alberton, Vic	Hydronic thermal generator	Wet sawdust and olive pips	Operating since 2010	1.5 MW	$500,000	Save $170,000 / y	
Mt Gambier Aquatic Centre, Mt Gambier SA	Biomass boiler	Forestry wood	Operating since 2013	520 kW		Save $40,000 / y compared to LPG	
Beaufort Hospital, Beaufort, Victoria	Wood fired boiler	Waste wood chips	Operating since 2013	110 kW	$430,000	Save $34,000 / y compared to LPG	
Murphy Fresh Hydroponics, Mansfield, Vic	Thermal generator	Waste hardwood	Operating	6 MW	$600,000	Save $1.65 M / y over LPG	

1.3 Gaseous Bio-fuels

1.3.1 Common Gaseous Bio-fuel Feedstocks

The most common gases generated from bio-fuels are as follows:

Bio-gas – a product of anaerobic digestion (AD) which is the biological decomposition of biomass in the absence of air produces a gas of between 40-80% methane content, with the balance of the gas constituents being mostly carbon dioxide, moisture, and oxygen with some other trace components. Both liquid phase (1-25% dry solids) and solid phase (30-60% dry solids) anaerobic digestion processes exist and can be applied depending on the feedstock or effluent available. Common sources of bio-gas include:

- Land fill gas – common at municipal waste landfills which are capped to prevent ingress and egress of air and/or bio-gas, and having a collection manifold systems to gather the gas to a central point for utilisation. The capping and collection of the gas mitigates uncontrolled methane emissions to atmosphere which would otherwise have a significant greenhouse gas impact.
- Sewage bio-gas – generally produced through the anaerobic digestion of sewage sludge, at municipal waste water treatment plants. There are a range of suitable AD approaches (covered lagoon, tank digesters, thermal hydrolysis methods, etc.) applied to successfully digest sewage sludge to generate high bio-gas yields. The process of digestion of the bio-solids reduces the sludge volumes and the level of biological activity for disposal and/or reuse.
- Industrial water treatment bio-gas – produced from the anaerobic digestion of process wastewater streams with high organic content, also known as chemical oxygen demand (COD) and biological oxygen demand (BOD), whereby the AD process has the dual benefit of making the effluent cleaner before discharge. Industrial wastewater sources may come from breweries, wineries, distilleries, other beverage factories, abattoirs, a range of different food manufacturing processes, pulp and paper factories, liquid bio-fuel/oil production processes (e.g. bio-ethanol, bio-diesel and vegetable/palm oils, glycerine etc).
- Municipal waste biological treatment gas – bio-gas produced in the process of anaerobically digesting the organic rich elements of municipal waste, normally as a part of a mechanical and biological treatment (MBT) method of municipal waste, known as MBT-AD (as opposed to MBT with composting). The organic elements of the waste such as food and garden waste are first separated, either at source through separate collection, or via a mechanical process treating mixed municipal waste collections. The organic stream is then processed in a one of a range of suitable AD reactor vessels to generate the bio-gas.

Agricultural residues bio-gas – produced for agricultural sources such as manure and slurry from livestock such as pigs, cattle, poultry etc. These residues, whilst having value as fertiliser/soil improver would otherwise emit considerable volumes of uncontrolled methane emissions to atmosphere. In addition, some crop material is sometimes considered for direct use for bio-gas production such as maize silage, sometimes in combination with other feedstock types listed above as a feedstock. Maize can boost digester bio-gas yield and has a high dry matter content. Some European projects target marginal or unsuitable land for valuable food crop production for purpose grown crops like maize for bio-gas feedstock such that sustainability and food vs. fuel issues are less significant.

Bio-methane – generally produced from the upgrading of bio-gas (as per generated by the above processes), bio-methane is generally greater than 95% methane content and is similar to natural gas in quality and in terms of suitable energy applications. The other non-energetic components of bio-gas are stripped out in one of commercially available gas treatment and scrubbing processes.

Producer gas and syngas – these gas types are produced from gasification and pyrolysis of biomass as described in Section 1.2 above.

1.3.2 Utilisation of Gaseous Bio-fuels

Gaseous bio-fuels are readily usable fuels in a range of energy applications which generate lower local environmental emissions issues at the end use point than solid biomass fuels, as there is no significant particulate matter emitted. The following dot-points highlight some of the most comment current practices.

Bio-gas is the most widely used and produced form of gaseous bio-fuel. Common current utilisation practice includes:

Stationary reciprocating spark ignition engines – the most common application of bio-gas use is gas engines which are not dissimilar to engines used for locomotion of automotive vehicles, but are connected to an electrical generator rather than a driveshaft. These engines can also produce low or high temperature useful heat from the engine cooling water circuit or through exhaust heat recovery boilers. Most bio-gases required some form of gas pre-treatment before they can be combusted reliably in gas engines.

Gas fired boilers – a common application of bio-gas energy at locations where there exists a significant demand for process heat in the form of hot water or steam (e.g. distilleries or wastewater treatment works for digester heating etc). There are some installations where bio-gas is also fired with solid fuels such as biomass in a boiler, particularly at installations co-located where solid biomass residues are also generated from a production process (e.g. food and drink sector). There are also examples where the boilers run in parallel and inter-linked with engine exhaust heat recovery systems.

Gas turbines and micro-turbines – a less common alternative for power and steam production, however there are some examples of bio-gases being use as the sole fuel or co-fired fuel with natural gas. Whilst efficiency levels of small gas turbines when operated in open cycle which might be expected with bio-gas applications, a greater proportion of the exhaust energy can be recovered as medium to high pressure steam for process use, which is sometimes of interest to large industrial processes. In some cases gas turbines can also offer longer lifecycles between major maintenance than gas engines, and lower maintenance costs. A high standard of gas pre-treatment is required for gas turbines however.

Fuel cells - A more niche or emerging application for the use of bio-gas is the use in fuel cells, which, whilst much more expensive, can offer higher electrical conversion efficiencies. This approach is not considered current standard commercial practice.

Stirling engines – Another emerging option for very small scale bio-gas applications, Stirling engines are heat driven engines but are not widely adopted commercially at this time.

Bio-methane for vehicle fuel - Bio-methane can be suitable for use as a vehicle fuel, via compression to compressed natural gas (CNG) or liquefied to liquefied natural gas (LNG). Fairly stringent quality standards of gas treatment are required from the gas upgrading process to satisfy vehicle engine manufacturer standards. There are a number of examples of vehicle fuels (e.g. buses, council vehicle fleets or refuse collection vehicles) reliably running on bio-methane in Europe, some of which have developed with grant funding as technology demonstrator projects.

Bio-methane for gas grid injection - It is also possible and is coming into commercial practice in some parts of Europe to compress and inject the gas into the natural gas network for wider distribution. Grid gas injection will likely require various regulatory gas quality requirements to need to be met, which might include adding odorants to the gas for safety reasons, and potentially adding other gaseous hydrocarbon elements such as propane etc., to make the gas more comparable to network natural gas in terms of Wobbe Index, which is an international standard measure of comparable combustibility for natural gas consuming appliances.

Producer gases and syngases - Generally these gases are consumed for use for heating and power applications as described in that section, but other '2nd and 3rd generation' reforming and upgrading options to natural gas like quality and into other useful fuel or higher value chemical products. These upgrading/reforming technologies are considered to be mostly either the subject of research and development or installed as demonstration facilities or prototypes, and thus are not considered further in this review of current commercial practice.

The following tables list and comment on various gaseous bio-fuel technology types which are considered commercially mature or are near to commercial deployment. One table presents international technologies whilst the other focuses on specific national and South Australian projects. The two tables present commentary on a range of high level considerations including:

- Feedstock types applicable with reference to the above list of biomass types
- Status of technology, whether the technology is considered fully commercial or more of an emerging technology
- Typical ranges in scale of the technology in terms of energy output or tonnes of feedstock input
- Indicative capital costs per unit of energy produced, where this can be provided
- Key conversion factors or thermal efficiencies of the technologies
- Any by-products produced and comments on their use or disposal requirements.

Table 1.3: International gaseous bio-fuel technologies considered commercially mature or nearing commercial deployment

Technology	Application	Feedstocks	Technology Status	Scale	Capex	Conv. Factor	Bi-products
Anaerobic digestion with bio-gas burnt in a boiler	Industrial heating applications	Sewage sludge, food production effluents, distilleries and breweries	Established in niche industrial examples, i.e. at sites where feedstocks are produced and where a heat demand exists	0.1 - 10 MWth	Whole system including digester ~$4,500/kWth[20], but depends on feedstock type and capacity	~90% (boiler efficiency)	In some low chemical risk feedstock cases (e.g. uncontaminated food waste) if local regulations allow, the digestate which is the undigested residual biomass or sludge, can be used as a fertiliser or soil improver
Anaerobic digestion with bio-gas used in a CHP gas engine	Site and export power and heat for industrial and community scale demands	Most feedstock types can be coupled with a bio-gas CHP engine	Well proven and established, assuming appropriate gas treatment is employed where required	0.1 - 10 MWe	Whole system including digester ~$12,000/kWe[20] but depends on feedstock type and capacity.	34 - 43% engine efficiency, CHP efficiency up to 70 - 80% possible	As above
Landfill gas with gas engine generator	Power production for grid export and site use.	Landfill gas	Proven at many installations worldwide	0.2 - 15 MWe	Engines only ~$2,500/kWe[20]	34 - 43% engine efficiency	None
Bio-gas burnt in a micro turbine or gas turbine	Site and export power and heat for industrial scale demands	Could potentially be any form of bio-gas. Some examples known to exist are sewage sludge and landfill gas	Proven in a small number of installations internationally, assuming appropriate gas treatment is employed where required	Micro turbines 0.3 - 1 MWe, gas turbines 1 - 5 MWe	Whole system including digester ~$15,000/kWe[22,20] but depends on feedstock type and capacity	25[21] to 35%, CHP efficiency up to 70-80% possible	In some low chemical risk feedstock cases (e.g. uncontaminated food waste) if local regulations allow, the digestate which is the undigested residual biomass or sludge, can be used as a fertiliser or soil

Technology	Application	Feedstocks	Technology Status	Scale	Capex	Conv. Factor	Bi-products
							improver
Bio-gas fuel cells	Base load high efficiency power generation	Could potentially be any form of bio-gas. Some examples known to exist are sewage sludge, food processing effluent and landfill gas.	Proven in a small number of installations internationally, assuming appropriate gas treatment is employed where required.	0.3 - 3 MWe[22]	~16,000/kWe[20,22] but depends on feedstock type and capacity	35 to 60% electrical	As above for digestate. Some fuel cells can also alternately produce hydrogen gas such as to fuel vehicles, at the expense of sacrificing a proportionate amount of power output
Anaerobic digestion with bio-gas upgraded to bio-methane	Vehicle fuel use or gas grid injection	Could potentially be any form of bio-gas. Some examples known to exist are sewage sludge, landfill gas and brewery effluent.	Proven in a low number of installations internationally. Gas upgrading technologies are similar to existing fossil gas and bio-gas processing equipment	300[24] – 5400[23] Nm3/h bio-gas	Excluding AD costs, upgrading is $1.4 M per 300 Nm^3/h of raw bio-gas[24]. Bio-gas volume equivalent to around 0.75 MWe of generation by gas engine.	Not applicable, can be used equivalent to natural gas applications	As above for digestate. CO_2 for industrial use could also be potentially produced at some facilities from the upgrading process

Table 1.4: Examples of Australian and South Australian gaseous bio-fuel projects that are commercial installations or demonstrated in deployment

Project / Location	Tech. / Application	Feedstocks	Technology Status	Scale	Capex	Conv. Factor	Bi-products
Multiple landfill sites	Landfill gas / reciprocating engines	In situ degradation of municipal waste	Commercial and well developed	100s MWe	Unknown	Unknown	None

Project / Location	Tech. / Application	Feedstocks	Technology Status	Scale	Capex	Conv. Factor	Bi-products
Various municipal waste water anaerobic digestion projects, e.g. **Melbourne Water, Werribee, Vic, total of 10 MWe from 9 engines.** **QUU Luggage Point, QLD, 2 x 1.2 MWe, Oxley Creek QLD, 1 x 1.4 MWe.** **SA Water, Bolivar, 3 x 2.4 MWe, Glenelg, and Christies Beach waste water treatment plants**	Anaerobic digestion and power generation in a gas reciprocating engine for on-site use and heat production for process use. SA Water plants also employ co-digestion with trade waste.	Sewage sludge	Mature, although some particular projects have suffered from poor engine availability due to insufficient gas pre-treatment. SA Water has achieved a 20% reduction in its overall external electricity requirements.	0.5 - 10 MWe	Depends on site specific costs	35 - 42%	SA Water biosolids are used as a soil conditioner for agricultural and landscaping purposes
Quantum Power bio-gas projects; **3 x 80kW piggery NSW, 1 x 250 kW poultry QLD, 4 x 250 kW renderer QLD**	Covered lagoon anaerobic digester and reciprocating gas engines. Some gas treatment also required	Pig slurry, poultry manure	Implementation stage following financing support from the Clean Energy Finance Corporation	0.2 - 1 MWe	Piggery unknown, egg farm $2.86 M, renderer $13.6 M[25]	Not stated	For some feed stocks there may be soil nutrient benefit in the digestate
Richgro Garden Project, Jandakot, WA	Anaerobic digestion (tank) and reciprocating gas engine	Organic waste including food waste.	Commissioning stage	1.2 MWe	Unknown	Not stated	For some feed stocks there may be soil nutrient benefit in the digestate
Australian Paper, Maryvale, Vic[26]	Kraft recovery boilers	Black liquor ex wood pulping process	Operating	55 MWe	Unknown	Unknown	Unknown

Project / Location	Tech. / Application	Feedstocks	Technology Status	Scale	Capex	Conv. Factor	Bi-products
Thomas Foods, Murray Bridge, SA	Anaerobic digesters and dual fuel boilers	Abattoir waste	Operating 2014/15	20 MWth	$20 M	Not stated, bio-gas offsets the use of natural gas	Unknown
Darling Downs Eggs, Pittsworth, QLD	Anaerobic digester	Chicken manure and other organics	Under construction		$2.86 M	Reduce electricity by 60%	Eliminate waste disposal costs
Berry Bank Piggery, Windermere, Vic	Vertical anaerobic digester	Pig effluent	Operating since 1991	185 kWe	$2 M		Saving on water, potting mix, fertiliser

1.4 Liquid Bio-fuels

1.4.1 Common Liquid Bio-fuels

There are many pathways for the production of bio-fuels from biomass sources, and these are sometimes broadly classified in terms of first, second and third generation bio-fuels, on the basis of the feedstock used and its potential for alternately producing food if not used for bio-fuels. A further generalisation could be made that in many cases first generation fuels are less complex to produce and also tend to have a higher degree of commercial proving than second and third generation fuels. The challenge faced by many bio-fuels projects worldwide is to produce fuels without displacing valuable food production activities or resulting in land clearing for bio-fuel crops, which is the rationale behind this classification method, however it is noted that the classifications below do not provide a complete picture of the overall sustainability of any particular bio-fuel project.

1st Generation Fuels - Traditional bio-fuel production methods are known as 1st generation which includes bio-fuels bio-ethanol and bio-diesel. These are produced from biomass materials where the precursors (e.g. wheat, corn, oil crops etc.) required for production such as sugars for fermentation into ethanol, and oils for trans-esterification into bio-diesel, are readily available in the feedstock. The feedstocks for these fuels generally could potentially be otherwise used for human or animal food production. There are also some vegetable, animal and wood derived bio-oils that are usable for energy production without refining to bio-diesel in some energy conversion technologies.

2nd Generation Fuels - The production of bio-fuels from more difficult feed stocks are known as 2nd generation methods, which are generally speaking use feedstocks which could not be used as a food source such as wastes and residues. The complexity of production from these feedstocks is generally higher, and the technologies are less commercially developed and the subject of continuing development and proving in demonstration plants. 2nd generation bio-fuels include production of bio-ethanol from cellulosic feedstocks such as wood which requires additional processing steps (e.g. more complex size reduction/milling and acid/alkali/heat etc pre-treatment to enhance hydrolysis) to break down the cellulose to useable sugars before fermentation to alcohol. Some differences in the fermentation step are also required so that C5 molecules can also be fermented with the C6 sugars. It would also include the production of bio-diesel from waste vegetable oils (such as used food frying oils). Another technology sometimes defined as 2nd generation is the production of bio-diesel from solid biomass using the Fischer-Tropsch process following gasification of the biomass. Pyrolysis of biomass to a bio-oil (as described above) could also be considered a 2nd generation method.

3rd Generation Fuels - Bio-fuels produced by aquatic autotrophic organisms such as algae are sometimes classified as 3rd generation bio-fuels. The algae feedstocks can potentially be produced from land or water bodies that do not compete with food production. There are algae technologies that rely primarily on sunlight, water and atmospheric carbon dioxide to grow a biomass which can become a feedstock for bio-fuels production. There are also some algae technologies that rely on a source of carbon dioxide rich gas such as flue gas from a combustion process (using fossil fuel or biomass) to grow the algae biomass. Some algae are high in lipid or oil content which make suitable bio-diesel feedstocks. The non-lipid (carbohydrate/cellulose) part of the algae can also become a bio-ethanol feedstock, and there are some algae species that can directly produce ethanol in an anaerobic fermentation process. Algae technologies for bio-diesel and bio-ethanol are generally speaking at the research and development stage with some small scale pilot facilities existing, but to our knowledge no commercial plants currently exist. There are algae plants in production however targeting higher value pharmaceutical and health food applications for the biomass produced from the process[27].

The most common fuels and their feedstocks are described briefly below (this list is not exhaustive):

Bio-ethanol (ethyl alcohol)

- First generation – from the fermentation, distillation and molecular sieving using feedstocks such as sugars or starch extracted from (in some cases with enzyme hydrolysis) from wheat, sorghum, corn, cassava, beet and molasses (cane sugar by-product) etc.
- Second generation - from cellulosic and lignin feedstocks such as wood, straw (e.g. wheat and rice straw and corn stover), bagasse (sugar cane fibre), and some grasses.
- Third generation – from the cellulosic part of algae or with algae species that can directly produce bio-ethanol.

Bio-diesel (fatty acid methyl ester)

- First generation - from trans-esterification process using oil seed rape, palm oil, canola, jatropha or other crops which produce an oily seed.
- Second generation – from waste bio-oils such as tallow and used cooking oil from food factories and restaurants/takeaways. Tall Oil can also be refined to bio-diesel and is a by-product of the KRAFT process for wood pulping of coniferous trees.
- Third generation – trans-esterification of lipids extracted from algae.

Bio-butanol (butyl alcohol)

- This product has a higher octane number than bio-ethanol and is derived from a different type of fermentation process of sugars to produce the larger alcoholic molecule from first generation feedstocks (with potential to be produced from second generation feedstocks in the future)[28].

Pyrolysis oil

- Second generation - from the fast or flash pyrolysis of solid biomass feedstocks such as wood and agricultural residues.

Biomass to liquid fuels from Fischer-Tropsch or Mobil processes

- Second generation technology which is at the pilot scale demonstration stage using various solid biomass feedstocks such as short rotation trees, perennial grasses, straw, forest thinnings, bark from paper-pulp production, bagasse, waste paper or reclaimed wood or fibre based-composites[29].

Glycerine

- A by-product of the production of bio-diesel by trans-esterification, which has reasonably high calorific value if impurities are removed.

1.4.2 Utilisation of Liquid Bio-fuels

Liquid bio-fuels present higher value opportunities for utilisation as they can substitute petroleum based fuels such as petrol and diesel. The following are the main potential applications for liquid bio-fuels:

Transport fuels

- Bio-ethanol is a substitute for petrol in transport vehicle applications and is a higher octane number fuel than normal petrol blends. For normal petrol engines, the substitution rate in petrol is typically limited to around 10% (E1027), such that the blended product can be used in engines requiring no modifications with minimal risk. Blends up to around 85 to 100% (E85 to E100) can be utilised in petrol engines with some modifications (optimally with engines with increased compression ratios) and bio-ethanol is utilised at these high blend rates commercially in Brazil on a large scale and also in some specific outlets in Australia and the US.

- Bio-diesel is a substitute for petroleum based diesel. There are some differing chemical properties with bio-diesel in terms of handling and storage which need to be considered when substituting bio-diesel, such as bacterial degradation. Blends up to 20% (B20) bio-diesel are possible to use in most conventional vehicle engines without modifications, although B5 is more commonly sold. Higher blend rates to 100% are possible with modified engines.
- Bio-butanol is another petrol substitute and can be more readily substituted with petrol because it is a larger molecule and has a more similar octane number to regular petrol. Bio-butanol is not yet commonly available for vehicle fuel.

Stationary reciprocating diesel engines

- Bio-diesel and some unrefined bio oils (palm oil, soy bean oil, rape seed oil, used vegetable and animal oils, pyrolysis oil etc)30 can be used directly or in blends with relatively high efficiency power generation diesel engines. Diesel engines provide specifications for bio oil and bio-diesel fuels that must be met to minimise technical issues with these fuels. Such engines can also be run as combined heat and power plants.

Burners and boilers

- Considered a lower value application for quality fuels of this type, unless they are unrefined or contain problematic constituents. Glycerine is one bio-fuel by-product that is sometimes burned because the production of bio-diesel has resulted in a glut of glycerine available for higher value applications. Pure glycerine has a high calorific value if the other impurities are removed. Pyrolysis oil is another oil that could be used in this way if not subject to further in a bio refining.

Anaerobic digestion

- Glycerine is one bio liquid that is considered as a potential high value feedstock for anaerobic digestion. Other bio-oil by-product wastes can also be considered as feedstock for anaerobic digestion.

The following tables list and comment on various liquid bio-fuel technology types which are considered commercially mature or are near to commercial deployment. One table presents international technologies whilst the other focuses on specific national and South Australian projects. The two tables present commentary on a range of high level considerations including:

- Feedstock types applicable with reference to the above list of biomass types.
- Status of technology, whether the technology is considered fully commercial or more of an emerging technology.
- Typical ranges in scale of the technology in terms of energy output or tonnes of feedstock input.
- Indicative capital costs per unit of energy produced, where this can be provided.
- Key conversion factors or thermal efficiencies of the technologies.
- Any by-products produced and comments on their use or disposal requirements.

Table 1.5: International liquid bio-fuel technologies considered commercially mature or nearing commercial deployment

Technology	Application	Feedstocks	Technology Status	Scale	Capex	Conv. Factor	Bi-products
1st generation fermentation of sugars and starch for bio-ethanol production	Bio-ethanol for vehicle fuel use or other industrial use	Wheat, corn, molasses, sorghum, cassava etc	Proven and many commercial scale installations	40 to 700[31] ML per annum	~$0.6 to 0.9 M / ML of annual capacity	Depends on feedstock	Distillers' grains (spent grains and syrup), either in wet or dry pelletised form used for animal feed
1st generation bio-diesel production from oily plant material	Bio-diesel for transport fuel (B45 to B100)	Oil seed rape, palm oil, canola, jatropha or other crops which produce an oily seed	Proven and many commercial scale installations	5 to 800 ML[32] per annum	~$ 0.8 -0.9 M / ML of annual capacity	Depends on feedstock	Glycerine potentially used for skin care and soap industries or as boiler fuel or anaerobic digester feedstock
2nd generation bio-ethanol production	Bio-ethanol from hydrolysis and fermentation of agricultural residues	Dupont Iowa plant: corn crop residues (stover)	The Dupont Nevada Iowa plant in the US is claimed as the first commercial scale installation of this technology, expected to commence operation in 2015	Dupont: 113 ML per annum	Dupont: ~$270 M[33], equivalent to ~$2.4 M / ML	375,000 dry tons of stover per year, equivalent to ~0.3 L/dry ton[34]	By-product is biomass residues that can be combusted for energy generation to offset fossil fuel use
2nd generation bio-diesel production: **Geismar Project, USA**	Bio-diesel from oily residues	Animal fats, used cooking oil and greases	Commercial plant operational since 2010	210 kT per year	$177 M[40]	Not stated	Glycerine potentially used for skin care and soap industries or as boiler fuel or anaerobic digester feedstock
2nd generation biomass to liquid bio-diesel, Southern	Bio-diesel production from solid biomass using gasification and	Solid biomass including municipal waste	Pilot plant operational since 2007	1,000 tonnes per year biomass	$38 M[40]	Not stated	Not stated

Technology	Application	Feedstocks	Technology Status	Scale	Capex	Conv. Factor	Bi-products
Research, Durham, USA	Fischer Tropsch catalytic conversion			feedstock			

Table 1.6: Examples of Australian and South Australian liquid bio-fuel projects that are commercial installations or demonstrated in deployment

Project / Location	Tech. / Application	Feedstocks	Technology Status	Scale	Capex	Conv. Factor	Bi-products
Wilmar Bio-ethanol, Sarina, QLD	Production of bio-ethanol for blending into E10, food and beverages, and industrial use	Molasses, a by-product of sugar cane processing	Mature, operational for a number of years	60 ML per annum	-	NA	None specifically from the bio-ethanol process. Molasses itself is a by-product of sugar production.
Manildra Ethanol Plant, Nowra, NSW	Bio-ethanol for blending into E10 and E85 and for industrial use.	Waste starch from the processing of wheat flour into various food grade products.	Manildra have been manufacturing ethanol since 1992, and their process has been upgraded in scale since that time.	300 ML per annum	-	NA	None specifically from the bio-ethanol process. Wheat starch itself is a by-product of wheat products production.
Dalby Bio Refinery, Dalby, QLD	Bio-ethanol for blending into E10	Red sorghum grain	Operation since 2007 using proven first generation technology	80 ML per annum	$140 M in 2007	1 tonne of sorghum grain can produce up to 400 litres of ethanol[35]	Produces a high protein value wet animal feed product from the spent grains and syrup (160,000 tonnes per annum)
ARfuels, Largs Bay, SA, Barnawartha, Vic and Picton, WA	Bio-diesel for use as pure bio-ethanol (B100) or blended (B5, B20, and B35), some exported to the US	Tallow and used cooking oil	Operational, had a fire at Largs Bay in 2011, but is now up and running again after rebuilding	45 ML per annum	$50 M for Barnawartha plant in Victoria which is 60 ML per annum.[36]	NA	Glycerine used to co-fire with LPG to raise steam in an on-site boiler for process use.
Ecotech Bio-	Bio-diesel for use as	Tallow and used	Commercial installation	30 ML / y	-	NA	Glycerine potentially used

Project / Location	Tech. / Application	Feedstocks	Technology Status	Scale	Capex	Conv. Factor	Bi-products
diesel, Narangba, QLD	pure bio-ethanol (B100) or blended (B5 and B20)	cooking oil	operational since 2006				for skin care and soap industries or as anaerobic digester feedstock[37]
Ecofuels Australia, Echuca, Vic	Bio-diesel for vehicle use on farms	Canola	Commercial demonstration facility operational since 2013	1.5 ML / y	$1.76 M[38]	NA	40,000 tonnes of animal feed. Other wastes may be fed to an anaerobic digester to produce bio-gas energy
Ethanol Technologies Ltd, Harwood, NSW	Bio-ethanol from cellulosic feedstocks employing an acid hydrolysis stage[39]	Bagasse and wood	Pilot plant, not a commercial installation	Unknown	-	NA	Spent biomass residues are proposed to be combusted in the on-site sugar mill bagasse boiler to generate heat and power for site use
Licella, Somersby, NSW	Bio-crude production via catalytic thermal hydrolysis of solid biomass using steam under supercritical pressure	Pine sawdust (sawmill residue) and other solid biomass including banana grass and algae	Pilot plant successfully demonstrated in 2012, demonstration plant in progress	350 tpa product	$10 M[40]	1000 oven dry tonnes of feedstock per annum. Equivalent to ~ 0.35 kg oil / kg dry feedstock	By-products not stated
Aurora Algae, Karratha, WA	Production of algae for various uses including as a potential bio-fuel feedstock	Micro algae production from sunlight and atmospheric carbon dioxide in saline water	Pilot demonstration project operated for 3 years, now closed	Up to 15 tonnes of dry biomass per month	-	-	Omega 3s for pharmaceuticals, health foods, beverages and fish feed
Muradel, Whyalla, SA[41]	Growing, harvesting and converting algae	Halophytic microalgae	Pilot plant started operating in October	30,000 L / y	$10.7 M		

Project / Location	Tech. / Application	Feedstocks	Technology Status	Scale	Capex	Conv. Factor	Bi-products
	to fuel or chemical feedstocks		2014				
Qantas/Shell, Sydney, NSW[42]	Jet fuel production from sustainable sources either via the waste to fuel process (Fischer-Tropsch), or, by the natural oils to fuel path	MSW for the waste to fuel pathway or oilseed producing crops or tallow for the natural oil to fuel pathway	50:50 blend of sustainable aviation fuel / crude oil based aviation fuel successfully trialled on commercial flights, feasibility study completed	-	-	-	Naphtha, gas, bio-diesel

1.5 Global Bio-energy Landscape

Bio-energy is moving forward fast in many parts of the world. The rapid deployment of sustainable biomass for energy is a key challenge within the global climate and energy policy areas.

Bio-energy technology is generally well established globally, and there are numerous ways of converting biomass into bio-energy on a commercial basis. These are 'mature' technologies. Additionally, new forms of technology are being investigated that may make better use of 'residue' materials from agricultural and forestry processes. These second generation technologies are now progressing through pilot phases and may present opportunities for Australian businesses. These are generally known as 'emerging' technologies. Some of the mature technologies have not reached their resource potential due to cost and commercial barriers. In that sense they are technologically mature but commercially borderline or emerging.

1.6 Australian and South Australian Bio-energy Landscape

Bio-energy in Australia and South Australia can be viewed favourably due to:

- The increases in local energy costs (electricity and gas).
- Changes in climatic conditions presenting land otherwise used for productive agriculture.
- Increases in weed composition within the landscape.
- Costs associated with dumping of agricultural wastes.
- Growth performance of agricultural crops providing opportunity straw harvest after the food crop has been harvested.
- Localised energy demands close to waste streams.

Existing support through bio-energy industry leadership .There are a number of challenges that beset the smaller scale, higher cost projects such as:

- The absence of an adequate carbon price signal that is commensurate with the risk of adverse climate change impacts is the fundamental reason why an optimal level of bio-energy is not currently achievable.
- The low price for Renewable Energy Certificates (RECs) and spot energy is a strong disincentive for the development of new projects.
- Regulatory gaps affecting eligibility and accreditation such as within the definitions of categories of fuels which may qualify as renewable energy.
- The high cost of arranging connection to the distribution system through project specific negotiation makes smaller projects non-viable.
- The lack of general information on the value of embedded generation to the network and the cost of connection make it costly to screen projects for viable options and to optimise project location.
- The lack of an effective process to co-ordinate many small projects in an area to justify a scale efficient network extension at the distribution level is similar to the same problem at the transmission level which is being addressed by the Australian Energy Markets Commission.
- Community support for local bio-energy projects can be difficult to sustain despite the benefits of local employment and security of electricity supply.

1.6.1 South Australian Bio-energy Political Landscape

In its Economic Statement of March 2009, the SA Economic Development Board (EDB) identified renewable energy as an important industry for South Australia's economic future and recommended strategies to promote technological innovation across a diverse range of technologies, the development of fast track demonstration plants, the minimisation of regulatory impediments and the securing of industry investment. Given current performance in renewable energy, the State is well placed to establish itself as the nation's leader in clean energy production and usage.

In 2009 the SA Government developed a renewable energy target of 33% by 2020 which was achieved in 2013 14. Most of this was a achieved via the adoption of solar and wind technologies.

Policies assisting the target included:

- Establishing Australians most streamlined planning framework for wind investors
- Introduction of Australia's first only payroll tax rebate scheme for wind investors
- Providing rebates and other financial assistance to the solar industry

In 2014 a renewable energy target of 50% by 2025 was set subject to a national renewable energy policy being retained.

Although part of the Government's planning considerations for other forms of energy, bio-energy has not yet been afforded the same opportunities as wind and solar. Bio-energy is featured in the State Development Plan's renewables section; however it is rarely present in council development plans. Bio-energy is not covered by the Office of the Technical Regulator at this stage.

2. Bio-energy Material Sources in South Australia

2.1 Relevant Materials

Feedstocks in SA can be grouped as noted in Table 2.1 below.

Table 2.1: Feedstock groupings

Feedstock	Constituents
Agricultural Waste	• Livestock manure • Abattoir waste solids • Other processing plants • Crop and food residues from harvesting and processing
Horticultural Waste	• Vegetables & fruit • Shells, pips, trees
Energy Crops	• Canola • Planted Mallee • Woody Weeds • Planted fast growing crops (annual and perennial) • Algae
Forest Residues	• Plantation forests • Saw mills residues • Manufactured wood plant residues
Municipal Waste	• Green organics, paper, Timber • Processed food

2.1.1 Existing Feedstocks

Animal Waste

Bioenergy potential exists with animal wastes from pig and dairy farming. These sources are generally high quality for anaerobic digestion processes. Other animal waste includes feed lots and potentially shearing sheds.

Animal waste is suitable for anaerobic digestion and is usually available as disposal can be a problematic for the farmer. Waste from milking sheds quite often requires permits to enable it to be irrigated to land. Processing the waste into energy can assist to deal with other environmental issues associated with the waste stream.

Animal waste is usually a very liquid waste with transport away from site to a central energy producing source expensive.

Refer to Figure 2.1 for a picture of a dairy shed effluent pond.

Figure 2.1: Dairy shed waste pond

Chicken Litter

In past years chicken shed litter (straw or sawdust, feathers and chicken excretion) has been taken away at no or little charge and provided to primary producers as a soil conditioner or poor quality fertiliser.

Most producers are now charged to remove their litter and because of the composition of the litter past recipients of the litter find it difficult to spread over their paddocks. The chicken industry continues to expand however disposal of the waste stream is now costly.

It is possible to produce reasonable amounts of energy from chicken litter. However transport away from site to a central energy producing source could become expensive. Chicken litter can be combusted or used in anaerobic digestion after addition of water.

Refer to Figure 2.2 for a picture of chicken litter.

Figure 2.2: Chicken litter

Horticultural Waste

Horticultural waste streams include end of growth materials from glasshouses, open paddock vegetable crops, fruit and nut crops and from tree and vine renewals. The waste stream is available for collection from all areas involved in horticultural activities. Collection of the waste would need to be well coordinated.

Figure 2.3: Waste from vineyard and other fruit tree renewal in the Barossa Valley, SA

Crop Stubble

Crop stubbles are available after initial harvest of grains from varieties of wheat and barley and are seen as a waste product from cropping programs. These stubbles may also be used for export orders making them unavailable. Removal of straw may reduce soil structure improvement attempts requiring additional fertilisers to be applied to grow the next crop. A reduction in stubble could also increase wind erosion of soil and accelerate moisture loss.

Baled straw ready for export is shown in

Figure 2:4

Figure 2:4: Stubble straw bales off to export, Kapunda, SA 2015

Forestry Waste

Forestry waste has two main streams:

- Trimmings (branches) left behind on the forests floor at the time of harvest
- Timber waste (bark and sawdust) from the saw milling processes.

Forestry waste is available for collection in all forestry areas; however it may be located in difficult to collect areas. There may be resistance to harvest as removal ultimately prevents nutrients returning to the soil.

Figure 2:5: Forestry waste placed in piles waiting to be burnt in the Barossa Valley, SA

2.1.2 Purpose Grown Biomass Feedstocks

The selection of plant species or biological materials for analysis in this project is based on the following:

- Planted species grow in areas not associated with high valued food crops
- The species are suited to dryland areas - regions with < 400mm annual rainfall and/ or with poor fertility
- The plant species can be planted or sown in these soil types
- Land cost is relatively low
- Land owners in these areas seeking alternatives to current activities
- Waste from existing known plant based growing activities eg horticulture
- Potential waste streams are currently poorly managed or not recovered as a potential use.

Selected species for purpose grown biomass crops include:

- Arundo Donax
- Brassica Juncea
- Sorghum Bicolour
- Phragmities Australia
- Mixed Mallee
- Woody weeds
- Corn / maize
- Cumbungie
- Algae

Arundo Donax

Arundo Donax (giant reed) is a rhizomatous grass widely found in temperate and subtropical regions. It was planted in the 1920 - 50's in SA because of its capacity to grow vigorously in marginal land to assist with the control of sand dune erosion and to provide tomato stakes for the horticultural industry. Many examples remain today.

Arundo Donax can be a medium biomass production crop on marginal lands and a high biomass producer with additional water. Arundo Donax is a perennial plant which can be harvested two times per year.   It has low fertility needs, however will respond to nitrogen fertilisers as required. Arundo Donax is a sterile plant and its propagation is based on vegetative propagation (rhizomes or canes) and in vitro culture, making establishing the crop more expensive than a seeded crop.

Refer to Figure 2:6 and Figure 2:7 for photos of Arundo Donax growing in SA.

Figure 2:6: Arundo Donax growing in 270mm rainfall region in the Mallee area of SA

Figure 2:7 : Arundo Donax growing in 350 mm rainfall coastal area of the Yorke Peninsula

Brassica Juncea

Brassica Juncea (Indian mustard), a close relative of canola (Brassica Napus) however it is more drought and heat tolerant and therefore an alternative oilseed to canola for the low rainfall zones in South Australia. Brassica Juncea is very tolerant of dry and climate variable conditions; however is not yet a mainstream dryland cropping plant. Refer to Figure 2:8 for a photo of Brassica Juncea in flower.

Figure 2:8: Brassica Juncea in flower

Sorghum Bicolour

Sorghum Bicolour (sweet sorghum) is receiving significant global interest because of its potential as a multi-product crop, however there has been minimal research under Australian growing conditions. Under favourable growing conditions, Sorghum can produce high biomass yields with low rates of nitrogen fertilizer. Growth can be exceptional growth under the correct moisture and temperature conditions. More trials are required to understand varieties and opportunities in Australia.

Refer to Figure 2:9 for an example of Sorghum growing in SA.

Figure 2:9: Sorghum growing at Loxton, SA with minor irrigation

Phragmites Australis

Phragmites Australis (common reed) is a plant associated with freshwater wetlands in South Australia; the River Murray Swamps, Lower Lakes and where fresh ground water rises to within 2 m of the soil surface. Phragmites Australis is very tolerant of swamps and waste water areas and could be harvested twice per annum. Phragmites Australis has a dormant period of around six weeks per year and requires either surface flooding or ground water close to the surface to thrive.

Refer to Figure 2:10 for an example of Phragmites growing in SA.

Figure 2:10: Phragmites growing on the River Murray swamps in 2013

Mixed Mallee

Mixed Mallee (eucalyptus sp) species vary with growth primarily based on rainfall. In the first two years rainfall is important for success however not essential. Methods of establishment include traditional seedlings or direct seeding which is successful at much lower lost to that of seedlings. Mixed Mallee is relative easy to establish in large areas at low cost, however it takes many years to grow in low rainfall areas prior to first harvest.

Refer to Figure 2:11 and Figure 2:12 for an example of Mallee at different growth stages.

Figure 2:11: 4 year old planted Mallee in 275mm rainfall area

Figure 2:12: 15 year old direct seeded Mallee

Woody Weeds

Woody weeds are plants (trees and shrubs) that have become problems species causing an impact to catchments, native vegetation areas, government and private land. Woody weeds include Aleppo pines, Olives, Pittosporum and Acacia. Many thousands of dollars are spent burning these weeds to control spread of these weeds every year. The weeds may be found in areas that are difficult to harvest.

Pines and olives actively growing in the Adelaide Hills are shown in Figure 2:13.

Figure 2:13: Pines and Olives smothering landscapes in the Adelaide Hills

2.2 Quantities and Geographical Origins

Jacobs has undertaken GIS mapping of the existing bio-energy feedstocks and purpose grown biomass. Key input information included in the maps is (depending on the particular product):

- Stock numbers from Primary Industries Information Management System (PIIMS) database
- PIRSA statewide land use classification
- Generalised land use
- Soil types
- Rainfall
- Various industries that could contribute feedstocks such as chicken growers, dairy milking sheds, feedlots, meat processing plants, horticulture, crops and the like
- Land parcels

The information sources that have been used are referenced in Appendix B.1. The sources are generally government departments such as PIRSA, DMITRE, BOM, SARIG and the like.

Quantities of feedstocks have been calculated subject to feedstock type by either:

- Known areas with that feedstock multiplied by typical yields per area for that particular area, or,
- Known stocks numbers multiplied by feedstock yield per animal for that animal.

The quantities have then been multiplied by the calorific value of the particular feedstock to determine the potential energy yield.

Summaries by feedstock grouping (slurries cf biomass) are shown in Figure 2.14 and Figure 2.15. The locations and quantities of the existing biomass energy sources are shown in Figure 2.16 for all feedstocks.

Figure 2.14: Summary of existing slurry type feedstocks by location

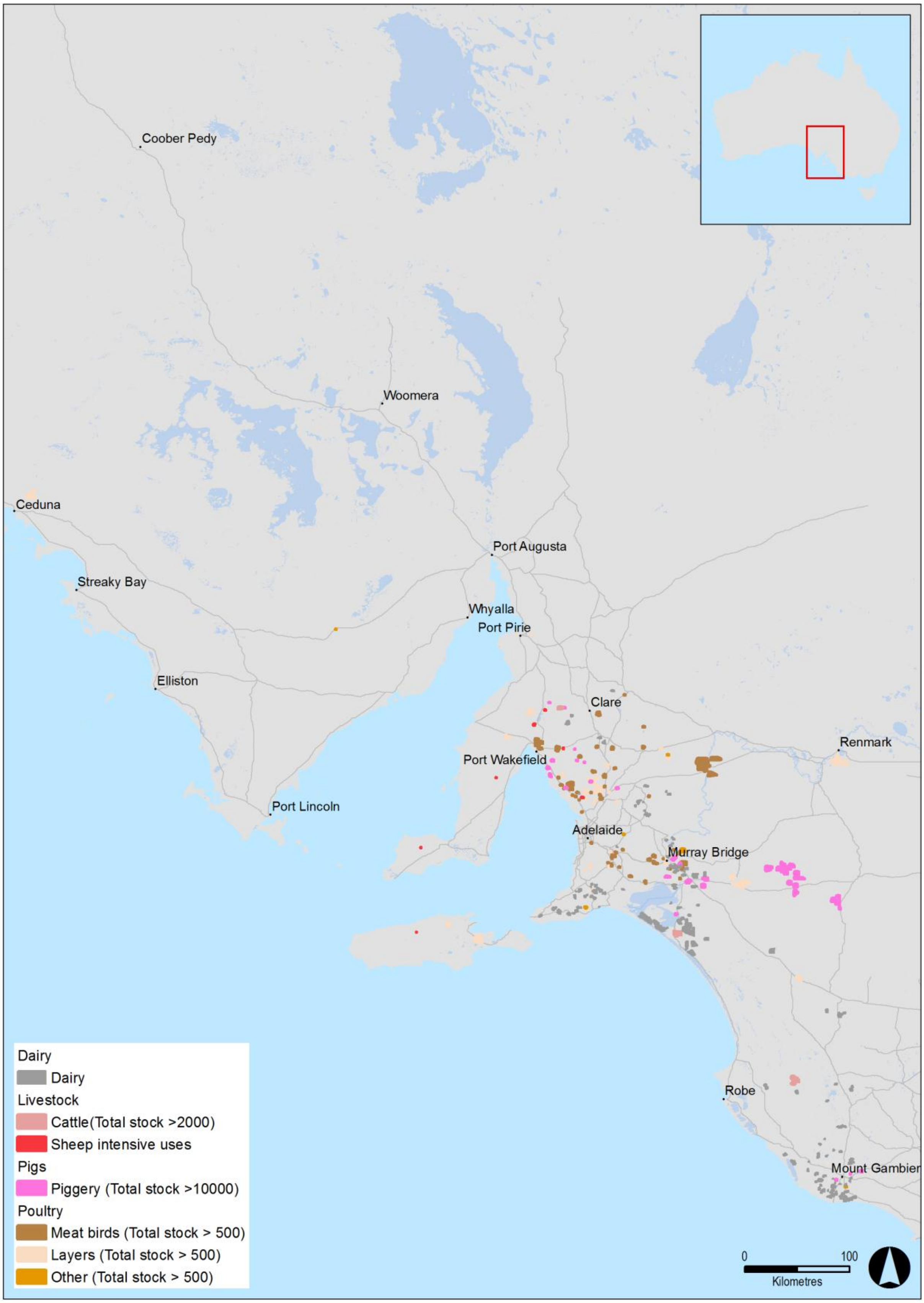


Figure 2.15: Summary of existing biomass type feedstocks by location

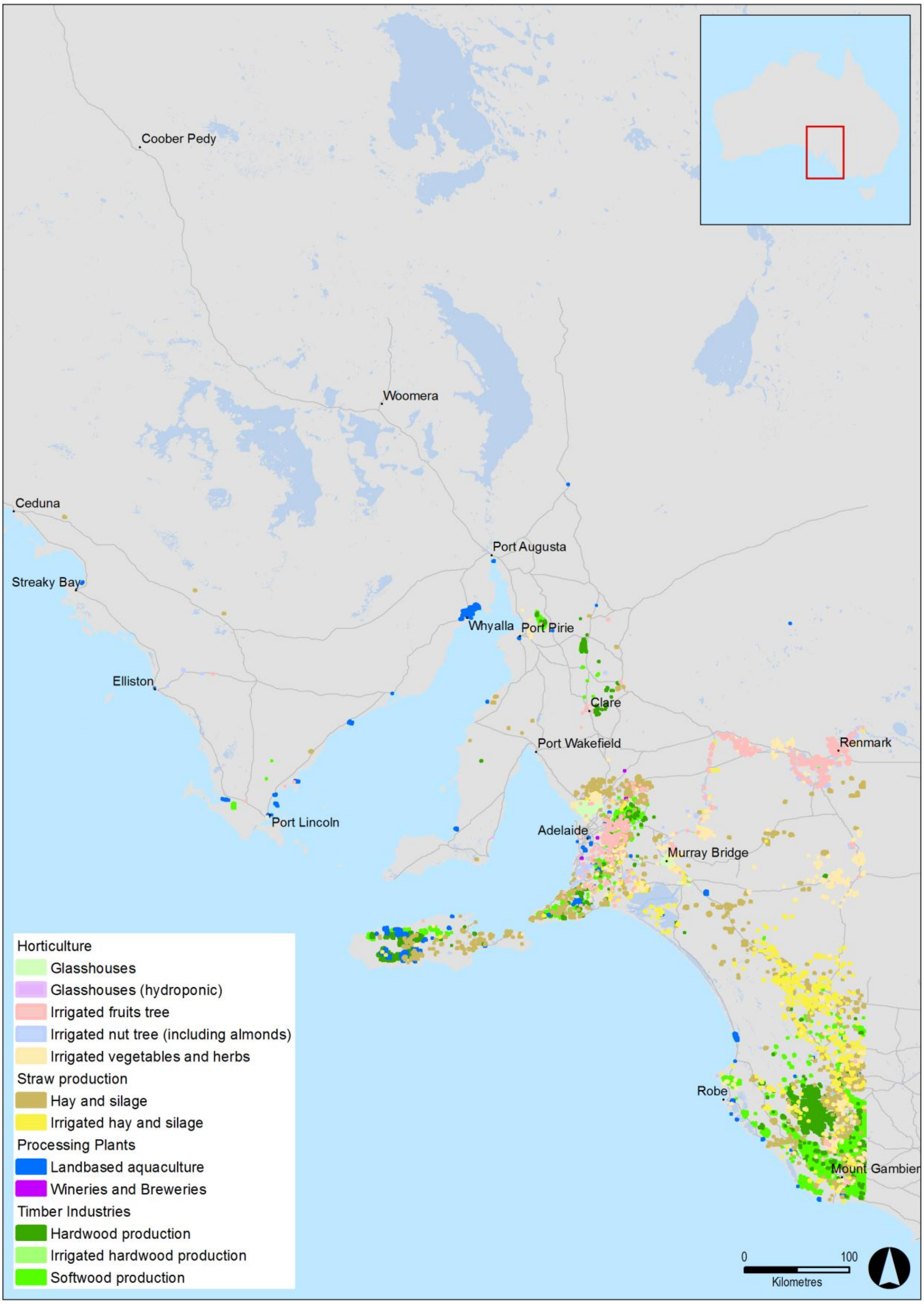
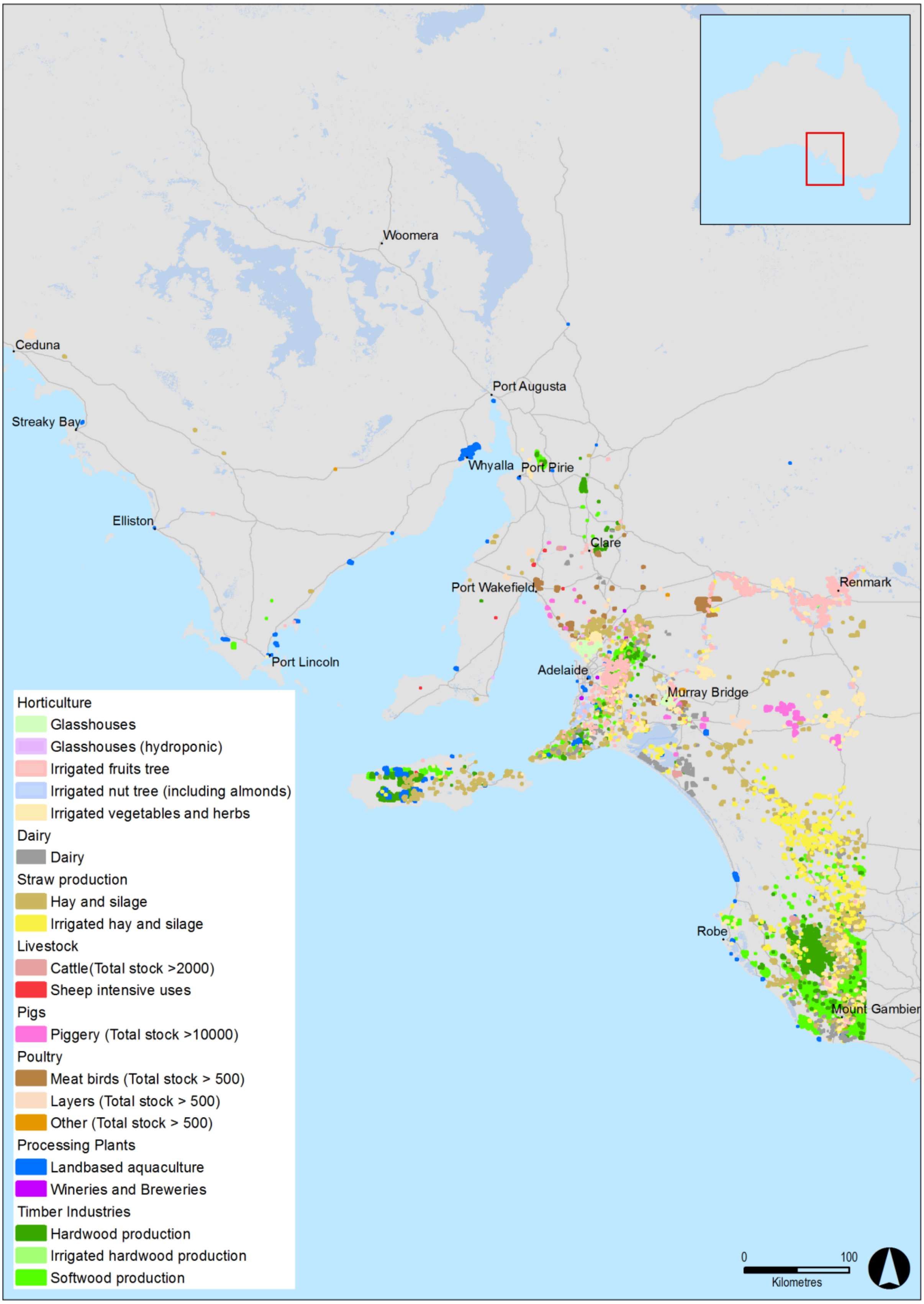


Figure 2.16: Summary of existing feedstocks by location



Expected quantities and calorific values for the existing feedstocks are shown in Table 2.2. The calorific values stated are at the moisture content stated in the table.

Table 2.2: Existing bio-energy materials

Material	Actual Tonnes (t) / Volume (m3) or No.s	Calorific Value (MJ/kg or MJ/No.)	Moisture Content (%)	Comment
Timber	984,000 tpa	7.7	50	
Poultry	30,310,000 chickens	96		Slurry
Broadacre	154,000 tpa	14	15	
Pigs	225,000 pigs	1,580		Slurry
Horticulture	112,500 tpa	10	50	
Livestock	15,200 cows	3,240		Slurry
Dairy	88,000 cows	3,240		Slurry

Locations to grow purpose grown biomass crops are summarised in Figure 2.16, Figure 2.17 and Figure 2.18 by crop and location.

Figure 2.16: Summary of potential growing areas for Algae, Arundo Donax and Corn / Maize

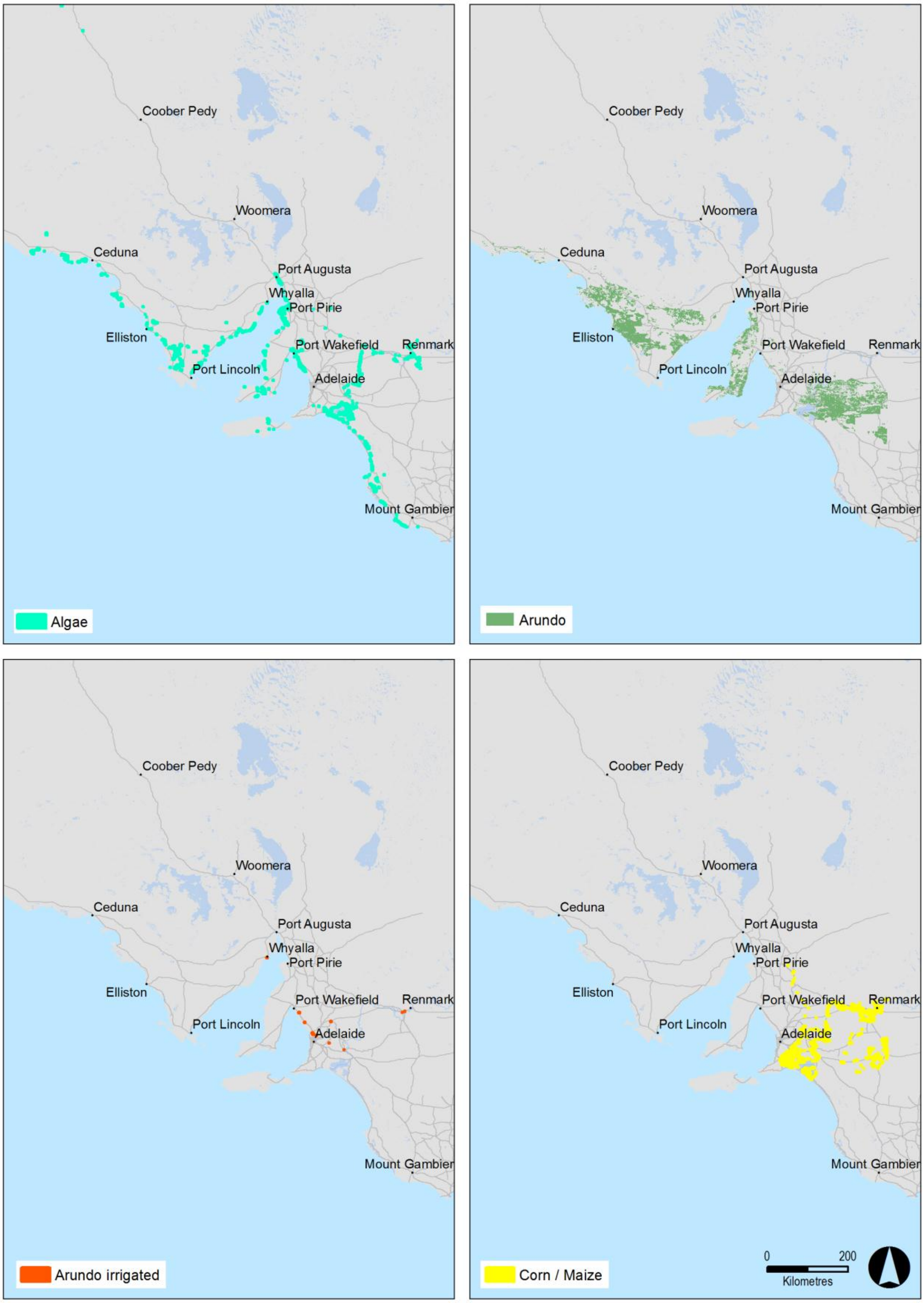


Figure 2.17: Summary of potential growing areas for Cumbungie, Mallee, Phragmities and Sorghum

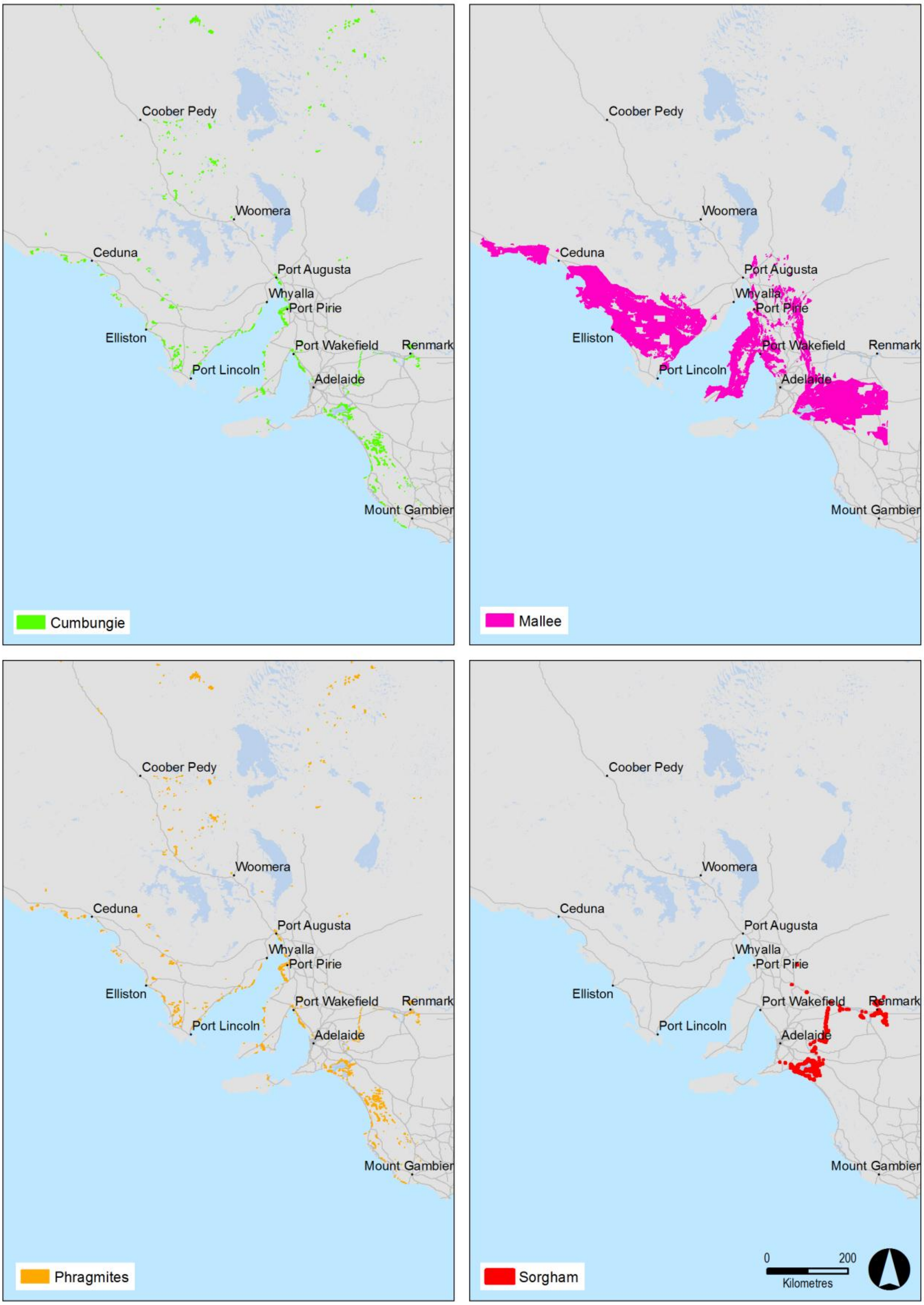


Figure 2.18: Summary of potential growing areas for Woody weeds, Brassica Juncea (Indian Mustard) and Acacia Saligna

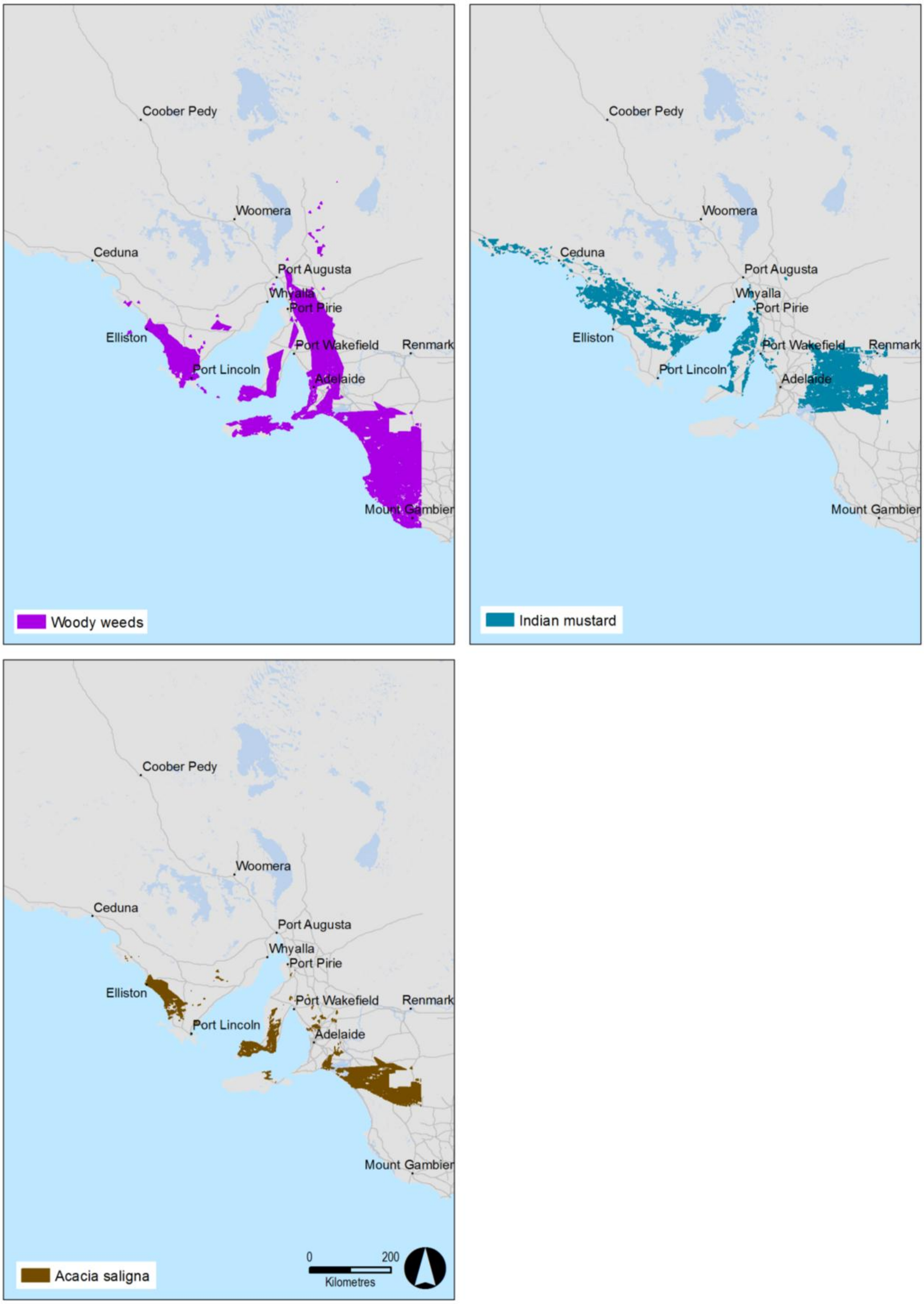


Table 2.3 summarises the potential purpose grown feedstock tonnages and calorific value. The calorific value is at the stated moisture content. The tonnages stated in the table have been factored by 30%. The factor has been applied to account for the following:

- Crop uptake by landholders.
- Unproductive areas such as roads, buildings and the like.

Table 2.3: Prospective bio-energy feedstocks

Feedstock	Potential Yields (Mtpa)	Calorific Value (MJ/kg)	Moisture Content (%)	Comment
Arundo Donax	93	7.6	50	
Woody weeds	150	7.7	50	
Mallee	23	7.7	50	
Cumbungie	4.2	10.7	35	
Corn / Maize	1.5	6.2	55	
Phragmities	4.2	11.7	30	
Acacia Saligna	5.7	8.2	50	
Brassica Juncea	1.2	6.0	50	

3. Bio-energy Demand Sources in South Australia

Most industries have some form of energy demand. The demand can be either be electricity or electricity and process heat. It would be unusual to have a process heat demand without having some form of electrical demand. The report focuses on users that have both electrical and process heat demand as it is expected that potential bio-energy plants will be more likely to be viable due to the combined heat and power returns. Key industries are:

- Meat processing, e.g. abattoirs and smallgoods manufacturers
- Rendering
- Dairy processing, eg bulk dairy commodities such as milk powder and cheese production
- Chicken breeding
- Food, e.g. bakeries and vegetable processing
- Beverage, e.g. softdrink manufacturers, beer, wine and dairy
- Pulp and paper, e.g. consumer products such paper towels and the like
- Timber, e.g. timber drying and manufactured wood products
- Cement
- Horticulture, e.g. vegetable production
- Wool processing
- Fish processing
- Metals, e.g. smelting, casting
- Feed mills.

Subject to the scale of the operation, the industries noted above generally have a higher energy use.

The meat processing industry is characterised by a range of plant sizes and configurations from boutique home kill to large multispecies export plants and from slaughter only to slaughter and further processing to just further processing. The larger more complex plants are more likely to have their own bi product processing plants on site and have an onsite wastewater treatment plant. The major meat processors are typically located as far north as Port Wakefield, as far south east as Naracoorte and near the SA / Vic border.

Meat processing and allied industries such as rendering are typically energy intensify in terms of process heat and electricity. Process heat demands typically include:

- Making hot water for equipment sterilisation, plant wash-down
- Hot water used directly in the process such as casings processing and tanning
- A variety of heating applications such as cooking offal, heating process vessels / tanks to prevent the solidification of tallow, coagulating blood and wool drying amongst others.

Electricity demands are typically dominated by the refrigeration plant electricity requirements.

The dairy industry is similar to the meat processing industry and is characterised by a broad range of plant sizes and complexity. Commodity dairy product plants are typically energy intensive with energy demands driven by powder drier heat requirements and process sterilisation requirements. Dairy plants are typically located in the Adelaide region and in the south east of the State. Most of the plants in the state are boutique through to small commercial operators. The old McCain potato plant at Penola is being modified into a commodity dairy plant. The Murray Bridge dairy plant has closed after the owner went into administration.

Chicken growers are typically located around the broader Adelaide region ranging from Tailem Bend through to Port Wakefield. Chicken growers typically heat and ventilate their sheds and therefore have both gas and electricity requirements. Chicken processing is typically located in the Northern Adelaide commercial suburbs. Chicken processing energy demands are similar in nature to meat processing energy demands.

The State's food processing industry appears to be dominated by niche to small plants with fewer large commercial operators. The larger operators are represented by the likes of Arnotts, Tip Top Bakeries and Quality Bakers. Food processor energy demands are similar in nature to meat and dairy plants, i.e, there are process heat requirements and electrical demands. Bakeries are less likely to have major electrical loads such as refrigeration. The state's major bakeries are generally located in suburban Adelaide.

The State has quite a number of beverage manufacturers. The beverage sector manufacturers wine, beer, cider, soft drinks, bottled water, flavoured milk and juice. The manufacturers range from the small niche producers to large commercial operators. The larger commercial operators are represented by the likes of Coopers, Lionco (Westend and National Foods), Coca Cola Amatil, Wolf Blass and Jacobs Creek. The manufacturers are typically in the broader Adelaide area with the wineries having the greatest geographic spread across the Barossa Valley, Clare Valley, McLaren Vale and the Riverlands. The beverage production sites have both process heat and refrigeration requirements to a greater or lesser degree subject to the sector. For example, breweries require process heat for fermentation, pasteurisation and equipment cleaning, however they are unlikely to have major refrigeration loads whereas flavoured milk manufacturers will.

Fish processing in the State is largely centred around Port Lincoln and Adelaide and involves catching, distribution and further processing. Fish processors process heat and electrical demands are similar in nature to the meat industry, i.e., heat is required for cooking, and equipment wash-down, and electricity is required for refrigeration with significant energy going into ice production for the fresh fish distribution.

SA has one commercial scale wool scour (Michell Wool) based in suburban Adelaide. The scouring requires process heat and electricity to remove the grease and other contaminates from the wool prior to the wool being further processed for use.

The State's horticulture industry, in particular glasshouse vegetable and fruit production and mushroom growing use both process heat and electricity at different times of the year. Process heat and electricity is required to maintain optimum growing conditions such as temperature and humidity during the summer and winter months. The glasshouse horticultural areas are typically located around Virginia and in the Riverland area.

SA has one cement manufacturing company (Adelaide Brighton Cement) with sites located in Adelaide and Angaston. The cement manufacturing process uses both process heat and electricity. The cement manufacturer kilns already use a process engineered waste for heating.

The State's metals processing industry includes a range of sectors and companies. These include Nyrstar's lead smelter / refinery at Port Pirie, BHPB's Olympic Dam near Roxby Downs, Adchem's copper concentrate plant at Burra and Intercast's foundry in Adelaide. The metal processing industry requires heat for their various process and often large amounts of electricity to drive grinding mills and the like.

The pulp and paper sector comprises of one plant (Kimberly Clark) located in the south east of the state. The plant manufacturers' paper based consumer products such as paper towels, nappies, toilet tissue, incontinence products and like. The manufacturing processes require both process heat and power as evidenced by the recent installation of a natural gas fired cogeneration plant (a biomass fired plant was considered but did not show economic advantage).

The SA timber industry is largely based in the south east of the state with various smaller scale operations located around Adelaide. The industry comprises of a range of producers from small scale sawmills to larger production plants. Small scale examples include South East Pine Sales, South East Pine Treatment and examples of the larger scale operations include Carter Holt Harvey wood products sawmill, particle board and laminated veneer lumber manufacturing. Process heat is required for timber drying and particle board production. Electricity is required for general power for the manufacturing processes. It is expected that, in general, sawmills will not have a large electricity demand compared to the manufactured wood products plants.

SA has several stock feed mills; these are typically located around the broader Adelaide area. Feed mills typically use process heat and power to manufacture the stock feed subject to the type of food being manufactured. Process heat may be required in palletisation processes and for equipment cleaning purposes. Electricity is required for general power for the manufacturing processes.

The potential demands and their locations are summarised in Table 3.1 below.

Table 3.1: Potential demands and their locations

Industry	Company	Location	Demand Quantum
Beverage	Bickfords	Salisbury	100kW to 1MW
Beverage	Coca Cola Amatil	Thebarton	1MW to 10MW
Beverage	Lionco	Salisbury	100kW to 1MW
Beverage	Nippy's	Regency Park	100kW to 1MW
Beverage	Nippy's	Waikerie	100kW to 1MW
Beverage	Nippy's	Moorook	100kW to 1MW
Brewing	Lionco	Thebarton	1MW to 10MW
Brewing	Coopers	Regency Park	1MW to 10MW
Brewing	The Hills Cider Company	Adelaide Hills	100kW to 1MW
Brewing	Barrossa Valley Brewing	Tanunda	100kW to 1MW
Cement	Adelaide Brighton Cement	Birkenhead	1MW - 10MW
Cement	Adelaide Brighton Cement	Angaston	1MW - 10MW
Chicken Growers	Southern Cross Farms Australian	Owen	100kW to 1MW
Chicken Growers	Unknown	Murray Bridge	100kW to 1MW
Chicken Growers	Unknown	Monarto	100kW to 1MW
Chicken Growers	Unknown	Port Wakefield	100kW to 1MW
Chicken Growers	Unknown	Langhornes Creek	100kW to 1MW
Chicken Growers	Unknown	Tailem Bend	100kW to 1MW
Chicken Processing	Inghams Chicken	Virginia	100kW to 1MW
Chicken Processing	Baiada / Adelaide Poultry P/L	Wingfield	100kW to 1MW
Chicken Processing	Goumet Poultry Service	Cavan	100kW to 1MW
Chicken Processing	Inghams Enterprises P/L	Bolivar	100kW to 1MW
Chicken Processing	Inghams Enterprises P/L	Wingfield	100kW to 1MW
Commercial Hub	Multiple	Monarto	100kW to 1MW
Confectionary	Haighs	Parkside	100kW to 1MW
Copper Mining	Unknown	Port Pirie	Unknown

Industry	Company	Location	Demand Quantum
Beverage	Bickfords	Salisbury	100kW to 1MW
Beverage	Coca Cola Amatil	Thebarton	1MW to 10MW
Beverage	Lionco	Salisbury	100kW to 1MW
Beverage	Nippy's	Regency Park	100kW to 1MW
Beverage	Nippy's	Waikerie	100kW to 1MW
Beverage	Nippy's	Moorook	100kW to 1MW
Brewing	Lionco	Thebarton	1MW to 10MW
Brewing	Coopers	Regency Park	1MW to 10MW
Brewing	The Hills Cider Company	Adelaide Hills	100kW to 1MW
Brewing	Barrossa Valley Brewing	Tanunda	100kW to 1MW
Cement	Adelaide Brighton Cement	Birkenhead	1MW - 10MW
Cement	Adelaide Brighton Cement	Angaston	1MW - 10MW
Chicken Growers	Southern Cross Farms Australian	Owen	100kW to 1MW
Chicken Growers	Unknown	Murray Bridge	100kW to 1MW
Chicken Growers	Unknown	Monarto	100kW to 1MW
Chicken Growers	Unknown	Port Wakefield	100kW to 1MW
Chicken Growers	Unknown	Langhornes Creek	100kW to 1MW
Chicken Growers	Unknown	Tailem Bend	100kW to 1MW
Chicken Processing	Inghams Chicken	Virginia	100kW to 1MW
Chicken Processing	Baiada / Adelaide Poultry P/L	Wingfield	100kW to 1MW
Chicken Processing	Goumet Poultry Service	Cavan	100kW to 1MW
Chicken Processing	Inghams Enterprises P/L	Bolivar	100kW to 1MW
Chicken Processing	Inghams Enterprises P/L	Wingfield	100kW to 1MW
Commercial Hub	Multiple	Monarto	100kW to 1MW
Confectionary	Haighs	Parkside	100kW to 1MW
Copper Mining	Unknown	Port Pirie	Unknown
Copper Mining	Rex Minerals	Ardrossan	10MW +
Copper Mining	Hillgrove Resources	Callington	10MW +
Dairy Processing	Farm cluster	Mt Gambier, Mt Shank	100kW to 1MW
Dairy Processing	United Dairy	Murray Bridge	100kW to 1MW
Dairy Processing	Alexandrina Cheese Company	Mt Jagged	100kW to 1MW
Dairy Processing	B-D Farm	Paris Creek	100kW to 1MW

Industry	Company	Location	Demand Quantum
Dairy Processing	Barossa Valley Cheese Company	Angaston	100kW to 1MW
Dairy Processing	Fleurieu Milk & Yoghurt Company	Myponga	100kW to 1MW
Dairy Processing	Udder Delights	Lobethal	100kW to 1MW
Dairy Processing	Woodside Cheese Wrights	Woodside	100kW to 1MW
Feed Mill	Laukies Feed mills	Daveyston	1MW to 10MW
Feed Mill	Balco Australia	Bowmans	100kW to 1MW
Feed Mill	Unknown	Southern Mallee	100kW to 1MW
Feed Mill	Unknown	Southern mallee	100kW to 1MW
Feed Mill	Unknown	Bowmans	100kW to 1MW
Feedlots	Unknown	Meningie/Field	less than 100kW
Feedlots	Iranda Feedlot	Tintinara	less than 100kW
Copper Mining	Rex Minerals	Ardrossan	10MW +
Copper Mining	Hillgrove Resources	Callington	10MW +
Dairy Processing	Farm cluster	Mt Gambier, Mt Shank	100kW to 1MW
Dairy Processing	United Dairy	Murray Bridge	100kW to 1MW
Dairy Processing	Alexandrina Cheese Company	Mt Jagged	100kW to 1MW
Dairy Processing	B-D Farm	Paris Creek	100kW to 1MW
Dairy Processing	Barossa Valley Cheese Company	Angaston	100kW to 1MW
Dairy Processing	Fleurieu Milk & Yoghurt Company	Myponga	100kW to 1MW
Dairy Processing	Udder Delights	Lobethal	100kW to 1MW
Dairy Processing	Woodside Cheese Wrights	Woodside	100kW to 1MW
Feed Mill	Laukies Feed mills	Daveyston	1MW to 10MW
Feed Mill	Balco Australia	Bowmans	100kW to 1MW
Feed Mill	Unknown	Southern Mallee	100kW to 1MW
Feed Mill	Unknown	Southern mallee	100kW to 1MW
Feed Mill	Unknown	Bowmans	100kW to 1MW
Feedlots	Unknown	Meningie/Field	less than 100kW
Feedlots	Iranda Feedlot	Tintinara	less than 100kW
Feedlots	S. Kidman & Co Ltd	Sedan	less than 100kW
Feedlots	Tungali Feedlot	Sedan	less than 100kW
Fish	Tony's Tuna	Port Lincoln	100kW to 1MW
Fish	SAFCOL	Elizabeth South	100kW to 1MW

Industry	Company	Location	Demand Quantum
Food	Arnotts	Marleston	100kW to 1MW
Food	Beerenberg	Hahndorf	100kW to 1MW
Food	Kytons Bakery	Edwardstown	100kW to 1MW
Food	Balfours Bakery	Dudley Park	100kW to 1MW
Food	Tip Top Bakeries	Dry Creek	100kW to 1MW
Food	Quality Bakers	Forrestville	100kW to 1MW
Forestry	Unknown	Nangwarry	10MW +
Forestry	Unknown	Mt Gambier	10MW +
Forestry	Unknown	Kuipto	10MW +
Horticulture	Unknown	Virginia	100kW to 1MW
Horticulture	Unknown	Virginia	100kW to 1MW
Horticulture	Unknown	Glandore	100kW to 1MW
Horticulture	Unknown	Riverland	100kW to 1MW
Horticulture	Unknown	Waikerie	100kW to 1MW
Horticulture	Unknown	Loxton	100kW to 1MW
Horticulture	Unknown	Virginia	100kW to 1MW
Horticulture	Unknown	Renmark	100kW to 1MW
Horticulture	Unknown	Monarto	100kW to 1MW
Horticulture	Unknown	Virginia	100kW to 1MW
Manufacturing	Intercast	Wingfield	100kW to 1MW
Meat Processing	Thomas International	Murray Bridge	1MW to 10MW
Meat Processing	Gawler River Cattle Co	Royal Park	100kW to 1MW
Meat Processing	JBS Australia	Bordertown	1MW to 10MW
Meat Processing	Camden Park	mybutcher	100kW to 1MW
Meat Processing	Thomas International	Lobethal	100kW to 1MW
Meat Processing	Strath Pastoral	Strathalbyn	less than 100kW
Meat Processing	Macro Meats,	Athol Park	100kW to 1MW
Meat Processing	Teys Australia	Naracoorte	100kW to 1MW
Meat Processing	Top Cut	Brompton	100kW to 1MW
Meat Processing	Wakefield Grange	Wattle Flat	less than 100kW
Meat Processing	Barossa Fine Foods	Edinburgh North	less than 100kW
Meat Processing	Prime Valley Pastoral Trading	Two Wells	less than 100kW
Meat Processing	Austral	Gepps Cross	100kW to 1MW
Meat Processing	Holco	North Cavan	100kW to 1MW

Industry	Company	Location	Demand Quantum
Metals	Nyrstar	Port Pirie	70 MW
Native forest trimmings	Unknown	Various	1MW - 10MW
Paper	Kimberly Clarke		20MW
Petfood	Bucket O Beef	St Marys	100kW to 1MW
Pig Farm	Unknown	Renmark	100kW to 1MW
Pig Farm	Unknown	Dublin/Pt Wakefield	100kW to 1MW
Pig Farm	Unknown	Barossa	100kW to 1MW
Pig Farm	Unknown	Lamaroo	100kW to 1MW
Pig Farm	Unknown	Murray Bridge	100kW to 1MW
Pig Processing	Unknown	MB Wosley Sheoak	100kW to 1MW
Pig Processing	Big River Pork	Murray Bridge	100kW to 1MW
Pig Processing	Primo Australia	Pt Wakefield	100kW to 1MW
Power	Infratil	Port Stanvac	10MW +
Power	Infratil	Lonsdale	10MW +
Power	Infratil	Angaston	10MW +
Power	Osbourne Cogeneration	Osbourne	10MW +
Power	Energy Australia	Hallet	10MW +
Power	AGL	Torrens Island	10MW +
Power	AGL	Regency Park	10MW +
Power	GDF Suez	Dry Creek	10MW +
Power	GDF Suez	Mintaro	10MW +
Power	GDF Suez	Snuggery	10MW +
Power	GDF Suez	Port Lincoln	10MW +
Power	GDF Suez	Pelican Point	10MW +
Power	Origin	Origin, Quarrantine	10MW +
Power	Origin	Ladbroke Grove	10MW +
Power	Alinta Energy	Port Augusta	10MW +
Rendering	MBL Protein	Keith	100kW to 1MW
Rendering	MBL Protein	Wingfield	100kW to 1MW
Temperature Controlled Storage	Lenswood Cooperative	Lenswood	100kW to 1MW
Temperature Controlled Storage	Unknown	Pooraka	100kW to 1MW
Temperature Controlled Storage	Swire	Cavan	100kW to 1MW
Timber - eucalyptus	New Forest	Kangaroo Island	1MW - 10MW

Industry	Company	Location	Demand Quantum
Timber - eucalytpus	Unknown	South East	1MW - 10MW
Timber - eucalytpus	Unknown	Mid-North	1MW - 10MW
Wineries	Project Wines	Milang	100kW to 1MW
Wineries	Unknown	Belvidere	100kW to 1MW
Wineries	Lake Breeze	Langhornes Creek	100kW to 1MW
Wineries	Temple Bruer	Langhornes Creek	100kW to 1MW
Wineries	Pure Vision Organics	Virginia	100kW to 1MW
Wineries	Waterloo	Virginia	100kW to 1MW
Wineries	Woodside	Adelaide Hills	100kW to 1MW
Wineries	Jeannerets	Sevenhill	100kW to 1MW
Wineries	Jim Barry	Clare	100kW to 1MW
Wineries	Paulett	Sevenhill	100kW to 1MW
Wineries	Kirrabilly	Clare	100kW to 1MW
Wineries	Mitchell	Penwortham	100kW to 1MW
Wineries	Tatachilla	McLaren Vale	100kW to 1MW
Wineries	Winemakers	McLaren Vale	100kW to 1MW
Wineries	Boars Rock	McLaren Vale	100kW to 1MW
Wineries	Foggo	McLaren Vale	100kW to 1MW
Wineries	Geddes	Blewitt Springs	100kW to 1MW
Wineries	Pirramimma	McLaren Vale	100kW to 1MW
Wineries	Rosemount	McLaren Vale	100kW to 1MW
Wineries	Tiers Wines	McLaren Vale	100kW to 1MW
Wineries	Trott	McLaren Vale	100kW to 1MW
Wineries	Wirra Wirra	McLaren Vale	100kW to 1MW
Wineries	Hollicks	Coonawarra	100kW to 1MW
Wineries	Katnook	Coonawarra	100kW to 1MW
Wineries	Leconfield	Coonawarra	100kW to 1MW
Wineries	Penley	Coonawarra	100kW to 1MW
Wineries	Zema	Coonawarra	100kW to 1MW
Wineries	Angoves	Renmark	100kW to 1MW
Wineries	Amakira	Loxton	100kW to 1MW
Wineries	Grant Burge	Lyndoch	100kW to 1MW
Wineries	Pernod Ricard	Rowland Flat	100kW to 1MW
Wineries	Bethany	Tanunda	100kW to 1MW
Wineries	Charles Melton Wines	Tanunda	100kW to 1MW

Industry	Company	Location	Demand Quantum
Wineries	Henschke	Keyneton	100kW to 1MW
Wineries	Harbord	Stockwell	100kW to 1MW
Wineries	Richmond Grove	Tanunda	100kW to 1MW
Wineries	Tarac Technologies	Nuriootpa	100kW to 1MW
Wineries	Viking	Marananga	100kW to 1MW
Wool	Michell Wool	Salisbury	1MW - 10MW

Demand locations are shown graphically in Figure 3.1: Potential demand locations and Figure 3.2.

Figure 3.1: Potential demand locations

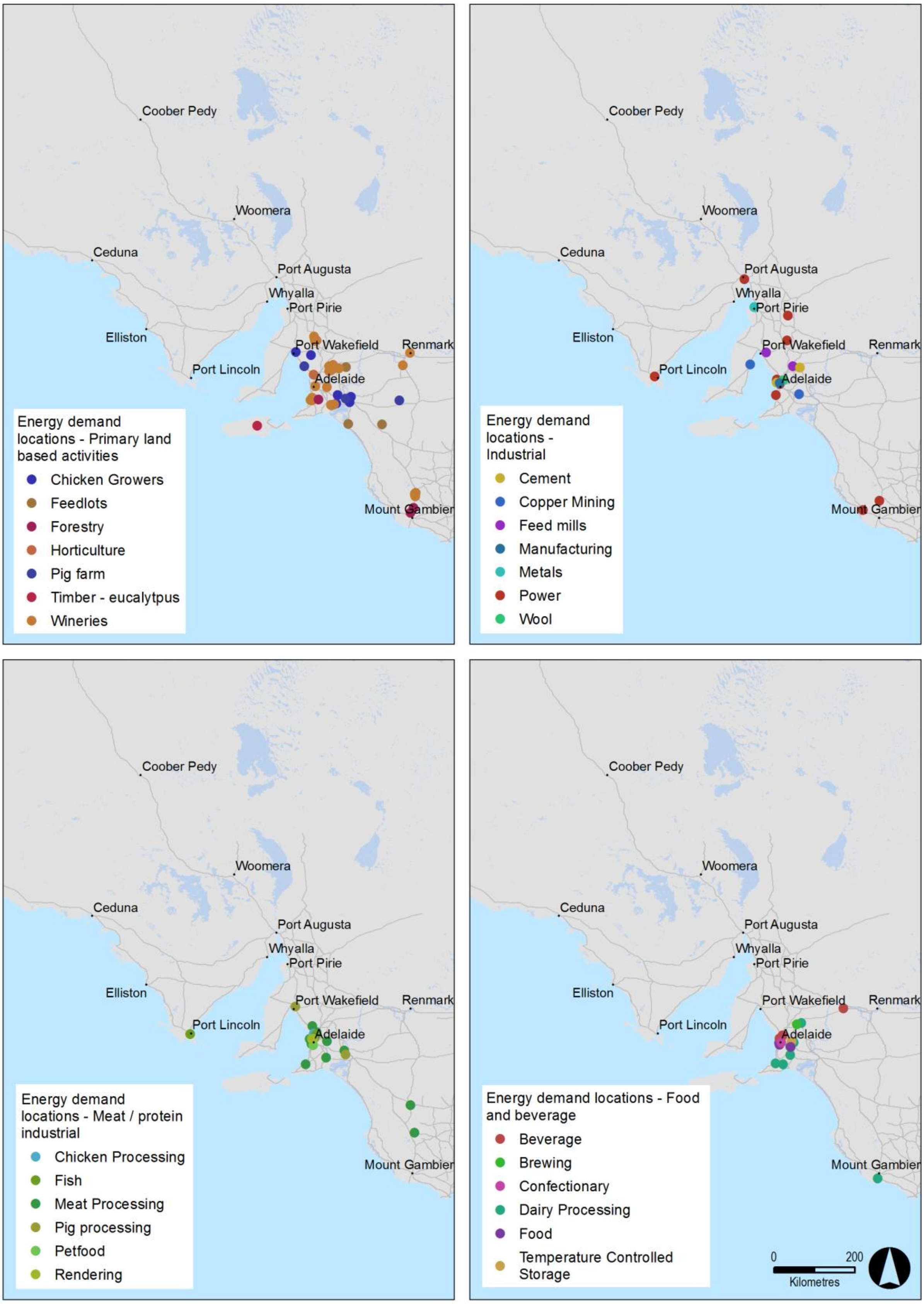
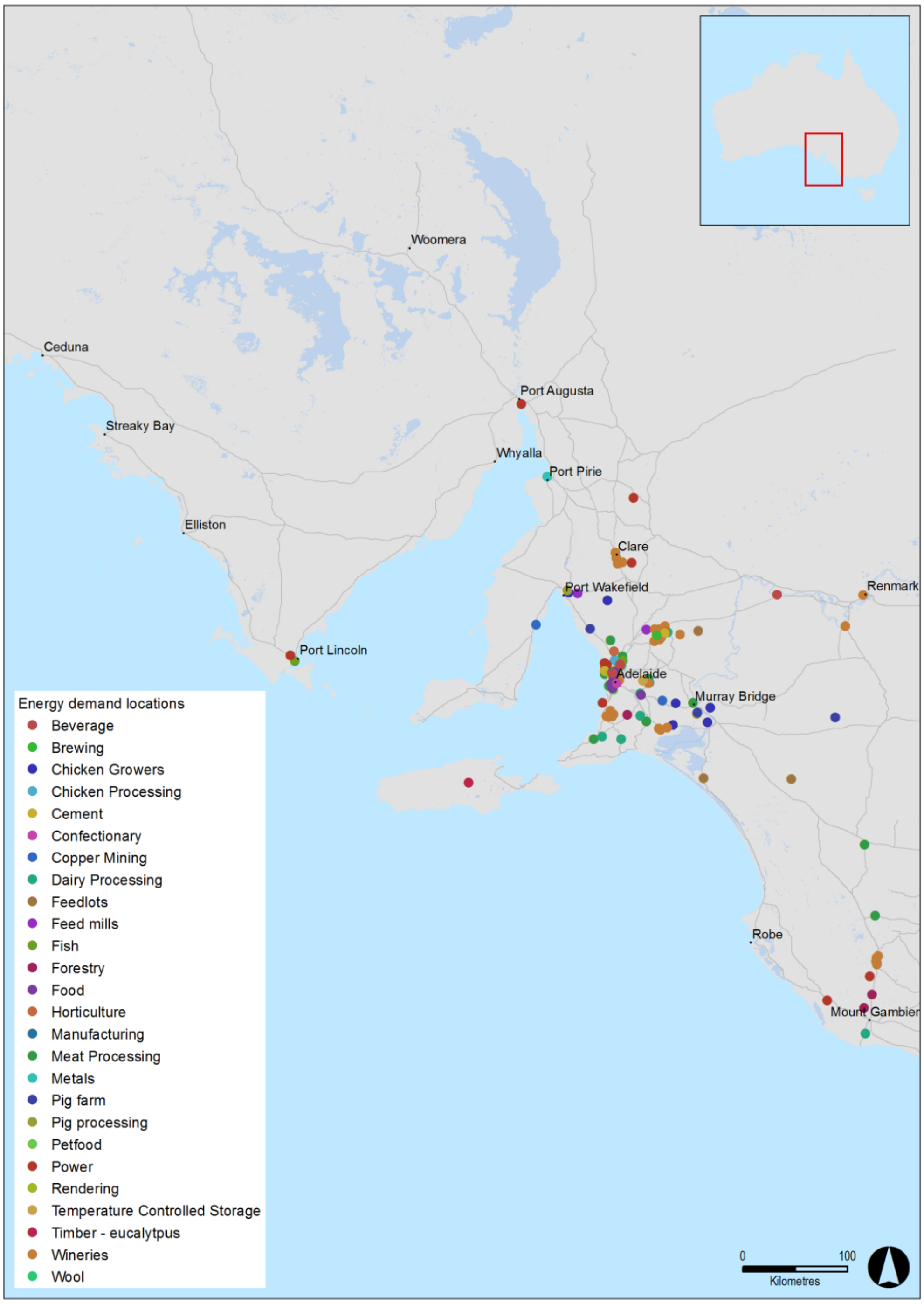


Figure 3.2: Demand location summary



4. Logistical Factors Influencing Bio-energy Projects in South Australia

There are several logistics challenges for hauling bio-energy feedstocks. These include low value per tonne,low density, few economies of scale and the need for purpose built vehicles.

Most bio-energy feedstocks will be of low unit value as they are typically bi-products of a current process. On this basis it will likely be economic to haul the feedstocks over short distances only, similar to other low value industry inputs. For example, sugarcane, or building inputs like sand and gravel are rarely hauled more than 40-50 km. 40-50 km is a road distance, so ‘as the crow flies’, the distance may be lower. Overseas experience has shown that feedstocks can be hauled over longer distances, potentially up to 100 km if the feedstock is readily transportable / has higher value.

Feedstock type, e.g., a solid such as straw bales compared to a slurry such as pig effluent, has an impact on the economic haul distance. The materials handling at either end of the trip also impacts the economics, e.g., a manual materials handling system will have a low capital cost but a higher operating cost versus a more automatic material handling system. Vehicles with more expensive body options e.g. tankers or covered bulk tippers will have an impact on the haulage economics. Neither of these vehicles has low operating costs further deterring long distance haulage. Purpose built vehicles, e.g., hauling woodchips using self-discharging trailers with moving floors may be required subject to the haulage volume. Low cost alternatives are possible, for example, old petroleum road tankers can be converted to carry bulk tallow by changing the tanker piping and installing an insulating cover.

Overseas experience has shown that solid easily handled feedstocks tend to be hauled the longest distance e.g. straw bales. Solid feedstocks that are less easily handled, e.g. MSW tend to be hauled shorter distances. We note that in South Australia MSW tends to be hauled longer distances and that there is already an established transport network to deliver MSW to the States landfill facilities. Liquid / slurry feedstocks tend to be used on the site that they are produced or an adjacent site.

There are few economies of scale in bio-energy fuel haulage as the volumes and weights are typically low. This means establishing specialist haulage fleets will not be economic. For example, in the organic recycling data sheet, the largest item was garden organics at 211,000 tonnes per annum. This equates to 840 tonnes per day which is 20 truckloads for the entire state. Most of the sources might need 6-8 truckloads per day

Economics of waste haulage will likely lend itself to short distances of typically up to 40-50 km. If there was a niche location where there was no nearby energy alternative and/or very large volumes, longer haulage may become feasible. However neither of these circumstances is relevant to this initial overview, which involves reviewing typical or average applications.

5. Technological Factors Influencing Bio-energy Projects in South Australia

5.1 Introduction

There are several existing feedstocks that have been identified as having potential for bio-energy in South Australia. These are:

- Council green waste (garden and park waste)
- Municipal solid waste
- Forestry waste and sawmill residues
- High moisture content organic wastes (pig slurries, chicken litter, dairy shed effluent, feedlot waste).
- Straw feedstocks
- Sewage bio-gas has already been investigated by SA Water and there are various projects underway or in operation.

The technology options for particular feedstocks are discussed in the following sections.

In addition, the following case studies and discussion are also provided:

- Small scale biomass heating which could be applicable for any of the woody biomass nodes or other areas where smaller volumes of clean wood chip like material available, such as forestry residues, woody energy crops and woody green waste sources (400 to 20,000 tonnes of feedstock available per annum)
- Bio-gas upgrading to bio-methane (as an alternate to bio-gas use in gas engines)
- Algae production and refining for liquid bio-fuels.

The indicative bio-energy project examples are based on a number of key assumptions which have not been verified as a part of this report. The assumptions are:

- Confirmation of availability of feedstock
- Assessment of potential gate fees or feedstock costs
- Feedstock quality details including chemical and physical properties including moisture content and energy value
- The standard of and source country of equipment manufacturing can impact considerably the capital cost of the technologies discussed below. Confirmation of economic feasibility of the economic feasibility of the technologies noted below has not been undertaken as a part of this work
- Capital costs and capital cost rates per MW are indicative of the order of magnitude of cost and are not suitable for project approval purposes.

5.2 Council Green Waste

Source segregated council green waste represents a biomass feedstock of relatively high biogenic purity (with some minor plastic contamination etc. possible), which may be suitable for use in either of the two following well technically proven and commercial technologies (other technologies are also possible but less well proven for this feedstock):

- A combustion type process to generate power and heat
- An anaerobic digestion process to produce bio-gas which could be used to generate power in a spark ignition engine and/or provide heat for process use.

Of the two options, the combustion power station option offers the following advantages:

- Higher diversion of waste from landfill (>90%), which may attract more waste disposal revenues for the facility
- Smaller volume of residues i.e. only ash which may be 5 % or less, rather than digestate which could be a much larger fraction of the incoming feedstock
- Lower CAPEX per tonne diverted from landfill
- More useful energy generated as power and heat.

Combustion power is also less susceptible to woody elements of the waste as these can be easily combusted but not readily digested.

Anaerobic digestion may be preferred if:

- The leafy and grassy components of the green waste which can be digested can be mechanically separated from the wood material and mixed with additional digestible feedstocks from other sources, such as kitchen waste from MSW, manures or other feedstock types of higher moisture content making them unsuitable for combustion e.g. >60% moisture by weight
- There are other waste or energy policy drivers such as technology specific energy tariffs or gate fees that can make the higher CAPEX per tonne diverted from landfill for anaerobic digestion to be more economic.

For indicative purposes, Table 5.1represent an example of a potential green waste facility that assumes a green waste volume of around 100,000 tonnes per annum could be collected and delivered to a central facility.

Table 5.1: Indicative 100,000 tonne per annum green waste combustion facility

Indicative Parameter	Assumption	Comment
Mass of green waste for facility	100,000 tpa	Assuming this can be source segregated within reasonable economic transport distance from a single facility.
Moisture content of green waste	35% by weight	Assumes some natural drying from green moisture content (circa 50%) at source or at transfer stations.
Net calorific value	11 MJ/kg	Assumes 2 % ash content
Boiler energy output – heat only	33 MWth	Maximum potential for energy production in the form of heat for steam production or other industrial energy heat forms
Boiler efficiency – heat only	86%	LHV basis
Net power output - power only	9 MWe	Net power output if high temperature steam is generated and all fed to a steam turbine.
Electric efficiency – power only	23%	LHV basis and net of power plant parasitic load
Max overall efficiency – CHP plant	75%	LHV basis and net of power plant parasitic load – Assumes large process heat demand exists near facility.
CAPEX for power and CHP options	~$5-6 M/MWe	EPC cost for power plant or CHP options which excludes owners development and site specific costs (e.g. land purchase, grid connection etc.)

The following issues need consideration for combusting green waste feedstock in this type of power plant:

- Normally this type of biomass material would be fired on a grate type boiler and produce steam in excess of 400^0 C if feeding to a steam turbine.
- Pre-processing will be required to shred to chip like particles or smaller for the purposes of handling and firing the material. Screening and stone removal is also recommended.
- Energy output per tonne combusted will be subject to the moisture content of the green waste.
- The high proportion of leaf and bark content of the green waste can mean it is higher in the elements sodium, potassium and chlorine than some other biomass feedstocks like clean wood chip. This needs to be considered in the boiler design and steam conditions to prevent fouling and corrosion problems in the operational boiler plant.
- Green waste could also be aggregated with other woody biomass types e.g. forestry residues or energy crops to fire in a larger facility. The facility would need to be carefully designed to handle and combust multiple fuel sources. An aggregated facility improves the economies of scale of such a project.

5.3 Residual Municipal Solid Waste

Residual municipal waste (RMW) collected separately from recyclables at source represents a biomass feedstock of perhaps approximately 50% biogenic or organic purity with significant plastic, textile and a number of other inorganic components. The RMW may be suitable for use in either of the two following technically well proven and commercial technologies:

- A combustion type process to generate power and heat
- An anaerobic digestion process to produce bio-gas which could be used to generate power in a spark ignition engine and/or provide heat for process use.

Other technologies are also possible but less well proven at large scale.

Either of the two options noted above could also be combined with a front end waste treatment process if there was a driver to increase recycling levels from this residual waste stream, which will still contain metals, glass and plastic bottles etc, that have not be placed in separate collection bins. Generally waste pre-treatment systems are of the mechanical and/or biological type, with many variants possible. The variants have different levels of recyclables extracted depending on the incoming waste composition and the treatment technology adopted.

Of the two options above, the combustion energy from waste (EfW) option offers the following advantages:

- Higher diversion of waste from landfill >75%, which may attract more waste disposal revenues for the facility
- Smaller volume of residues i.e. only ash which may be 25 % or less, rather than digestate and non-recyclable inorganics which could be a much larger fraction of the incoming feedstock
- Lower CAPEX per tonne diverted from landfill
- More useful energy generated as power and heat
- Such a facility can combust the organic fraction and the in-organic fraction in an environmentally responsible and efficient, well proven process.

Anaerobic digestion may be preferred if:

- The organic fraction of the MSW can be source segregated in collection regimes such as green bins which can receive only kitchen and garden waste.
- There are other waste policy drivers that seek to drive higher levels of recycling which would make the additional CAPEX and OPEX costs of operating a mechanical and/or biological pre-treatment plant viable.
- Pre-treatment is generally preferred to first separate the organic from the inorganic fraction of the incoming waste. Anaerobic digestion is then applied to a relatively high organic content feedstock.

Jacobs understands that the majority of South Australian MSW is collected and transported centrally to one of two landfill sites near urban areas. At the time of writing of this report, waste volume data for residual waste (i.e. non-recyclables) has not been provided for these landfills, however on a per capita basis, it has been assumed that municipal waste generation for the state will be more than one million tonnes per annum.

For indicative purposes Table 5.2 represents an example of an energy from waste facility assuming a residual municipal waste volume of around 1,000,000 tpa could be diverted from the existing landfills located near urban areas and delivered to a central facility nearby. The following example is based on no pre-treatment of the waste which would be expected to maximise energy recovery, minimise waste to landfill, and give the lowest cost per tonne of waste diverted from landfill. To make such a facility economic, in addition to power revenues, it would need to be reliant on charging gate fees per tonne of waste processed. For example, in the UK where there are many such energy from waste plants, facilities of this type can be economic on a large scale (e.g. greater than around 200,000 tpa) when charging of the order of A$150 to 200 per tonne of waste received.

Table 5.2: Indicative 1,000,000 tonne per annum residual municipal solid waste combustion facility

Indicative Parameter	Assumption	Comment
Mass of residual municipal waste	1,000,000 tpa	Assuming this can be diverted from existing landfills located nearby to a centralised facility.
Moisture content of MSW	27% by weight	Typical assumption, moisture content will vary depending on waste composition and also seasonally.
Net calorific value	9.5 MJ/kg	Assumes 24 % ash content
Boiler energy output – heat only	285 MWth	Maximum potential for energy production in the form of heat for steam production or other industrial energy heat forms
Boiler efficiency – heat only	85%	LHV basis
Net power output - power only	89 MWe	Net power output if high temperature steam is generated and all fed to a steam turbine.
Electric efficiency – power only	26.5 %	LHV basis and net of power plant parasitic load
Max overall efficiency – CHP plant	75%	LHV basis and net of power plant parasitic load – Assumes large process heat demand exists near facility.
CAPEX for power and CHP options	~$2000 to 3000 / MWth fuel input	EPC cost for large scale EfW power plant or CHP options which excludes owners development and site specific costs (e.g. land purchase, grid connection etc)

The following issues need consideration for combusting municipal solid waste feedstock in this type of power plant:

- Normally this type of waste material would be fired on a hydraulic ram stoker grate type boiler and produce steam in excess of 400^0 C if feeding to a steam turbine.
- Pre-processing is not required for robust and proven grate designs for MSW feedstock, and waste can be handled with a grab crane.
- Post combustion gas clean-up is required for emissions control.
- Energy output per tonne combusted will be subject to the waste composition and moisture content of the MSW which should be examined carefully as part of the EfW project development.

- MSW is high in the elements sodium, potassium and chlorine. This needs to be considered in the boiler design and steam conditions to prevent fouling and corrosion problems in the operational boiler plant.
- MSW could also be aggregated with other non-hazardous MSW-like wastes such as commercial and industrial (C&I) waste, to fire in a larger facility if that facility was carefully designed to handle and combust multiple fuel sources.
- Geographically large collection areas can result in a number of different recycling and waste collection regimes between the local government authorities. This has the potential to change the composition of the waste and affect the EfW plant output. The risk can be mitigated by all stakeholders agreeing to a common standard.

5.4 Forestry and Sawmill Residues Project

Within South Australia, particularly within the south eastern part of the state, there is a forestry industry generating which generates considerable biomass. This project example focuses on the utilisation of wood residues derived from saw mills or residues left in the forest after harvesting. When forests are harvested for logs, there is a significant volume of material such as branches which are cut away in the forest and could be chipped into a useful solid biomass fuel. In addition, sawmill residues include sawdust, shavings and wood cut away from the trunks during the production of useful timber. Residues generated at the mill can be of the order of 50% of the incoming volume of wood. Both these forms of woody biomass have similar characteristics and can sometimes be combined to form the feedstock for a biomass energy project.

Depending on the volume of woody material available there may be one of two established and commercialised technologies for converting the woody biomass residues to useful energy.

- A combustion type process with a steam turbine to generate power and heat on a medium to large scale.
- A combustion process coupled with an organic Rankine cycle (ORC) for smaller scale projects.

Option 1 above is applicable at scales circa > 1 MW electrical output equivalent and will be the more efficient of the two at larger scales e.g. greater than 5 MW equivalent of electrical capacity. Option 2 is applicable for electrical capacities up to a single unit size of around 2 MW electrical and will normally be more efficient at those lower capacities. Both options have the potential to produce useful heat as well as power, and operate as a combined heat and power (CHP) plant. Locating such a project at a sawmill or similar wood processing facility may present an opportunity where there is both feedstock and energy demand in the forms of power and heat all present on the one site. Stand-alone power export projects are also possible in the right economic context.

For indicative purposes Table 5.3 represents an example of a potential sawmill and forestry facility assuming a wood residue volume of around 100,000 tonnes per annum could be collected and delivered to a central facility. At this capacity, it is assumed a steam turbine cycle will be the preferred option.

Table 5.3: Indicative 100,000 tonne per annum forestry and sawmill combustion facility with steam turbine

Indicative Parameter	Assumption	Comment
Mass of woody residues	100,000 tpa	Assuming this can be source segregated within reasonable economic transport distance from a single facility.
Moisture content of wood waste	50% by weight	Assumes green wood is used without natural drying prior to use.
Net calorific value	7.9 MJ/kg	Assumes 0.5% ash content
Boiler energy output – heat only	28 MWth	Maximum potential for energy production in the form of heat for steam production or other industrial energy heat forms

Indicative Parameter	Assumption	Comment
Boiler efficiency – heat only	84%	LHV basis
Net power output - power only	6 MWe	Net power output if high temperature steam is generated and all fed to a steam turbine.
Electric efficiency – power only	22 %	LHV basis and net of power plant parasitic load
Max overall efficiency – CHP plant	74%	LHV basis and net of power plant parasitic load – Assumes large process heat demand exists near facility.
CAPEX for power and CHP options	~$5-6 M / MWe	EPC cost for power plant or CHP options which excludes owners development and site specific costs (e.g. land purchase, grid connection etc).

The following issues need consideration for combusting forestry and saw mill residue feedstocks in this type of power plant:

- Most commonly this type of biomass material would be fired on a grate type boiler and produce steam in excess of 450^{0} C if feeding to a steam turbine, however fluidised bed boilers are also a feasible option for clean and reasonably high moisture content feedstock
- If wood chips are produced at the saw mill or in a chipper in the field they will generally be fairly uniform and easy to handle. If material is processed in a hammer mill it could be less uniform. Forestry residues could contain some stones or rocks also, so screening may be advisable.
- Energy output per tonne combusted will be subject to the moisture content of the wood waste
- This type of clean wood chip is low in the elements sodium, potassium and chlorine and should not result in major fouling and corrosion problems in the operational boiler plant.
- Wood residues could also be aggregated with other woody biomass types (e.g. energy crops) to fire in a larger facility if that facility was carefully designed to handle and combust multiple fuel sources. This would improve the economies of scale of such a project.

5.5 High Moisture Content Organic Feedstock Project

This example project could be applied to a number of high moisture content bio-feedstocks where technologies like combustion are inappropriate. This could include a range of feedstocks such as livestock animal manures, food wastes, garden wastes and similar feedstocks with moisture contents in excess of 55 to 60% by weight. This study has identified that within South Australia there are some hot spots for the production of pigs and chickens. The associated manures or slurries may have some potential for aggregation to a centralised facility to give sufficient volume for a bio-energy project.

For feedstocks of this type the preferred energy conversion technology is anaerobic digestion (AD) because of the high moisture content. AD is a naturally occurring biological process that uses microbes to break down organic materials in the absence of oxygen. The digestion of organic wastes takes place inside a reactor in which the pH, moisture content and temperature are maintained to give the optimal gas yield. Depending on the feedstock and the type of system used, digestion can take as little as a day or two or up to two months in some circumstances. Sometimes the gas needs to be cleaned of contaminants, which include the highly corrosive hydrogen sulphide, moisture, and for some feedstocks also siloxanes which can be damaging to downstream equipment using the bio-gas.

There are a number of AD technology options which could be chosen depending on a number of factors not the least being the chemical and physical properties of the digester feedstock, and in particular, the solids content is very important. This report does not investigate in depth the various AD options, however careful consideration of the following issues is required for a specific feedstock or feedstocks:

- Selection of a wet or dry phase digestion process.
- Thermophilic (higher) or mesophilic (medium) operating temperatures.
- Continuous or batch flow process.
- Pre-treatment requirements or options to enhance bio-gas yields (e.g. thermal hydrolysis).
- Post treatment requirements for the digestate residues may be required so that they can be made safe to use.

Anaerobic digestion is a proven technology that has been operational at industrial scale for several decades. Historically, the AD market has been given significant government support in continental Europe, especially in the Netherlands, Belgium and Germany and it is from these countries that many of the well proven technology designs originate.

The methane content of bio-gas produced by different feedstocks can vary between 55 to 75%, which is normally sufficient for use as a fuel directly in various energy applications. The most commercialised options for the conversion of the bio-gas to useful energy include:

- Use in a gas boiler for heat generation only if there is sufficient local heat demand to consume the volume of gas generated.
- Use in spark ignition gas engines for power generation with the potential for heat recovery if required for temperature control of the AD process or for other heating applications if such a demand exists.
- Use in gas turbine generator(s) also for the generation of heat and power. Micro or mini turbines could be considered.
- Use in fuel cells for the generation of power and potentially also some heat.

A further option to upgrade the bio-gas to bio-methane is discussed further in Section 5.7.

Of the above options, bio-gas use in spark ignition engines offers the following advantages:

- Produces power at relatively high efficiency which is a higher value energy product than heat. Spark ignition engines have a higher efficiency than gas turbines, only fuel cells may be higher out of the three non-boiler options.
- Lower in capital costs per unit of power generation installed than fuel cells.
- The most well proven and commercialised conversion technology option.
- A technology which is readily scalable for a wide range of capacities of digesters by varying engine unit sizes and with multiple modules as required.

Heat only boilers may be preferred if:

- The organisation generating the bio-gas or its neighbour(s) has a considerable demand for heat.
- No readily available electricity grid connection exists.

Gas turbines may be preferred if:

- High electrical conversion efficiency is not the priority.
- Significant demand for process steam exists at or near the site, which can be generated from the turbine exhaust gases.

For indicative purposes, Table 5.4 represents an example of anaerobic digestion plant with spark ignition gas engines for power generation utilising around 30,000 tpa of mixed feedstocks made up from primarily pig slurry (20,000 tpa) and chicken litter (10,000 tpa), presuming this could be collected and delivered to a central facility. It is noted however that different sized facilities may be feasible at specific locations as AD projects are technically scalable from small systems at single large farms up to industrial scale facilities.

Table 5.4: Indicative 30,000 tpa feedstock anaerobic digestion facility with engine generator

Indicative Parameter	Assumption	Comment
Mass of AD plant feedstock	30,000 tpa	Assuming this can be sourced cost effectively within reasonable economic transport distance from a single facility.
Moisture content manure feedstocks	80% by weight	Assumes mixed feedstock 2:1 ratio of pig slurry and chicken litter.
Bio-gas yield per tonne	65 Nm^3/tonne	Assumes medium yields from combined waste at 65% methane content.
Bio-gas produced	1.95 Million Nm^3/annum	At 65% methane content.
Equivalent gas energy value	47,000 GJ/annum	LHV basis assuming 24 MJ/Nm^3
Power generation capacity	620 kW	Assumes a 38% engine efficiency on a lower heating value basis
AD plant including engine CAPEX	~$10 -14 M / MWe	Construction cost for production of AD plant including engine which excludes owner's development and site specific costs (e.g. land purchase, grid connection etc.)

The following issues need consideration for this type of AD gas engine power plant:

- It is key requirement to understand the particular feedstock quality in detail for the specific project, including undertaking digestibility assessment and bio-gas yields assessment. The selection of the appropriate digester type to employ for a specific project should be based on the feedstock quality assessment.
- It is also very important to understand the feedstock market in depth to confirm ongoing availability of feedstocks at an appropriate cost or gate fee if the feedstock is a waste where disposal fees can be charged.
- Achieving appropriate gas quality is key to reliable and continuous operation of the engines. Removing elements like moisture, hydrogen sulphide and siloxanes (if present) in the bio-gas produced, will lower maintenance costs and improve engine availability.
- Heat recovery from spark ignition gas engines is possible from the radiator cooling system (hot water) and also from the engine exhaust (can be either hot water or low pressure steam).

5.6 Straw Feedstock Project

This study has identified significant quantities of straw are available in some regions which could support a straw to power project. This project example focuses on the utilisation of straw left over from harvesting of cereal crops like wheat. These materials can be baled at the farms and stored to dry, and then transported by truck to a centralised facility which stores and handles the straw in bale form. This type of facility is common in Europe and China. Both countries have established methods for handling and converting the straw to useful energy.

Depending on the volume of straw material available there may be one of two potential technologies for converting the straw residues to useful energy:

- A combustion type process with a steam turbine to generate power and heat for medium to large scale
- A gasification process coupled with a combustion burner and steam turbine.

Of these two options, combustion is the most widely adopted and practiced internationally, this option has proven designs and reliability. Currently straw energy is abundant throughout Europe, however the only large scale installations exist in the UK, Spain and Denmark. Although straw energy potential is high, it is often not linked to the technology options and therefore is overlooked as an energetic resource.

The development of the utilisation of cereal straws and other baled biomass materials for energy recovery has the longest historical track record in Denmark compared to any other country in the world. This development was driven further forward by a Danish government decision in 1993 to instruct power utility companies to burn 1.2 million tonnes of surplus straw per annum by the year 2000.

Straw is one of the primary sources of domestic biomass in Denmark and the first generation of biomass CHP plants that were built in Denmark were 100% straw fired. The first straw fired power plant was commissioned in 1989 in Haslev with the next two being commissioned shortly afterwards in Slagelse and Rudkobing in 1990.

In 1996 the first of the second generation of biomass plants was commissioned in Masnedo, Denmark. This plant had a significantly higher steam and boiler temperature. In Denmark today there are 13 operational straw fired power plants.

Ely power station was built in 2001 in Cambridgeshire, UK. Ely has a capacity of 38 MW and requires 200,000 tons of straw each year making it the world's largest single straw boiler. Two other straw fired projects are now under construction/initial operation at Sleaford and at Brigg (both circa 40 MWe).

The Sanguesa power plant in Spain went operational in June 2002 and provides 25 MWe to a nearby industrial estate. Long-term contracts with farmers were created for providing the 160,000 tons of straw that is needed yearly to run the plant.

Outside of Europe, China is focusing on increasing its production of energy from straw. China produces over 700 million tons of straw each year with a surplus of 150 million tons that are wasted. Straw fired power stations would be able to consume this fuel surplus and reduce CO_2 emissions. The first biomass power plant built in China was the Shandong Shanxian plant which went into operation at the end of 2006. Currently there are over 21 straw fired power plants constructed and in development in China alone.

Wheat straw is the predominant fuel type used in straw plants, however, some of the other fuels that have been combusted include:

- Barley straw
- Rye straw
- Oats straw
- Oil seed rape straw
- Maize straw.

Wood chips can also be co-fired in straw plants to supplement fuel supply if a separate chip handling system is provided. A straw boiler with the ability to handle other types of fuels offers potential for risk mitigation for times when straw availability is reduced. The use of other fuel types is normally supply chain driven to give more certainty over supply volumes which may suffer from seasonality or weather issues or rely ultimately on the choices of crops that local farmers decide to plant. Two projects in the UK are known to have been designed to burn up to 10-20% wood chips co-fired with straw through a separate wood chip handling conveyor system.

For indicative purposes Table 5.5 represents an example of a potential straw fired plant assuming a volume of around 200,000 tonnes per annum could be collected and delivered to a central facility. At this capacity, it is assumed a steam turbine cycle will be the preferred option, and it is assumed that the plant will be a stand-alone power generator which does not provide heat.

Table 5.5: Indicative 200,000 tpa straw combustion facility with steam turbine

Indicative Parameter	Assumption	Comment
Mass of straw	200,000 tpa	Assuming this can be source segregated within reasonable economic transport distance from a single facility.
Moisture content of straw	16% by weight	Assumes green wood is used without natural drying prior to use.
Net calorific value	14 MJ/kg	Assumes 6% ash content
Boiler efficiency	92 %	LHV basis
Net power output - power only	32 MWe	Net power output if high temperature steam is generated and all fed to a steam turbine.
Electric efficiency – power only	33 %	LHV basis and net of power plant parasitic load
CAPEX for power and CHP options	~$4-6 M / MWe	EPC cost for power plant or CHP options which excludes owners development and site specific costs (e.g. land purchase, grid connection etc).

The following issues need consideration:

- Most commonly this type of biomass material would be fired in a water cooled grate type boiler and produce steam in excess of 500^{0} C if feeding to a steam turbine
- Bales are typically stored in a barn onsite, handled automatically with cranes and then conveyed into the boiler house to be broken by devices called scarifiers. The loose straw is fed on to the grate by water cooled screw feeders.
- Energy output per tonne combusted will be subject to the moisture content of the straw, so in wet periods where bales do not dry well in the field, output may be constrained. Wet straw can also cause boiler fouling problems.
- Straw is notoriously high in the elements of potassium and chlorine and major fouling will result if proven boiler designs are not adopted. Corrosion problems could also occur in the operational boiler plant if the boiler metallurgy is not correctly specified. There are however some specific boiler suppliers worldwide who can however resolve these issues to construct reliable and efficient plant.

5.7 Indicative Small Scale Heating Project

This energy conversion technology example is not node specific and could be applied to a range of smaller scales such as from 100 kWth to 5 MWth where there is a suitable matching heat demand. Demand locations may include hospitals, municipal swimming pools, small industrial demands or district heating schemes. Heating schemes in this size range would normally use clean wood chip feedstocks between 30 to 50% moisture content, which could be sourced from any of the following feedstock types:

- Forestry residues
- Saw mill residues
- Purpose grown woody energy crops
- Woody green waste.

Smaller boilers may also use wood pellets, although this have significantly more expensive ongoing costs and pellet feedstock may need to be sourced from outside the local region.

The options for a small scale heating application are:

- A grate boiler combustion type process to generate heat in the form of hot water or steam
- As above but coupled with an Organic Rankine Cycle (ORC) engine which also would allow power generation up to a scale of around 500 kWe.

Of the two above options, the combustion and heat only option offers the following advantages:

- Less complex to construct and operate (normally unmanned operation with minor daily to weekly routine checks and de-ashing)
- Lower CAPEX
- Does not require a grid export connection.

An ORC engine option may be preferred if:

- The site also has a significant power demand which must be imported from the grid at retail price levels
- A readily available grid connection exists
- It is co-located at a larger site where there are already suitable O&M personnel who can monitor, operate and maintain the more complex electro-mechanical plant.

In many instances, it is expected that a heating only boiler may prove the simplest and most cost effective option of the two.

For indicative purposes Table 5.6 represents an example of a potential wood chip biomass of around 2,000 tpa could be collected and delivered to a central facility.

Table 5.6: Indicative 2,000 tpa wood chip combustion facility

Indicative Parameter	Assumption	Comment
Mass of wood chip for facility	2,000 tpa	Assuming this can be sourced cost effectively within reasonable economic transport distance from a single facility.
Moisture content of wood chip waste	45% by weight	Assumes little natural drying from green moisture content (circa 50%).
Net calorific value	9 MJ/kg	Assumes 0.6 % ash content
Boiler energy output – heat only	500 kW	Maximum potential for energy production in the form of heat for hot water or steam production or other small industrial energy heat forms.
Boiler efficiency – heat only	85%	LHV basis
CAPEX for power and CHP options	~$400 to 800 / kWth	Installed cost for boiler plant assuming typical fuel handling requirements (e.g. underground tipping bunker) which excludes owners development and site specific costs (e.g. land purchase, grid connection, back-up systems and accumulation tanks, heat supply piping etc).

The following issues need to be considered for this type of heat generation plant:

- Normally this type of biomass material would be fired on a grate type boiler at this scale
- Pre-processing will be required to chip to uniform particles sizes with top size between 30-50 mm for the purposes of handling and firing the material
- Energy output per tonne combusted will be subject to the moisture content of the green waste

- Biomass heating boilers generally are best running to serve a base load demand so if the demand is variable and peaky, a peaking gas boiler or an accumulator tank may be advisable to maintain steadier boiler operation throughout the day.

If 24/7 continuity of heat supply is required a backup boiler may be also be advisable of some sort.

5.8 Indicative Bio-methane Upgrading Project

This energy conversion technology example could be applied as an alternative to using anaerobic digester gas in a reciprocating engine, and may be applicable at scales in excess of 500,000 to 1 million normal cubic meters of gas per annum. Bio-gas produced from AD is made up of between 20 to 40% CO_2, and 55 to 75% CH_4 plus a number of other impurities depending on the feedstock. To make bio-methane suitable for gas network injection or for road transport fuel use the bio-gas needs to be ‘upgraded’ to meet the engine’s specifications. It should be noted that the gas quality necessary for the generation of electricity in stationary engines is much lower than for gas network injection or road transport fuel and therefore the capital cost of gas upgrading can be higher than that required to use the bio-gas in a stationary engine for power and heat production. The economics of bio-gas gas power generation are generally more attractive than upgrading unless a significant financial incentive exists for renewable heat or transport fuels, or capital grant funding is available. The economics of any anaerobic digestion plant is enhanced if the facility can charge gate fees for disposal of waste or save costs for disposal via another route such as to landfill.

Technology to upgrade bio-gas to bio-methane is well established with water scrubbing methods (around 45% of the market share) and pressure swing adsorption (PSA) currently being the most popular. Other techniques include organic solvent scrubbing and membrane separation. Hydrogen sulphide and moisture removal are additional processing steps that are also normally required. Some gases may also need a siloxane removal step.

As part of the CIVITAS SMILE programme, the Swedish city of Malmo, built a plant to upgrade bio-gas that was produced in the sewage wastewater treatment plant to meet transport requirements. The bio-gas upgrading plant has been running since summer 2008 and produces bio-gas equivalent to 2 million litres of petrol each year[43] (CIVITAS Website, 2009). The Adnams brewery in Suffolk was the first facility in the UK to commence gas grid injection in 2010 and produces up to 4.8 million kWh per year of gas at grid quality[44].

Technically any feedstock that can be digested to produce bio-gas with a reasonable methane content could be used to make bio-methane. The more common applications to date include sewage bio-gas food and drink waste, agricultural wastes and landfill gas from municipal solid waste.

The two options for bio-methane use are:

- Bio-methane to natural gas standards for grid injection

Bio-methane for vehicle fuel use either as compressed or liquefied natural gas.

Of the two above options, grid injection offers the following advantages:

- Less complex supply chain for end users e.g. CNG and LNG distribution and sales
- Less infrastructure costs for vehicle refuelling stations.

Vehicle fuel use may be preferred if:

- The organisation generating the bio-methane has a considerable demand for vehicle fuels e.g. waste management, council fleet etc.
- No readily available gas grid connection exists.

For indicative purposes, Table 5.7 represents an example of a bio-methane upgrading facility utilising around 30,000 tonnes per annum of mixed food waste and the organic fraction of MSW feedstocks, presuming this could be collected and delivered to a central facility.

Table 5.7: Indicative 30,000 tonne feedstock anaerobic digestion facility with bio-methane upgrading

Indicative Parameter	Assumption	Comment
Mass of AD plant feedstock	30,000 tonnes	Assuming this can be sourced cost effectively within reasonable economic transport distance from a single facility.
Moisture content of food and organic MSW	70% by weight	Assumes mixed feedstock of food and MSW organic fraction.
Bio-gas yield per tonne	75 Nm^3 / t[46]	Assumes medium yields from combined waste.
Bio-methane produced	2.25 Million Nm^3 / y	Purified bio-methane volume
Equivalent energy value	81,000 GJ / y	LHV basis assuming 36 MJ/Nm^3
Auxiliary power consumption	450 MWh / y	Assumes 0.18 to 0.22 kWh/Nm^3 of raw gas, Schmack Carbotech PSA process[45].
AD plant CAPEX only	~$3-5 million[46]	Construction cost for production of bio-gas only excluding engine or upgrading costs which also exclude owner's development and site specific costs (e.g. land purchase, upgrading, grid connection, vehicle refuelling equipment etc.)
Gas upgrading CAPEX only	~$2 million[46]	Based on CENEX Bio-methane Toolkit Data (Euro 1 M / 300 Nm^3/h of raw gas processing). Excludes building costs.

The following issues need to be considered for this type of bio-gas upgrading plant:

- Grid injection will require meeting local natural gas grid standards which may require the injection of some larger molecule hydrocarbon gas than methane to correct the Wobbe index to match natural gas, and also the adding of odorant for gas safety. The operators of the gas network may also have other regulatory hurdles that need to be overcome before grid injection is legally possible.
- Similarly there exist international and engine manufacturer specific vehicle fuel gas standards that an upgraded fuel may need to meet to be used without vehicle warranty implications. A robust assessment of available supply chain demand for suitable CNG or LNG fuelled vehicles that could consume the fuel would also be needed in the feasibility investigations of a vehicle fuel upgrading facility.

5.9 Algae Production for Bio-fuels

The key criteria for the potential production of algae are not specific to availability of a feedstock, but rather the availability of suitable sites and land area which have appropriate environmental conditions that promote algae growth by photosynthesis.

In the case of algae fuels produced from natural sunlight, atmospheric carbon dioxide, and a water source (often salt water), the ready availability of these precursors are the main criteria. It is recognised that South Australia, particularly along coastal areas has good technical potential for the production of algae. This production process has been in the demonstration phase since 2014 by Muradel in Whyalla, a $10.7 million and around 1,000 litre per year of bio-crude project with core funding by ARENA ($4.4 million) and also supported by Whyalla council and the South Australian government.[47] The Muradel process grows the algae in open salt water ponds. A significant land area allocated primarily for ponds will be required to produce algae on a large scale.

It is also possible to utilise a more engineered photo-bioreactor solution which is a series of glass vessels that can absorb sunlight through the glass. This requires less land area, however this method is expected to have higher capital cost than using open ponds.

An option that has also been trialled in Australia for algae production requires the co-location of the algae production facility at a thermal power station producing a carbon dioxide rich flue gas stream. The carbon dioxide is converted to algae biomass in enclosed photo-bioreactor vessels. This second option is understood to be trialled at Bayswater Power station in NSW with Algaetec providing the algae production equipment. Algaetec indicates the process requires approximately one tenth of the land area required by open ponds for a similar production rate[48]. The first phase of this trial was proposed to start in 2014. A flue gas CO_2 algae trial has also been undertaken by Stanwell Corporation (formerly Tarong Energy) at Tarong Power station in Queensland which commenced in 2009 with MBD Energy Ltd[49], and utilised coal ash dam water to meet the process water consumption needs.

Production of the algae is the first step in the process, which then needs to be converted to a useful bio-fuel (normally liquid, although anaerobic digestion of algae is also possible to produce a bio-gas). Some conversion processes produce a crude bio-fuel that needs refining to be useful for automotive or even jet fuel applications based around a diesel like end product. For this method the lipids within the algae are the oil pre-cursor which can be around 30% of the algae biomass by weight. There are also processes where the algae can produce bio-ethanol or other alcohols through fermentation which can be used as a petrol replacement. Most demonstration projects to date in Australia have explored bio-diesel production options.

It is noted however that in the present market, that the production of bio-fuels from algae is not considered a commercially demonstrated technology, and the costs of production of bio-oil by this route are expected to be higher than from conventional fossil sources. In 2010, Bloomberg New Energy Finance reported the costs of various technologies (micro algae production in open ponds, photo-bioreactors and fermentation) for bio-fuel production at between US$ 2 to 10 per litre[50]. Most projects in Australia and elsewhere in the world to date producing algae on a more commercial basis have targeted other higher value end use applications which yield better returns than bio-diesel production. From Jacobs' discussions with Muradel regarding the South Australian project, it is understood that whilst bio-crude can be produced, at present Muradel's algae product is more valuable to use for other applications than for the production of bio-oil. High value end products targeted to date from algae projects have included the production of fish and animal feed, the production of Omega 3 oils, for pharmaceuticals and health supplements, cosmetics and beauty products, and also for the production of human food and beverages.

6. Areas of Opportunity for South Australia

Jacobs has undertaken GIS mapping of the existing bio-energy feedstocks, purpose grown biomass and potential energy demand. Analysis of this data has identified a number of 'hot spots' around the state where a bio-energy plant could be considered. 'Considered' means there are comparatively high concentrations of a particular feedstock and a potential match with a demand source. The heat maps do not take into account technology type, project economics, logistics, environmental restrictions and the lake. Key input information included in the maps is (depending on particular product):

- Stock numbers
- Forestry plantation areas
- Soil types
- Rainfall
- Various industries that could contribute feedstocks such as chicken growers, dairy milking sheds, feedlots, meat processing plants, horticulture, crops and the like
- Various demand locations
- Land parcels
- State transmission and distribution networks, 11kV and above.

Note that the hot spots shown on the following maps are summarised based on feedstock category (e.g. mixed slurry or solid biomass), whereas the list above shows the hot spots for the particular feedstocks. Please manipulate the GIS tool for maps of the individual feedstock hotspots.

6.1 Existing Feedstocks

The GIS mapping has indicated a number of areas for potential bio-energy projects across the various existing feedstocks. These are summarised in Table 6.1 below. The intensity of the background shading indicates the degree of potential.

Table 6.1 : Hot spots for potential opportunities for existing feedstocks

Feedstock	Constituents	Hot Spot Centre	Stock No.s	Quantity (Tpa)	Energy Potential (GJpa)	Potential Tech.	Other Comments
Timber	Forest slash, sawmill residue etc	Penola and Mt Gambier		684,000	5,700,000	Combustion	Demand from sawmills and wood processing plants, also municipal heating
Poultry	Chicken litter	Wasleys	18.8 million		1,800,000	AD	Demand from associated processes
Broadacre	Hay, straw, silage	between Naracoorte, Bordertown, Keith		62,000	878,000	Combustion	No obvious local demands so stand-alone power plant most likely
Poultry	Chicken litter	Murray Bridge	8 million		774,000	AD	Demand from associated processes
Pigs	Pig waste	Wasleys	255,000		355,000	AD	Demand from associated processes

Feedstock	Constituents	Hot Spot Centre	Stock No.s	Quantity (Tpa)	Energy Potential (GJpa)	Potential Tech.	Other Comments
Horticulture	Glasshouses, fruit trees, nuts, vegetables and herbs	Barmera		46,000	270,000	Combustion or AD for high moisture feedstock	Demand from associated processes Volume may not be present to economically support a combustion project. AD could be small and expensive.
Pigs	Pig waste	Peake	130,000		205,000	AD	Demand from associated processes
Dairy	Dairy cow waste from diary sheds	near Mt Gambier	43,000		141,000	AD	Demand from associated processes
Livestock	Feedlots	south of Meningie	8,000		25,000	AD	Demand from associated processes

Figure 6.1: Summary of the existing mixed slurries hot spots

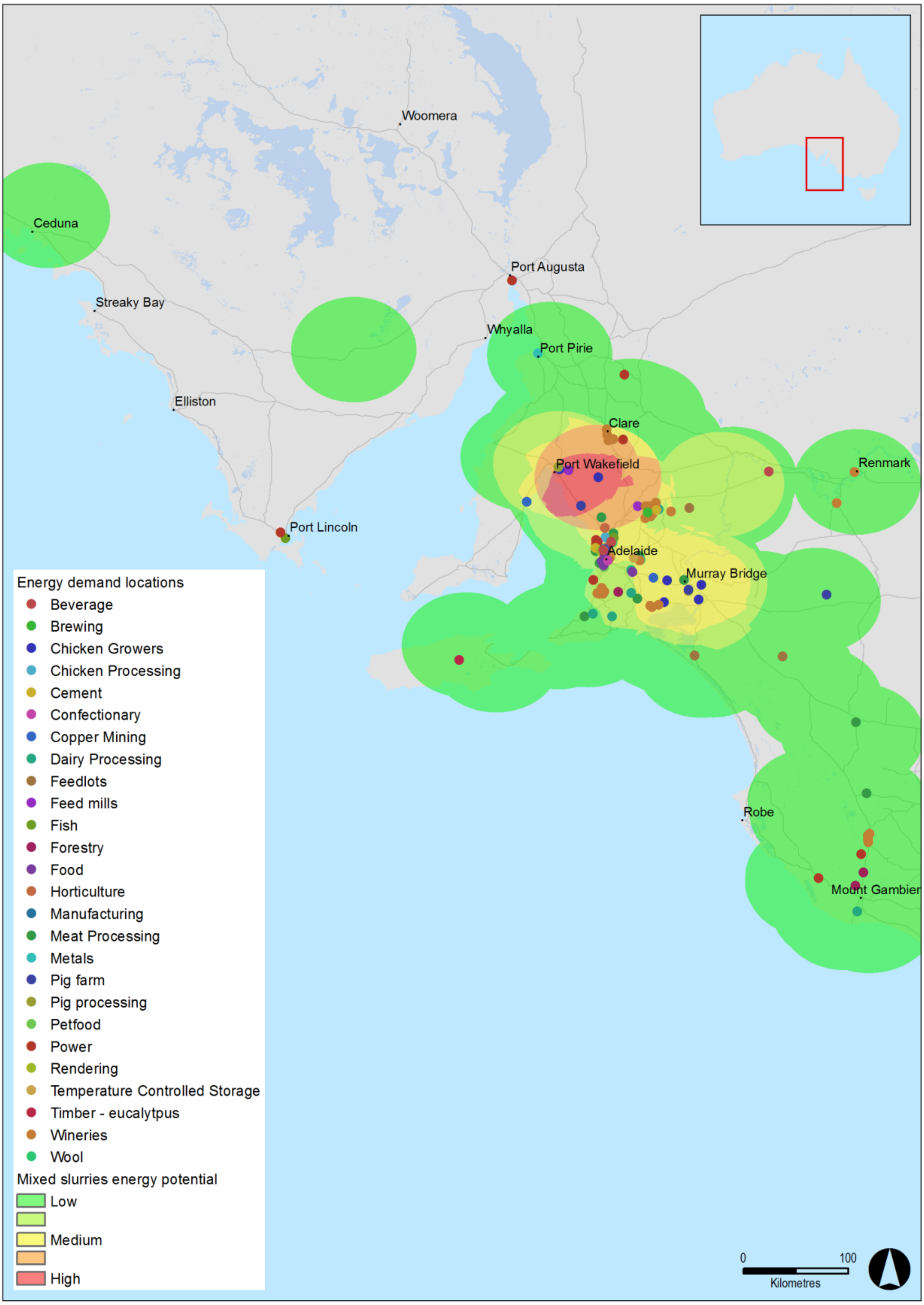
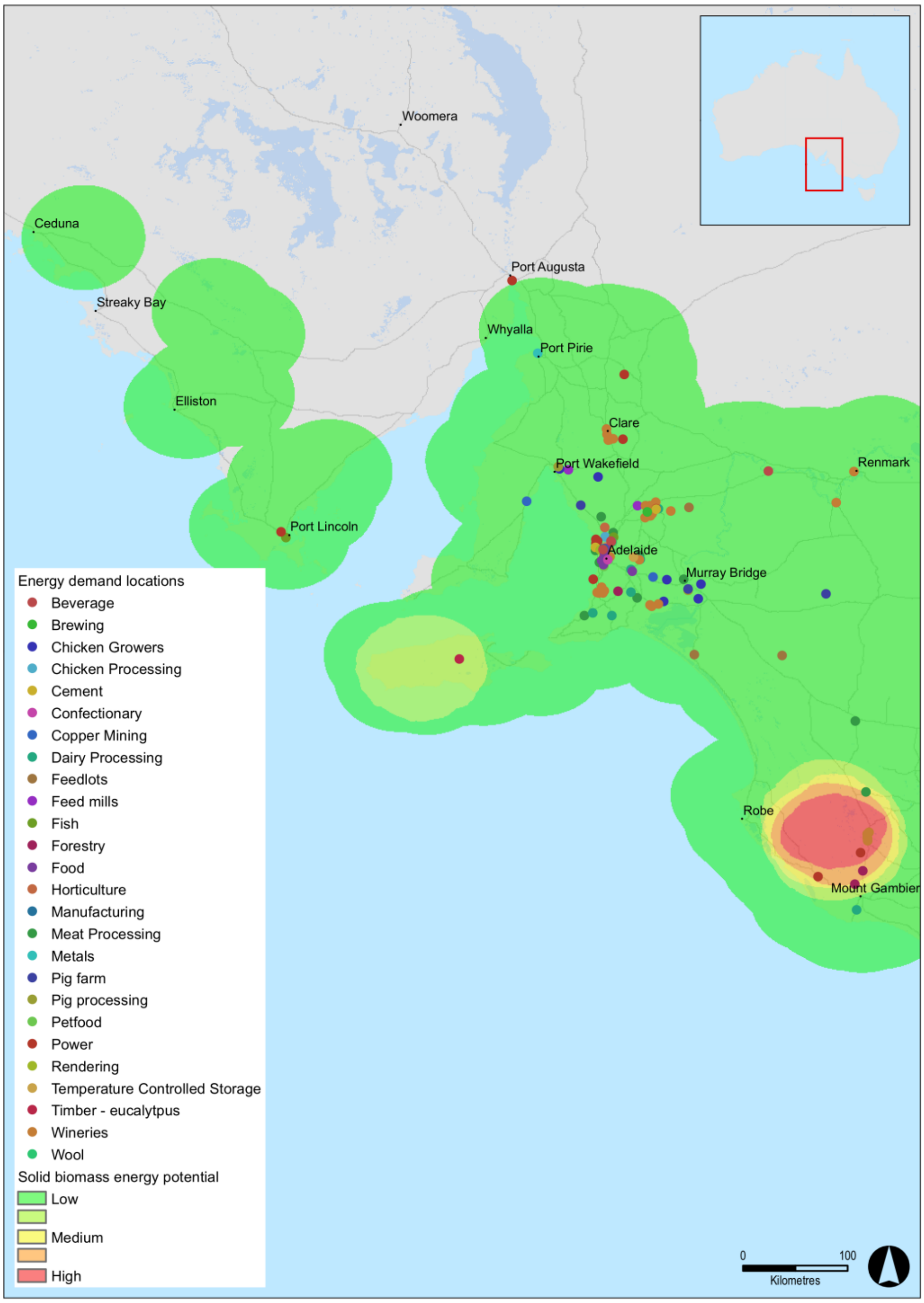
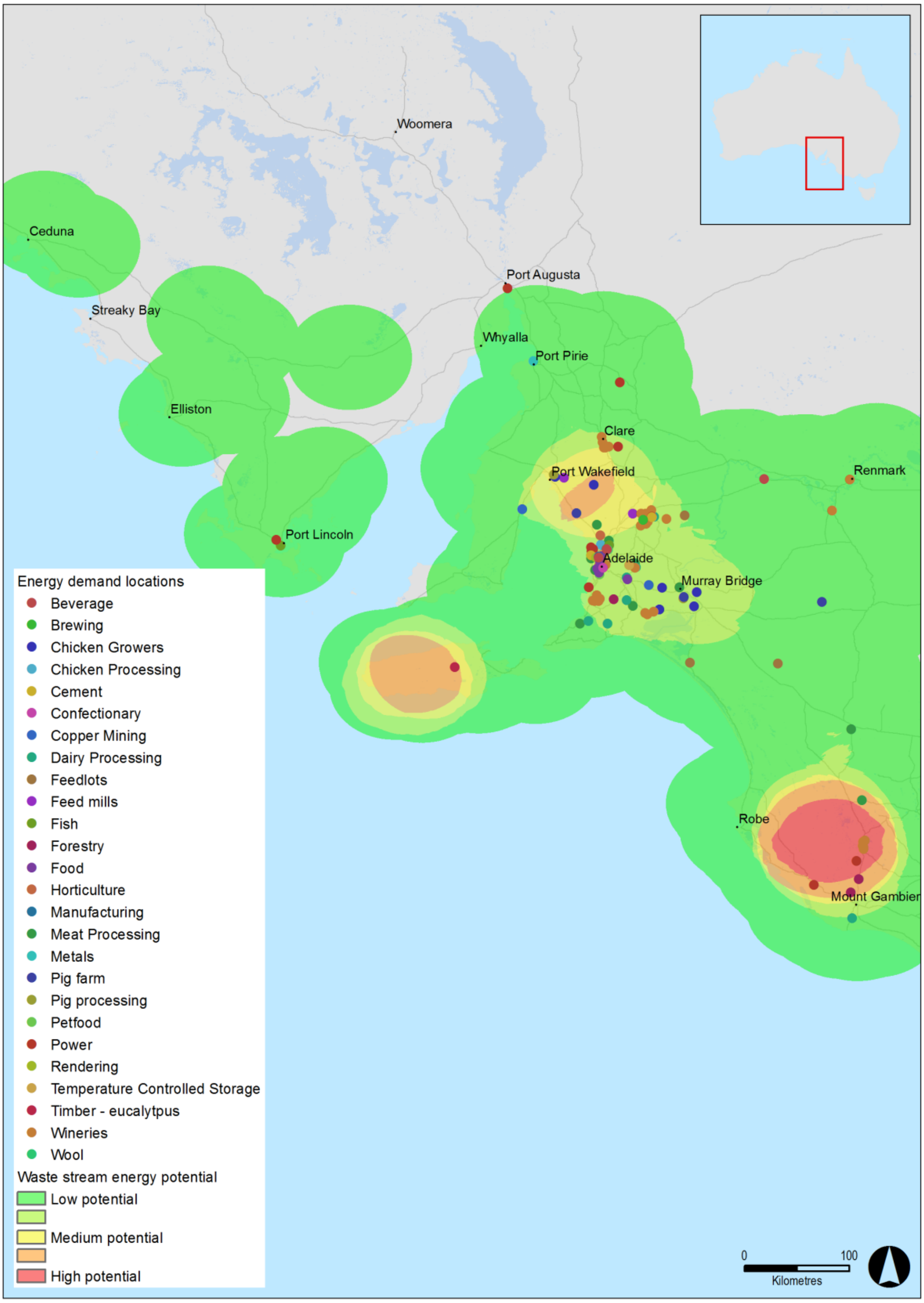


Figure 6.2: Summary of the existing solid biomass hot spots



The opportunity hot spots for the existing feedstocks is summarised in .

Figure 6.3: Summary of existing feedstock hot spots



6.2 Purpose Grown Biomass Crops

GIS mapping has indicated a number of areas for potential bio-energy projects utilising purpose grown feedstocks. These are summarised in Table 6.2 and Figure 6.4 below.

Table 6.2: Hot sports for potential opportunities for utilising purpose grown biomass feedstocks

Feedstock	Hot Spot Centre	Area (Ha)	Factored Quantities (Tpa)	Factored Energy Potential (GJpa)	Potential Technology	Other Comments
Arundo Donax	Peake	597,000	7,170,000	89,700,000	Combustion of chipped fuel in a boiler for heating or power	Likely to be a stand-alone power plant, minor potential for heat demands
Woody weeds	Naracoorte	800,000	7,200,000	55,500,000	Combustion of chipped fuel in a boiler for heating or power	Likely to be a stand-alone power plant, minor potential for heat demands
Arundo Donax	Elliston	983,000	11,820,000	54,300,000	Combustion of chipped fuel in a boiler for heating or power	Likely to be a stand-alone power plant, minor potential for heat demands
Woody weeds	Spalding	560,000	5,070,000	39,000,000	Combustion of chipped fuel in a boiler for heating or power	Likely to be a stand-alone power plant, minor potential for heat demands
Woody weeds	Cummins	460,000	4,140,000	31,800,000	Combustion of chipped fuel in a boiler for heating or power	Likely to be a stand-alone power plant, minor potential for heat demands
Mallee	Peake	679,000	1,020,000	7,830,000	Combustion of chipped fuel in a boiler for heating or power. Oil extraction may also be possible	Likely to be a stand-alone power plant, minor potential for heat demands
Mallee	east of Elliston	624,000	930,000	7,200,000	Combustion of chipped fuel in a boiler for heating or power. Oil extraction may also be possible	Likely to be a stand-alone power plant, minor potential for heat demands
Cumbungie	Tilley Swamp	74,000	450,000	4,740,000	Combustion of chipped fuel in a boiler for heating or power	Likely to be a stand-alone power plant, minor potential for heat demands

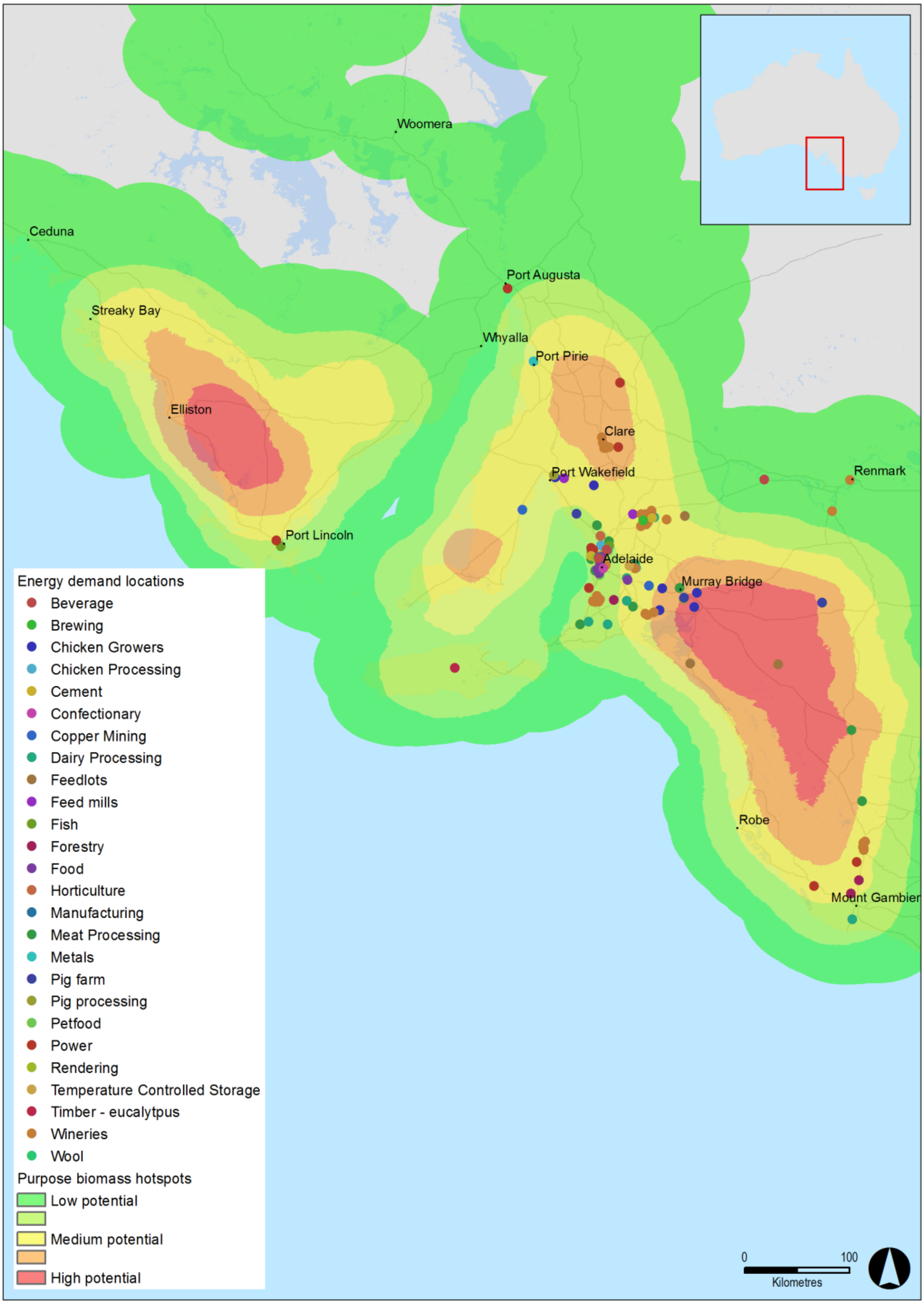
Feedstock	Hot Spot Centre	Area (Ha)	Factored Quantities (Tpa)	Factored Energy Potential (GJpa)	Potential Technology	Other Comments
Phragmities	Tilley Swamp	32,000	192,000	2,250,000	Combustion of chipped fuel in a boiler for heating or power	Likely to be a stand-alone power plant, minor potential for heat demands
Corn / Maize	between Murray Bridge and Mt Barker	22,000	300,000	1,860,000	AD / bio-ethanol production	Food crop so competing uses may make unviable
Phragmities	Port Pirie	15,000	93,600	1,080,000	Combustion of chipped fuel in a boiler for heating or power	Likely to be a stand-alone power plant, potential for serving industrial heat demands
Sorghum	Lake Alexandrina	18,000	80,700	27,000	Bio-ethanol production	Volume may not be large enough to support a bio-energy project

Key points to note in relation to the maps and tables:

- The potential tonnages and energy values are based on an area contained within a 50 km radius circle.
- The opportunities have been derived on the basis of potential feedstock growing area and energy demands. The growing areas have been factored by 30% to reflect issues such as biomass crop take up by land holders and other miscellaneous factors such as unsuitable land within the area, e.g. roads. Other local conditions may exist that need to be considered, for example, planning and environmental issues.
- The commentary on the suitability of the feedstock volume to support a bio-energy project is based on our overseas bio-energy experience. There may be other local conditions that have not been considered.
- Generally power demand forecasts are relatively static with an oversupply of generation in the market at the time of writing this report. The potential for inclusion in a renewable energy programme will affect the economic viability of stand-alone bio-energy projects.

While not specifically mentioned in the table, there are opportunities for creating hubs for similar feedstocks / technologies that are in reasonable co-location. This may have additional benefits in reducing the seasonality of supply.

Figure 6.4: Summary of purpose grown biomass hot spots



Key points to note in relation to the maps and table for purpose grown crops:

- The potential tonnages and energy values are based on an area contained within a 50 km radius circle
- The tonnages are theoretical and do not consider alternative uses or economic viability
- The opportunities have been derived on the basis of feedstocks and energy demands. Other local conditions may exist that need to be considered, for example, planning and environmental issues
- The commentary on the suitability of the feedstock volume to support a bio-energy project is based on our overseas bio-energy experience. There may be other local conditions that have not been considered
- Generally power demand forecasts are relatively static with an oversupply of generation in the market at the time of writing this report. The potential for inclusion in a renewable energy programme will affect the economic viability of stand-alone bio-energy projects.

While not specifically mentioned in the table, there are opportunities for creating hubs for similar feedstocks / technologies. For example, AD hubs could be created in the south east of the state and north of Adelaide by combining poultry, dairy, piggery and feedlot waste streams.

7. Conclusions and Recommendations

There is considerable up-take of bio-energy worldwide and, to a lesser extent, in Australia. However uptake in SA is presently low. There are many well established conversion technologies and so technology risk is not a major deterrent to developing projects in SA.

There is a regional demand for and potential to supply additional energy. Industries that could benefit or expand from the opportunity include:

- Horticulture – heating
- Intensive industries (e.g. chickens and pigs) – process heating and electricity generation
- Processing plants – heating and power generation
- Processing hubs – heating
- Forestry processing – heating and power generation

Our investigation has shown that there are both untapped existing and potential sources of biomass. These sources have been identified on a geographic basis that has led to the identification of potential bio-energy nodes across SA. These nodes are highlighted in Table 6.1and Table 6.2

The feasibility of utilising these sources has not been investigated and further work including consultation with stakeholders is a logical next step to determine:

- If the sources have been adequately characterised – and do, in fact, exist
- The barriers to use of the sources
- What other uses of the land / products would be displaced if the biomass was produced and used for bio-energy
- The environmental and social impacts of growing and utilising these sources
- The economics of bio-energy projects including the value of the unconverted biomass and hence the likelihood of landowners using their land to grow additional biomass or to divert wastes from existing uses.

Appendix A. GIS User Guide

Bioenergy Roadmap for SA

Web mapping application user guide

JACOBS

Flex web mapping application

Rev 1

5/08/2015

Document history and status

Revision	Date	Description	By	Review	Approved
A	20/03/2015	Initial draft	CJ	-	-
1	05/08/2015	Final issue	CJ	JB	TJ

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Contents

1. Introduction 3

1.1 Key features 3

1.2 Support contacts 3

2. User access 4

2.1 Login details 4

2.2 Server details 4

3. Using the web mapping application 5

3.1 Using the application 5

3.2 Web application interface 5

3.3 Zoom and pan tool 6

3.4 Navigation panel 6

3.4.1 Layer list 7

3.4.2 Legend tool 8

3.4.3 Basemap switcher 9

3.4.4 Bookmarks tool 11

3.4.5 Enhanced draw tool 12

3.4.6 Print tool 14

3.4.7 Identify tool 15

3.4.8 Swipe spotlight tool 16

3.4.9 HTML pop up 17

1. Introduction

Jacobs' web mapping application provides access to spatial data for Bioenergy roadmap SA project. The map viewer is updated with new data as the project progresses to ensure the latest information is readily available to the project team.

1.1 Key features

The Jacobs' web mapping application's key purpose is to share information across the project team. The application is accessed via a web browser over the internet. The data is centrally stored and maintained on a secure server.

Key features of the application include:

- Spatial data stored in a central repository that can be accessed globally via the internet for project work
- The ability to provide GIS tools and spatial data for external and internal team members who don't have GIS training or skills
- Access is password secured and only allows authorised users to see the project data
- Data updates are managed by GIS specialists to ensure the latest data is quickly available
- Widgets provide ability to draw, measure, edit, query, analyse data and print maps.

1.2 Support contacts

The contacts for user queries or data updates:

Chris Johnson

GIS Analyst (Jacobs)

Phone: (08) 8424 3845

E-mail: Chris.Johnson@jacobs.com

Hannah McInerney

Graduate GIS Analyst

Phone: (08) 8424 6578

E-mail: Hannah.McInerney@jacobs.com

2. User access

2.1 Login details

Access to the web mapping application requires a username and password.

Username: bioenergysa_user

Password: bioenergy_315

2.2 Server details

The web mapping application and map service is hosted by Jacobs. Spatial services are provided by the Jacobs’ Adelaide office. Maintenance performed by the Jacobs’ spatial team includes data updates, project user creation and control, team support, web application refreshes and updates.

3. Using the web mapping application

3.1 Using the application

The following are the minimum requirements for run the application:

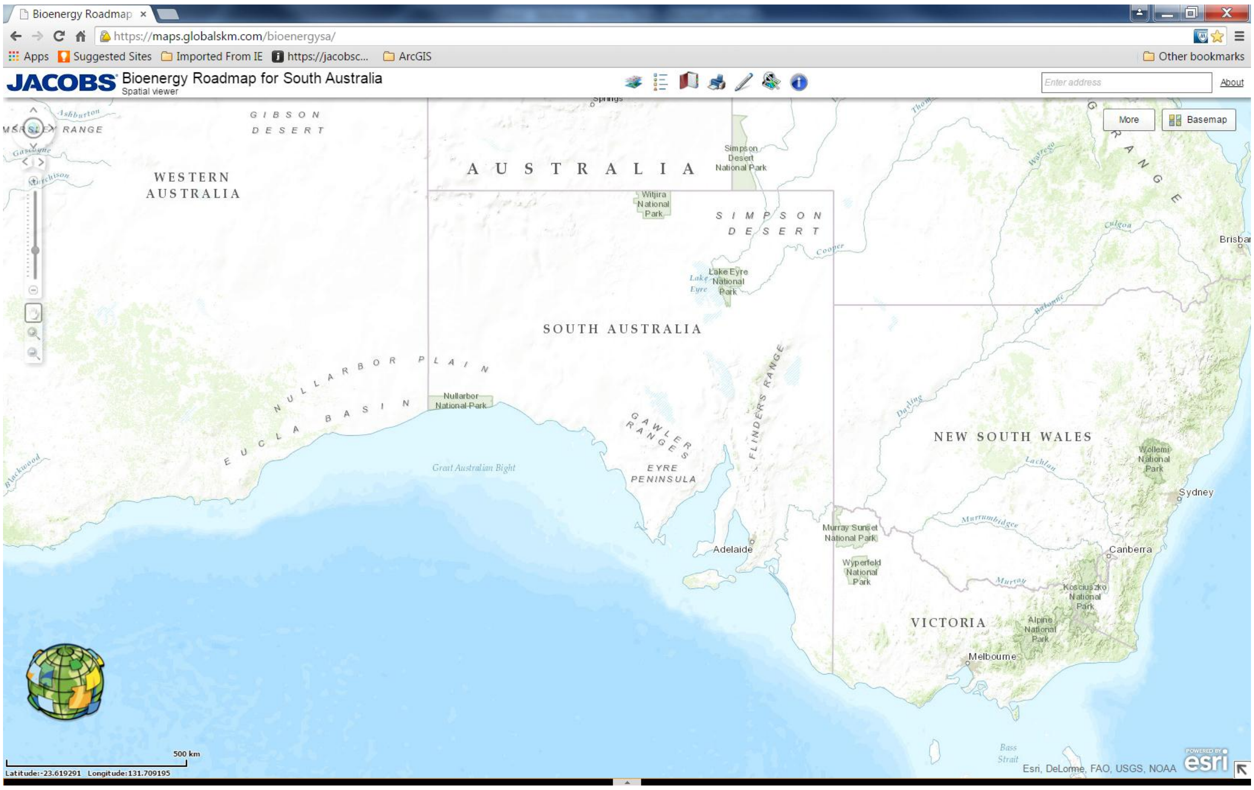
- Google Chrome or Internet Explorer version 7.0 or above
- Broadband or high speed internet capability.

Click on the below link, or copy and paste the URL into a browser window:

https://maps.globalskm.com/bioenergysa/

The initial screen of the application is shown below and displays the login screen.

Login using your username and password

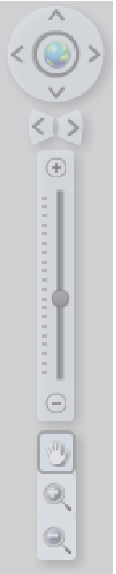


3.2 Web application interface

Once logged-in the web mapping application displays the base map.

3.3 Zoom and pan tool

- Using the Zoom and Pan tool shown below, click on the zoom tool to zoom to a box and pan across the map.
- The left mouse button allows users to pan across the map and the mouse scroll wheel (if applicable) allows zooming in and out.
- Click and hold the left mouse button over the zoom slider to see the scale of the map.
- The navigation tools fade when not in use, hover over the tools to make them visible.



3.4 Navigation panel

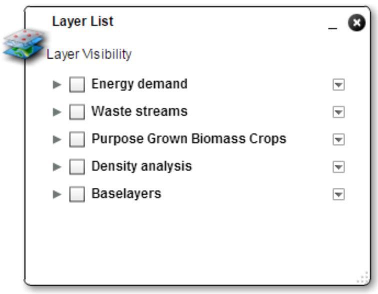
The Navigation Panel at the top of the browser contains the application toolboxes. Once opened each toolbox can be moved around, minimised / maximised and resized bigger/smaller by dragging the right bottom corner of the toolbox. Multiple toolboxes can be opened at once.

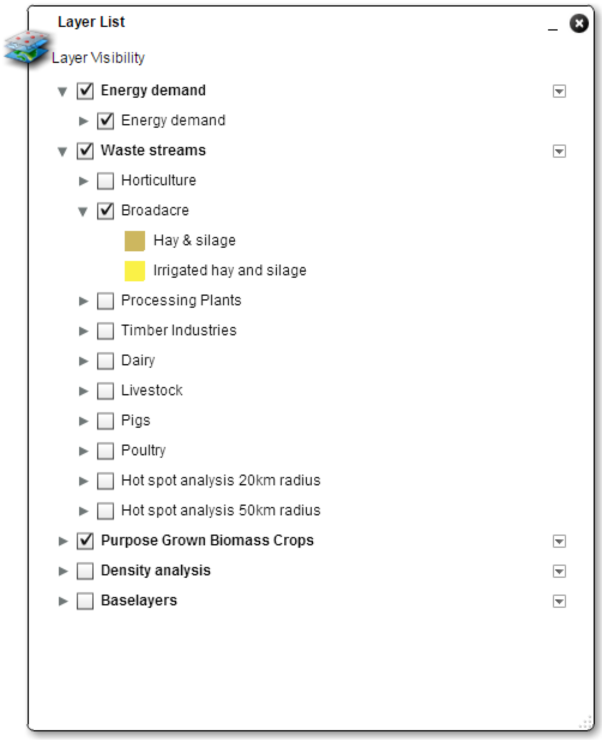
3.4.1 Layer list

The Layer List controls which layers are displayed on the screen and the legend tool displays the symbology for the layers which are turned on. In the Layer List there are major categories of layers which contain subcategories. The Layer List also controls the transparency of layers and can zoom to a layer.

- The Layer List will generally already be displayed, but if it isn't then click on the Layer List tool
- To reveal subcategories click on the horizontal down arrow next to each category, as shown below.

- Use the tick boxes to display/hide single layers, major categories and subcategories.
- The major category and subcategory layers must both be selected to display information on the map.
- The drop down menu to the right of each major category can be used to:
  - Zoom to all layers in the major category
  - Adjust the transparency of the layers in the major category
  - Re-order layers by using the Move Up / Move Down options.





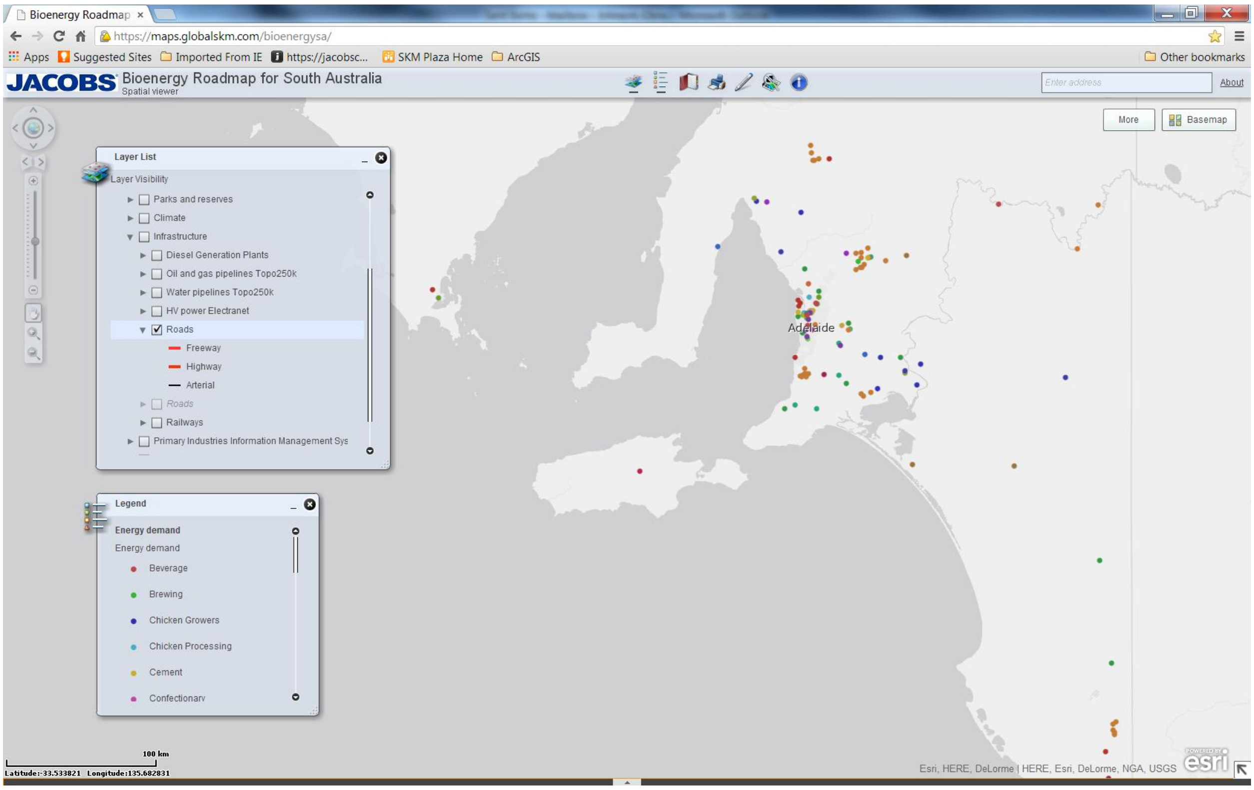
TIPS:

Please note that displaying a large number of layers at once can affect the application speed, to avoid this, turn off irrelevant layers.

The Layer List tool can be resized larger to view more layers at one time.

3.4.2 Legend tool

- Click on the Legend tool in the Navigation Panel 
- The symbology for the layers turned on in the Layer List (see 0 above) will display.

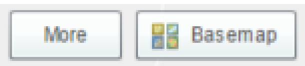


TIPS:

The Legend Tool can be resized larger to view more layers at one time.

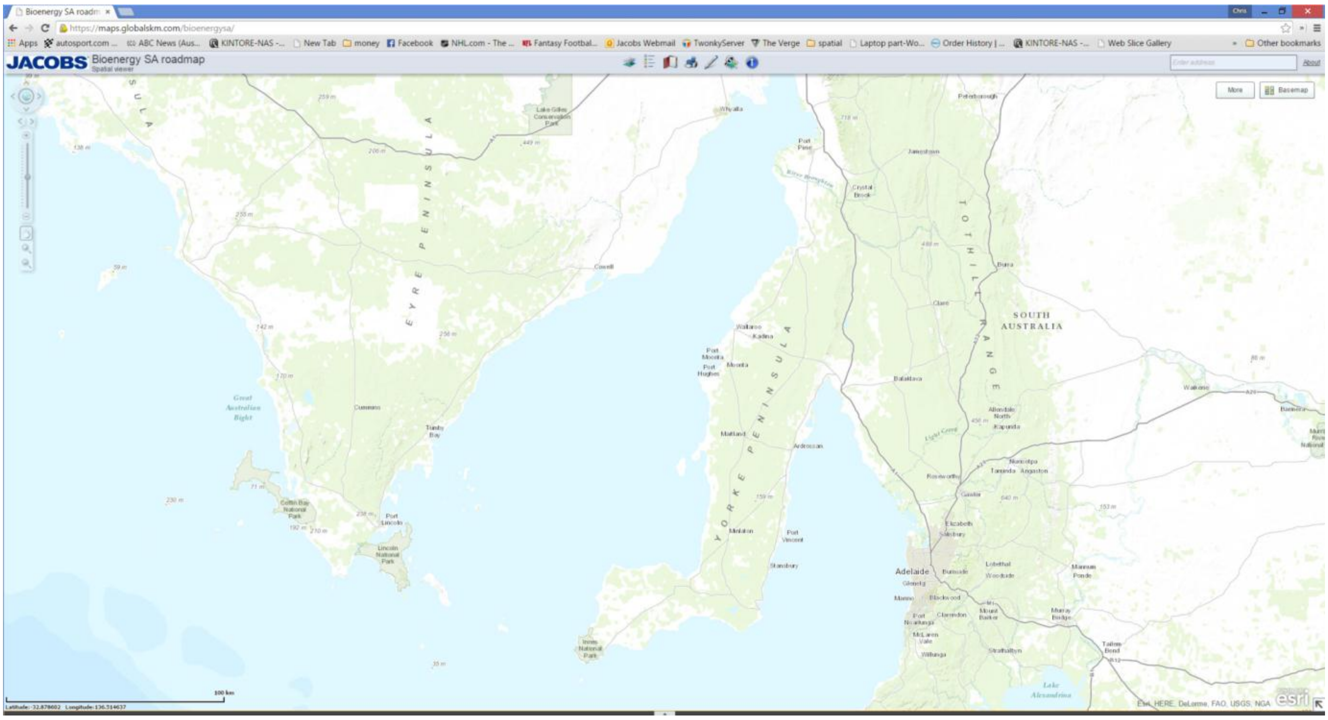
3.4.3 Basemap switcher

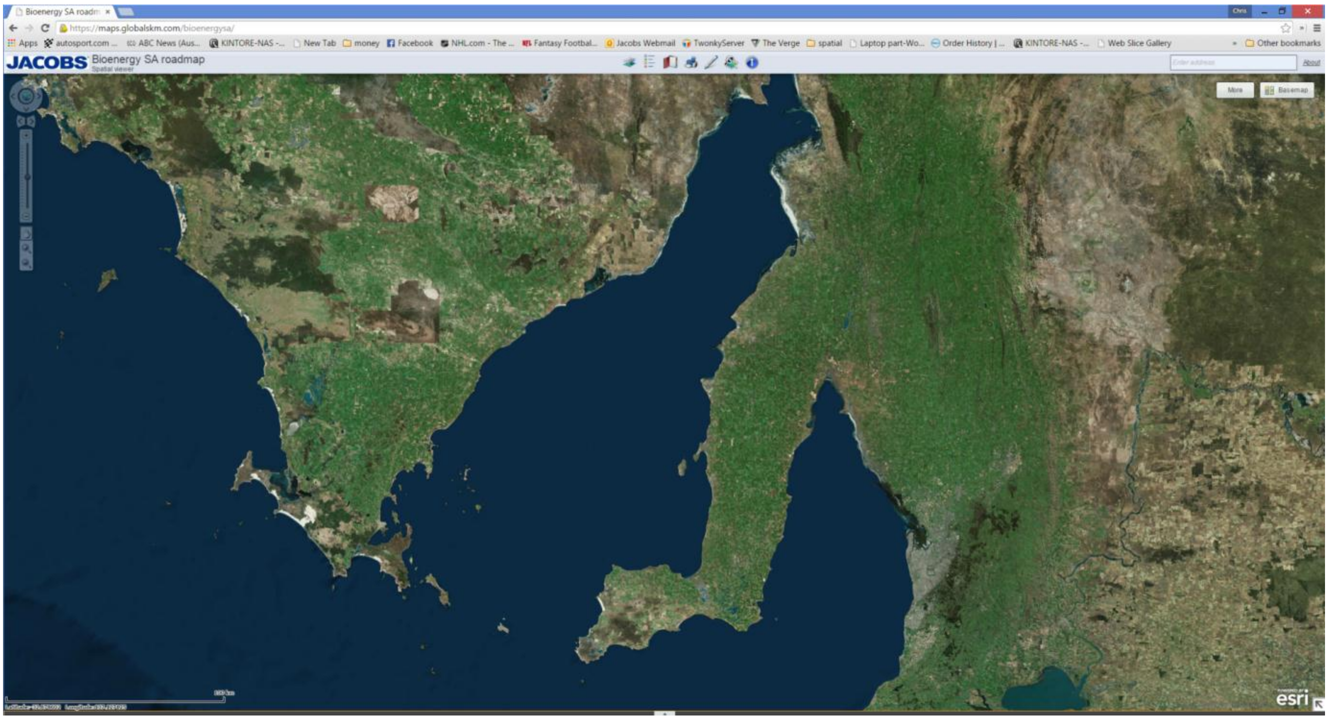
The basemap options at the top right corner of the application window appear as per below:



These buttons allow the user the following basemap options:

- World imagery (as shown in the screen shot below)
- World imagery with labels
- Topographic maps (as shown in the screen shot below)
- Light grey canvas


Bioenergy SA roadmap
https://maps.globalskm.com/bioenergysa/
JACOBS Bioenergy SA roadmap
Spatial viewer
More
Basemap
EYRE PENINSULA
YORKE PENINSULA
SOUTH AUSTRALIA
Adelaide
esri

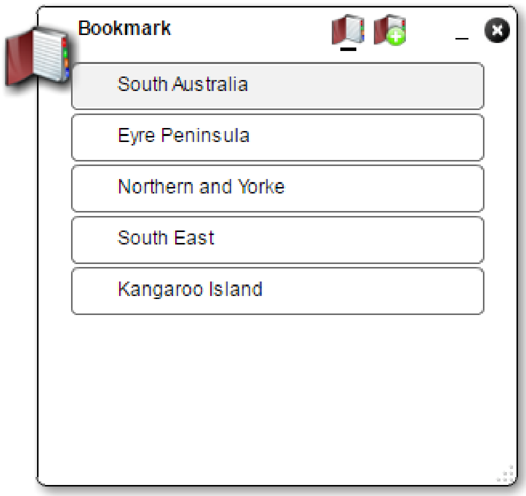

Bioenergy SA roadmap
https://maps.globalskm.com/bioenergysa/
JACOBS Bioenergy SA roadmap
Spatial viewer
More
Basemap
esri

3.4.4 Bookmarks tool

The Bookmarks tool is used to identify map extents that the user wants to save and refer to later. Bookmarks saved in your session are available in subsequent sessions, only on the same machine under the same user profile.

To add a bookmark to refer to the current map extent:

- Click on the Bookmarks tool in the Navigation Panel 
- The Bookmark tool will pop up.
- Click on the Add Bookmark button (icon with green ‘add’ button on book) 
- Name the bookmark appropriately and click Add Bookmark.
- To show all existing bookmarks click on the Bookmarks button at the top of the Bookmarks tool.



TIP:

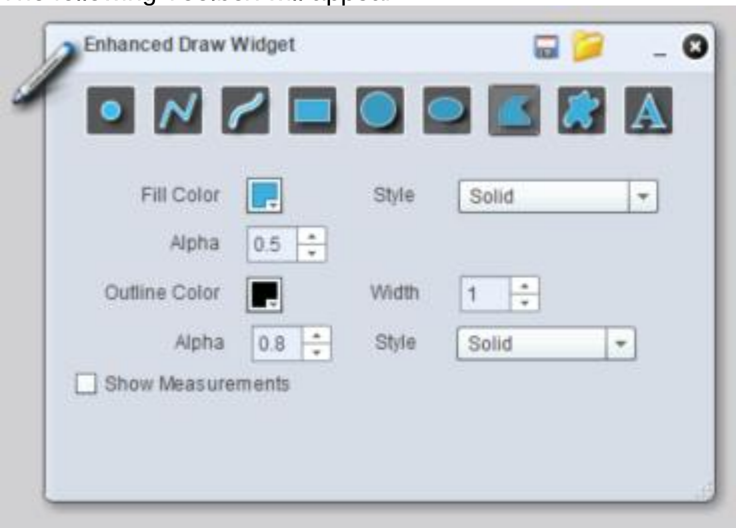
It is good practice to name bookmarks in an appropriate and consistent manner to avoid confusion, such as the locality/purpose of the bookmark.

3.4.5 Enhanced draw tool

The Draw and Measure tool is used to measure, add points, lines, polygons and text labels to a map.

Click on the Draw and Measure tool in the Navigation Panel 

The following Toolbox will appear



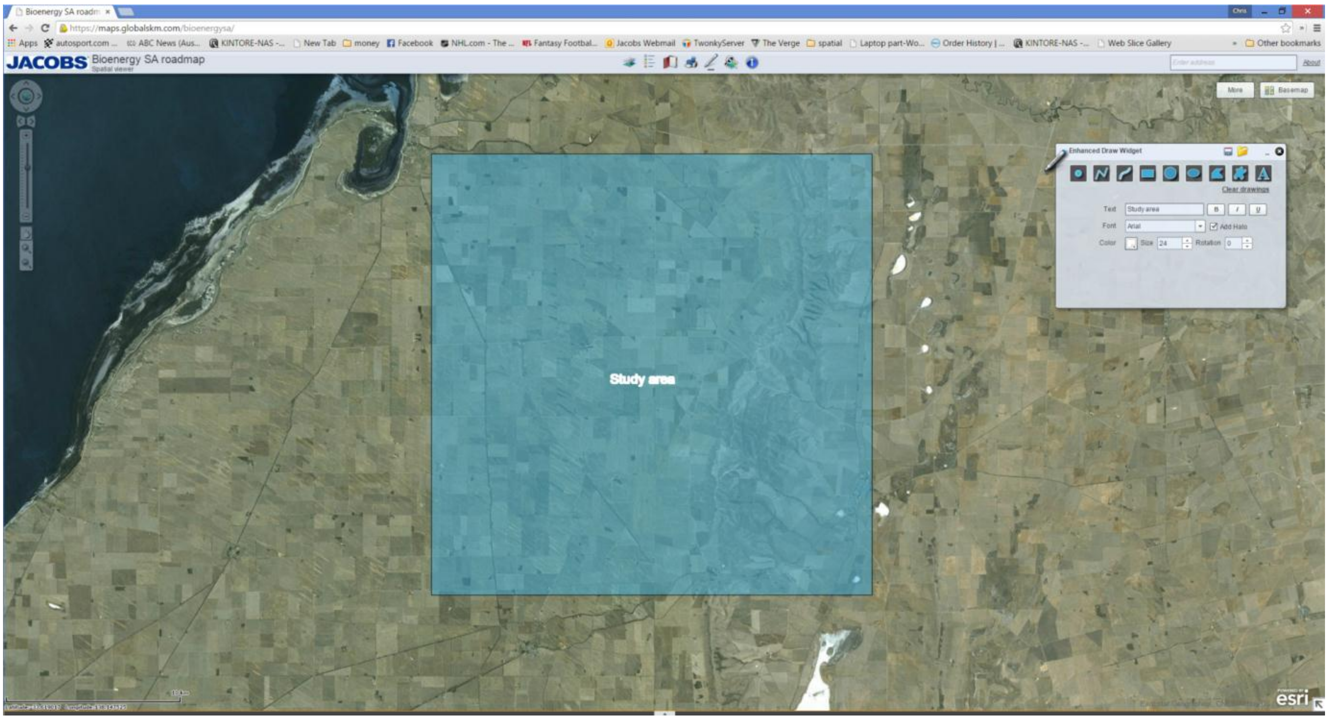
- Select a drawing tool.
  - Choose the colour and style.
  - Click on the map to draw points, lines and shapes.
  - To measure lines and polygon areas on the map:
  - Tick the Show Measurements box prior to using the draw tool.
  - To add a text label:
  - Select the text tool.
  - Type the text
  - Choose the colour and size
  - Click on the map and the label will appear.
- To delete or edit drawings and measurements:
  - To delete all edits:
  - Click on the Clear Drawings on the right hand side of the Draw and Measure Tool.
- To delete specific drawings or measurements:
  - Right click over the drawing within the map

- Click on the Clear option
- Click on Esc to get out of the right click options box.

- To edit a drawing:
  - Left click over the object to bring up the vertices
  - To delete the vertex, right click over a vertex and click on the Delete option
  - To move a vertex, left click on a vertex, hold the left mouse button down and drag the vertex.

TIP:

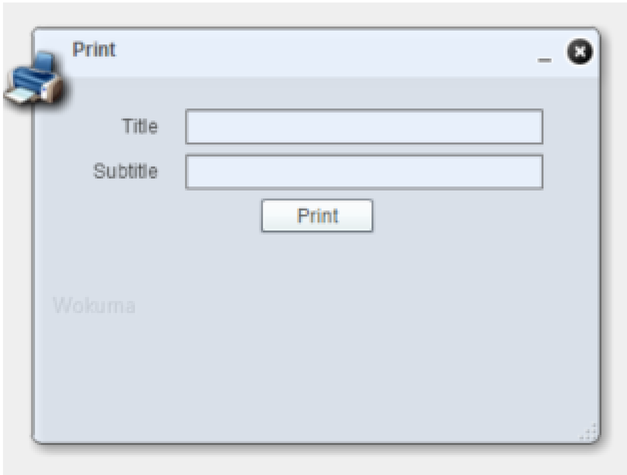
Drawing features will not be saved for your next session. If the record is to be kept on record either print the map, or take a screen grab of the map.



3.4.6 Print tool

The Print tool prints a copy of the screen extents, with a title and sub title.

- Click on the Print tool in the Navigation Panel to create a print layout 
- Add the required title and author in the Print tool window.
- Select a layout template in the printer window.
- Select a file format.
- Specify a scale if required
- Click on the Print button
- The map can only be printed as a PDF using this tool if you have Adobe Acrobat or PDF writer software on your computer.



3.4.7 Identify tool

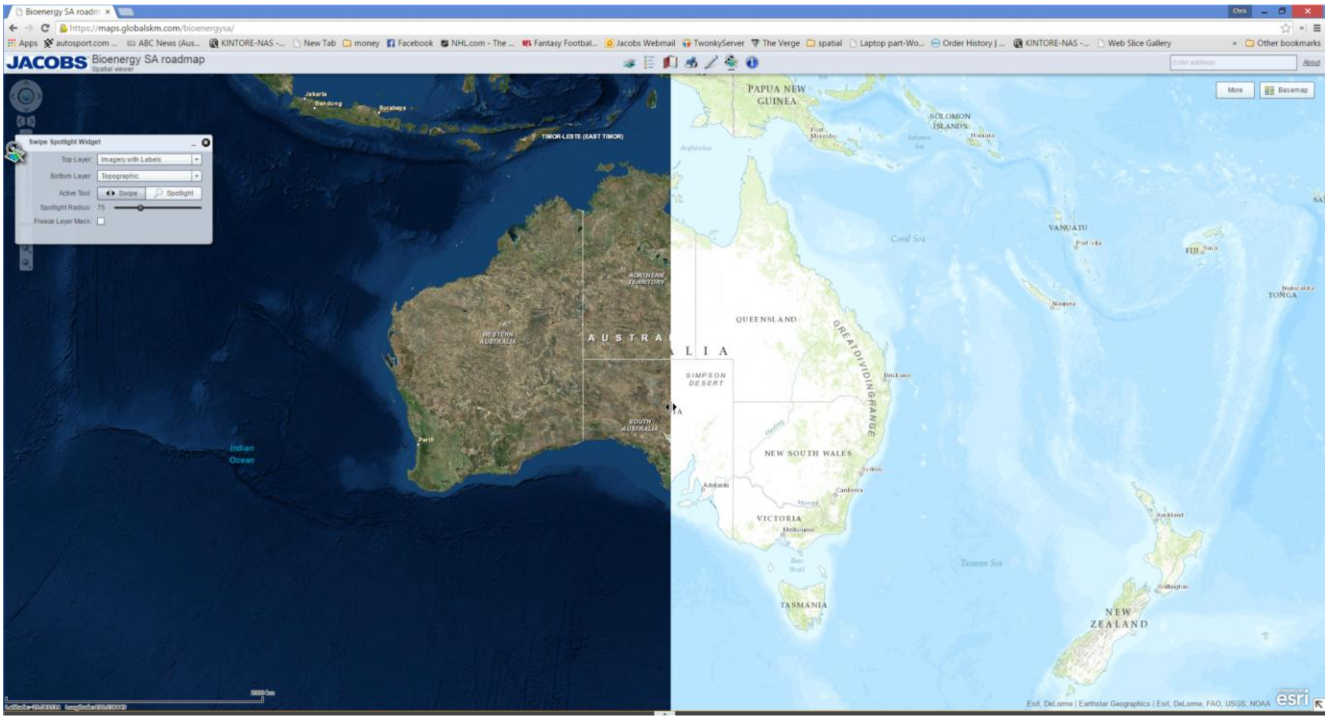
- Click on the Identify tool in the Navigation Panel 
- Select the ‘Identify by…’ option to choose point, line rectangular polygon etc. which will be used to select a feature/features.
- Select a feature to identify

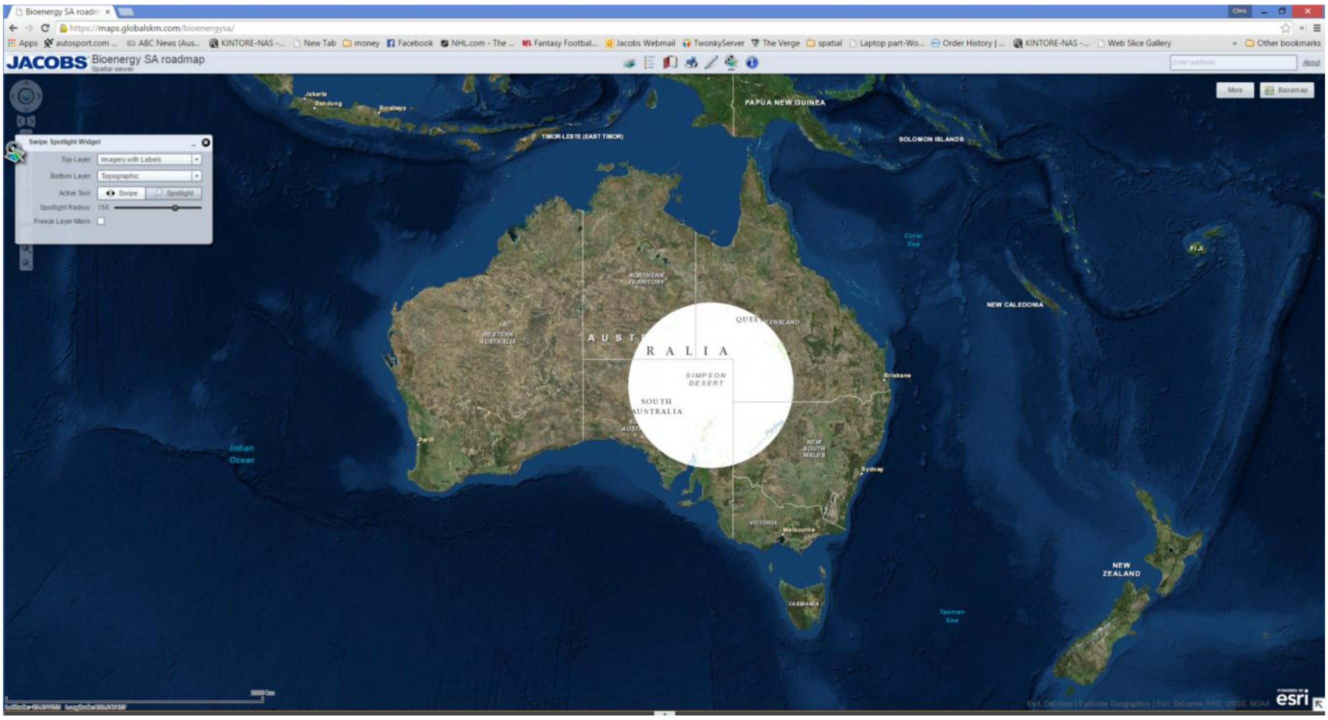
3.4.8 Swipe spotlight tool

- Click on the Swipe Spotlight tool in the Navigation Panel 
- Use the dropdown options to select the two layers that you would like to swipe/spotlight
- Select the Swipe or Spotlight option (and Spotlight Radius if relevant)

TIP:

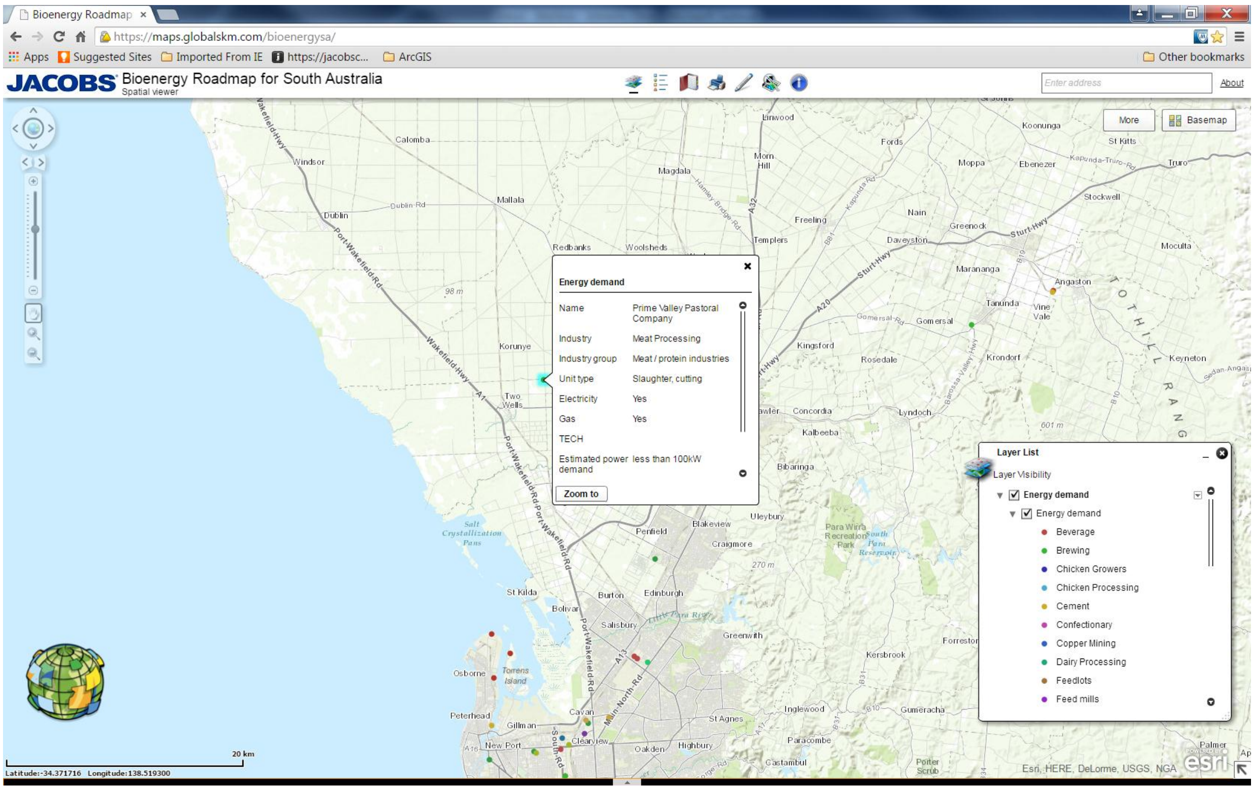
- Select Freeze Layer Mask to freeze the Swipe/Spotlight view





3.4.9 HTML pop up

- Click on map features to display pop up containing details about the map layer.



Appendix B. References

B.1 GIS Maps

Dataset	Description	Source
Rainfall	Annual averages and monthly averages	BOM
Temperature	Average temperature	BOM
Land use 2008	State land use classification (ALUM)	DWLBC, 2008
Soils	Soils of South Australia's Agricultural Lands	DWLBC, 2002
Gas	Topo250k pipelines	Topo250k
Electricity HV power	Electranet tranmission lines (132 and 275 kV)	Electranet
Electranet substations	Electranet substations	Electranet (manley.david@electranet.com.au)
Electricity LV power	SA Power Networks, distribution lines >11 kV	SA Power Networks (owen.moulds@sapowernetworks.com.au)
Electricity substations	SA Power Networks	SA Power Networks (owen.moulds@sapowernetworks.com.au)
Major water pipelines	Topo250k pipelines	Topo250k
Roads	State roads	DPTI, downloaded from data.sa.gov.au 18/03/2015
Railway	State railways	DPTI, downloaded from data.sa.gov.au 18/03/2015
Local Government Area		DPTI, downloaded from data.sa.gov.au 18/03/2015
Land Development Zones		DPTI, downloaded from data.sa.gov.au 18/03/2015
NPWSA Reserves		DEWNR, downloaded from data.sa.gov.au 18/03/2015
State Marine Park Network	State marine park network	DEWNR, downloaded from data.sa.gov.au 18/03/2015
NPWSA Properties	National park properties	DEWNR, downloaded from data.sa.gov.au 18/03/2015
Evaporation		BOM
Power stations	Power stations (Gas, Coal, Wind, Diesel, Biomass)	DMITRE (reinhard.struve@sa.gov.au)
Diesel generation plant		Download from SARIG 25/03/2015
Roads	DPTI Roads	Downloaded from data.sa.gov.au 18/03/2015

Dataset	Description	Source
Lease applications	Aquaculture tenements	Downloaded from SARIG 25/03/2015
Active leases	Aquaculture tenements	Downloaded from SARIG 25/03/2015
Licence Applications	Aquaculture tenements	Downloaded from SARIG 25/03/2015
Active Licenses	Aquaculture tenements	Downloaded from SARIG 25/03/2015
Aquaculture zones	Aquaculture tenements	Downloaded from SARIG 25/03/2015
Animal waste	PIRSA PIIM database	
Power stations	Power stations (Gas, Coal, Wind, Diesel, Biomass)	DMITRE (reinhard.struve@sa.gov.au)
Diesel generation plant		Download from SARIG 25/03/2015

B.2 Report

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