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# The economic and bio-energy production potential of South Australian food waste using Anaerobic digestion

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*Australia is one of the highest food waste generating countries in the world per head of population with over 7.3 million tonnes of food waste generated in Australia in 2008. Anaerobic digestion (AD) is a promising and environmentally sustainable organic waste treatment technology which digests organic waste into a stabilise residue and generate biogas, which can be used to produce energy. Despite large-scale application of AD in the USA and Europe, AD has not been applied widely in Australia. This paper investigates the challenges and opportunities of managing organic waste in South Australia using AD. Following a comprehensive literature review of AD technologies in relation to challenges, barriers and scope of implication in the global context, the study forecast the bio-energy production potential in South Australia using AD. This paper finds that the small AD plant could generate 39kWh from around 589 tonnes of food waste annually. The study also forecast the bio-energy potential by 2021 and if 15% of South Australia's food waste (of year 2021) were treated with AD, a 256kWh energy could be generated. The addition of poultry waste would dramatically increase the proposed plant size up to 3556kWh. This would be a large energy plant that would be a considerable contributor to the SA power grid, provide a level of SA energy security. The payback time for all plant sizes is between 2.5-3.5 years.*

***Keywords: organic waste, waste management, waste-to-energy, anaerobic digestion, renewable energy policy***

## 1. Introduction

Australia is one of the highest food-waste generating countries in the world per head of population (Mason, 2011) with over 7.3 million tonnes of food waste generated in Australia in 2008 (Reynolds et al 2014). A study shows that around 74% of total food was wasted in Sydney in 2009 before it reached the consumer - despite the fact that food waste was of edible quality (EPA-NSW, 2010).Organic waste such as food waste not only imposes risks on the global food security, but it also contributes Methane ($CH_4$) and Nitrous Oxide ($N_2O$), which have 21 and 310 times greater global warming potential respectively than carbon dioxide (IPCC, 1996). There are growing concerns about the economic and environmental variability of existing organic waste disposal systems.

According to the World Bank report, around 87% of waste sent to landfill or open dumping globally and based on organic contents, organic waste produces 300-1000kg of $CO_2$ for every tonne of waste sent to landfills, therefore, it is estimated that the organic fraction of municipal solid waste (MSW) contributes approximately 0.2-0.6 billion tonnes of greenhouse gas (GHG) to the atmosphere every year (Manfredi et al. 2009, World Bank, 2012). Worldwide, $CH_4$ emissions from the waste sector constitute approximately 18% of the global anthropogenic $CH_4$ emissions (Scheutz et al., 2009). GHG emissions reduction to the atmosphere is one of the key challenges and priority actions against climate change around the globe. Biofuel technologies use waste feedstock from various sources, including wood from forest industry, biomass from agriculture and poultry industries and organic MSW to produce energy and fuels. Therefore, biofuel technologies, such as Anaerobic Digestion (AD), not only manage organic waste, but it is also produces energy and biofuels.

This study will examine the key issues, challenges and opportunities in implementing AD in South Australia, and act as a scoping study for the development of AD in South Australia. Section 2 consists of a literature review of AD technology; Section 3 discusses the economic and regulatory feasibility of AD deployment in South Australia. Finally, the study concludes by acknowledging the fundamental barriers and challenges of implementing AD in South Australia.

## 2. Review of Anaerobic digestion

Anaerobic digestion is a biological process to produce biogas from organic waste. Organic waste from farms, agricultural lands, households, food processing industries, meat and fish industries and other sources can be used in an anaerobic digester to produce biogas. Biogas is used to produce heat, electricity and biofuel. Figure-1 shows a simplified diagram of organic waste to bioenergy process.

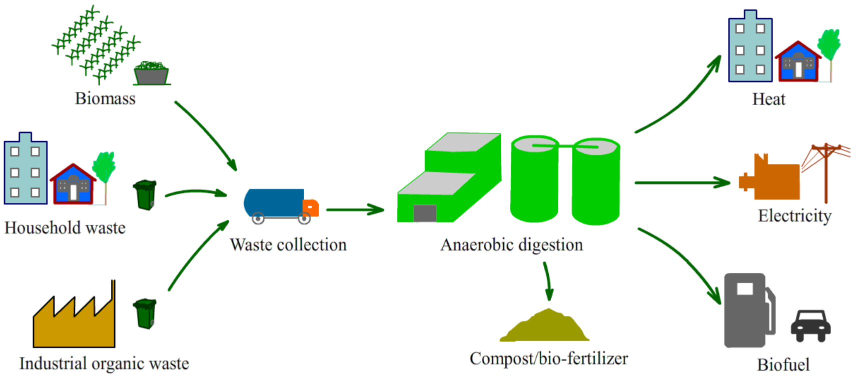

**Figure 1**: A simplified diagram of organic waste to bio-energy using anaerobic digestion

Biogas mainly consists of 50-75% methane, 25-45% carbon dioxide, 2-8% water vapour and traces of O2, N2, NH3, H2, H2S (Dimpl, 2010). A typical biogas composition can be found in the Sustainable Energy Development Authority's report into the potential for generating energy from wet waste streams in NSW (in Table 1).

Table 1: The composition of biogas (SEDA, 1999)

| **Components** | **Content % (v/v)** |
|---|---|
| Methane | 52-95 |
| Carbon dioxide | 10-50 |
| Hydrogen sulphide | 0.001-2 |
| Hydrogen | 0.01-2 |
| Nitrogen | 0.1-4 |
| Oxygen | 0.02-6.5 |
| Argon | 0.001 |
| Carbon monoxide | 0.001-2 |
| Ammonia | trace |
| Organics | trace |

Anaerobic digestion is a series of four complex biological processes such as hydrolysis, acidification, acetogenesis and methanogenesis (Moriarty, 2013). Fermentative bacteria excrete exo-enzymes to transform the particulate organic substrate into liquefied monomers and polymers in hydrolysis (solubilisation) process (Ostrem, 2004). Hydrolysis is a relatively slow process and generally it limits the rate of the overall anaerobic digestion process. In acidogenesis (acidification) process, hydrolysed products are broken down into simple molecules and short chain volatile acids, ketones, alcohols, hydrogen and carbon dioxide (Ostrem, 2004). In the third step, acetogenesis, the products of the acidification are converted into acetic acids, hydrogen, and carbon dioxide by acetogenic bacteria. The first three steps of anaerobic digestion are often grouped together as acid fermentation. Hydrogen plays an important intermediary role in this process, as the reaction will only occur if the hydrogen partial pressure is low enough to thermodynamically allow the conversion of all the acids (Mata-Alvarez, 2003). Methanogenesis is the final step of the anaerobic digestion process where methanogens bacteria (microorganisms) convert the hydrogen and acetic acid formed by the acid formers to methane gas and carbon dioxide (Verma, 2002). Figure 2 shows the biological processes of AD.

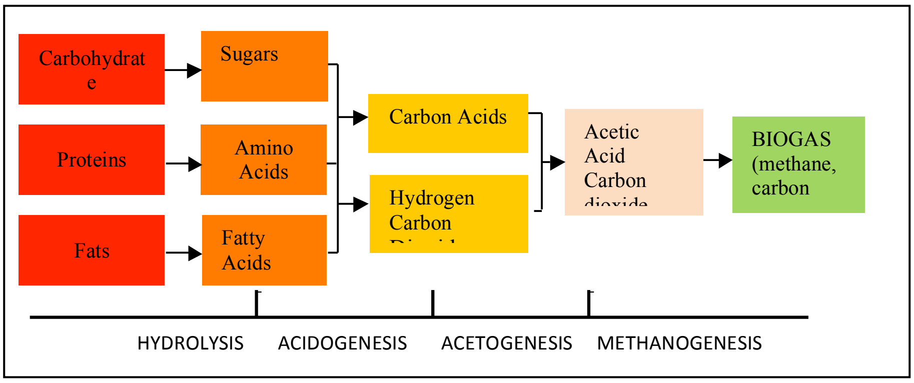

**Figure 2**: Anaerobic digestion process (Moriarty, 2013)

### 2.1. Gas yield and energy efficiency of anaerobic digestion

Biogas yield varies depending upon the composition of feedstock and the ambient conditions in the digester. Electricity and heat generation from biogas varies depending on the methane content of the biogas. It is estimated that 2kWh electricity and 2kWh heat can be generated from 1 cubic meter of biogas (55% $CH_4$ content biogas, 20MJ/$m^3$, 38% electrical and thermal efficiency CHP unit) (SEAI, 2010).

### 2.2. Benefits of AD

Anaerobic digestion offers multiple benefits. The broad range of benefits including social, environmental and economic benefits can be achieved from AD of organic waste. AD encourages local community to recycle organic waste and thus involves local people to the recycling activities. By managing organic waste in a sustainable way, AD solves waste problems as well as environmental problems, such as global warming. AD avoids and reduces GHG emissions to the atmosphere by utilizing biogas as a source of renewable energy. In addition, AD improves health and safety issues associated with pathogen spreading and protects from water and land pollutions. Most importantly, AD produces renewable bio-energy from waste and produces bio-fertilizers. Therefore, AD reduces the dependency on fossil fuels and inorganic fertilizer which is damaging to our environment.  AD also creates jobs and business opportunities, though these are only quantifiable in a site specific context.

### 2.3. The state of anaerobic digestion in the global context

Anaerobic digestion is used for managing organic waste (including poultry and biomass) in both developed and developing countries, with the size of AD plants varying with local needs. In developing countries such as Bangladesh, India, Nepal and China, small scale anaerobic digestion plants are the norm, with the biogas that is produced mainly used for cooking purposes. Large scale AD plants feature in developed countries and are used to generate heat and electricity with combined heat and power facilities (Baker, 2014; Biogas-info, 2014; BRE-info, 2014; Biogaspedia, 2014; EPA, 2010). The annual capacity of the biggest energy plant from biomass (wood pallet) is 750MW and located in Tilbury, UK. In 2011, the UK also opened the largest anaerobic digestion plant using food scraps of 6MW electricity capacity (EurObserver, 2011; Waste Management World, 2011).

## 3. Feasibility of AD for managing organic waste in South Australia

### 3.1. Economic feasibility of AD

### 3.1.1. Biogas and energy potential in SA

In a pilot study in 2009-2010, conducted by the Zero Waste SA, 589 tonnes of food waste were collected from the 17,000 households' green bin (34.7 kg/year/household) for processing and treatment (ZWSA, 2010a; ZWSA, 2010b). The environmental impacts of avoidance and composting of this food waste were explored in Reynolds et al (2011). With this pilot data, we forecast three separate scenarios of the biomass energy potential in SA. The first scenario examines the biomass energy generation potential from the South Australian food waste pilot study. The second scenario builds upon scenario one upgrading to a larger AD plant with the capacity to treat 15% (3877 tonnes) of South Australia's total food waste. We sourced South Australian population data from the Australian Bureau of statistics (1999, 2011) – chiefly that in 2011 there were 643,886 households in South Australia; this is forecast to grow to 745,000 by 2021. The total projected food waste generation in South Australia by 2021 is 25,851 tonnes. The third scenario expands further with the introduction of co-digestion practices to incorporate 100% South Australian poultry/chicken waste into the AD waste stream.

### 3.1.2. Data assumptions

The food waste generation of 34.7 kg/year/household was sourced from Zero Waste SA reports (ZWSA, 2010a; ZWSA, 2010b). South Australian chicken and poultry waste generation (89,508 tonnes per year: 3508 tonnes of chicken carcasses, 16,380 tonnes of meat processing waste, and 69,620 tonnes of manure) was sourced from Environmental Protection Agency Reports (EPA-SA, 1999).

We sourced the biogas yield for food scraps, manure, and chicken waste as 265m$^3$, 82m$^3$ and 280m$^3$ per tonne, from standard figures for biogas production (Biogasinfo 2014, Navaratnasamy et al 2008 ). Total AD energy generation potential was sourced from Navaratnasamy et al (2008), which detailed potential electricity generation at 2kWh per m$^3$ of biogas (55% $CH_4$ content biogas, 20 MJ/m$^3$, 38% electrical and thermal efficiency CHP unit), with additional heat generation of 2 kWh per m$^3$ of biogas or 7.7 MJ per m$^3$ of biogas.

The 2011/12 average cost of electricity in South Australia was found to be 27.25 c/kWh, with the heat from natural gas costing 3.29 cents per MJ (Essential Services Commission of South Australia 2014). The cost of electricity has been forecast to increase past 28.6c/kWh by 2014, with the cost of gas remaining constant at 3 cents per MJ (Energy Users Association of Australia 2012, Australian Energy Market Operator 2013). We have selected 28.6c/kWh as our electricity price and 3 cents per MJ as our gas price.

Functional costs of running an AD operation were sourced from Navaratnasamy et al (2008), these include a 30 days per year maintenance shut down, and a starting capital cost of $7000 per kWh for construction of biogas electricity generating plant, and a further operational cost of $0.02/kWh. We also assume a 24 hour per day operation of the plant. Our assumptions are solely based on technological cost and revenue. We did not consider the biomass collection and transportation cost, or administration cost our scenario analysis. Inclusion of these factors would which increase investment will return time.

### 3.1.3. Energy from bio-waste scenarios in South Australia

The size of AD plant required to treat the volume of food waste collected in the pilot would be 39 kWh generating plant (scenario 1). The size of AD plant required to treat the 15% of the total food waste generated in SA (scenario 2) would be larger at 256kWh. The addition of poultry waste (scenario 3) would dramatically increase the proposed plant size to 3556kWh – a large plant that would be a considerable contributor to the SA power grid and provide a level of energy security to SA (Australian Energy Market Operator 2013). The payback time for all plant sizes is between 2.5-3.5 years depending on the inclusion of heat capture facilities.

The electricity produced in all these scenarios is suitable for small scale power plants compared to the existing power plants in South Australia, such as the Playford B Power Station that produces approximately 240 MW of electricity and the Torrens Island Power plant that produces 1280 MW of electricity (Australian Energy Market Operator

2013). To be eligible for renewable energy target funds (RET), the energy plants needs to produce minimum 1MW of electricity, thus the scenario 1 and 2 would not be eligible for RET fund and only scenario 3 which is energy from co-digestion of animal fat, manure with household organic waste is eligible for RET fund and the most viable option is SA.

### Scenario 1: Energy from food waste pilot

In scenario 1, the food waste collected in a pilot study conducted by the ZWSA in 2011 were considered and assumed to be homogeneous as they collected from organic bins and thus available for AD. Therefore, only 1700 households were considered for scenario 1 (in Table 2).

**Table 2:** Scenario 1 - Energy from SA food waste pilot

| **Assumptions** | | |
|---|---|---|
| Food waste collected | 589 | tonne |
| Biogas yield | 265 | $m^3$/tonne |
| Total biogas yield | 156,085 | $m^3$ |
| Electricity generation | 2 | kWh/$m^3$ |
| Heat generation | 7.7 | MJ/ m3 biogas |
| **Total electricity generation** | 312,170 | kWh |
| **Total heat generation** | 1,201,854.5 | MJ |
| Average cost of electricity | 28.60 | c/kWh |
| Average heat cost | 3.00 | c/ MJ |
| **Total income from electricity** | $89,280.62 | |
| **Total income from heat** | $36,055.64 | |
| Number of operating days | 335 | per year |
| Operational Hours | 24.00 | per day |
| Capacity of the electricity generator | 38.83 | kWh |
| Capital cost of plant | $7,000.00 | per kWh |
| **Total capital cost** | $271,789.80 | |
| Operation cost | $0.02 | per kWh |
| **Total operation cost** | $6,243.40 | year |
| **Total yearly revenue** | $119,092.86 | a year (with heat capture facilities) |
| **Total yearly revenue** | $83,037.22 | a year (without heat capture facilities) |

### Scenario 2: Energy from projected food waste

In scenario 2 (in Table 3), the projected amount of available food waste in 2021 was considered. Only 15% of the projected food waste in South Australia was considered to estimate the potential energy from bio-waste in SA.

**Table 3:** Scenario 2 - Energy from 15% of SA food waste

| **Assumptions** | | |
|---|---|---|
| Food waste collected | 3878 | tonne |
| Biogas yield | 265 | $m^3$/tonne |
| Total biogas yield | 1,027,597 | $m^3$ |
| Electricity generation | 2 | kWh/$m^3$ |
| Heat generation | 8 | MJ/$m^3$ biogas |
| **Total electricity generation** | 2,055,194 | kWh |

| | | |
|---|---|---|
| **Total heat generation** | 7,912,498 | MJ |
| Average cost of electricity | 29 | c/kWh |
| Average heat cost | 3 | c/ MJ |
| **Total income from electricity** | $587,785.56 | |
| **Total income from heat** | $237,374.94 | |
| Number of operating days | 335 | per year |
| Operational Hours | 24.00 | per day |
| Capacity of the electricity generator | 256 | kWh |
| Capital cost of plant | $7,000.00 | per kWh |
| **Total capital cost** | $1,789,348.23 | |
| Operation cost | $0.02 | per kWh |
| **Total operation cost** | $41,103.89 | year |
| **Total yearly revenue** | $784,056.61 | a year (with heat capture facilities) |
| **Total yearly revenue** | $546,681.67 | a year (without heat capture facilities) |

**Scenario 3: Energy from projected food waste and poultry waste**

In scenario 3 (in Table 4), a combined mixed feedstock, food waste and chicken and poultry waste were considered as there are several poultry processing plants in SA and chicken fats and poultry waste have higher biogas production yield.

**Table 4:** Scenario 3- Energy from 15% of SA food waste and poultry/chicken waste

| **Assumptions** | | |
|---|---|---|
| Chicken carcasses and meat processing waste | 19888 | tonne |
| Chicken manure | 69620 | tonne |
| Food waste collected | 3878 | tonne |
| Biogas yield | 380 | m$^3$/tonne of carcass waste |
| Biogas yield | 82 | m$^3$/tonne of manure |
| Biogas yield | 265 | m$^3$/tonne of food waste |
| Total biogas yield | 14,293,877 | m$^3$ |
| Electricity generation | 2 | kWh/m$^3$ |
| Heat generation | 8 | MJ/m$^3$ biogas |
| **Total electricity generation** | 28,587,754 | kWh |
| **Total heat generation** | 110,062,854 | MJ |
| Average cost of electricity | 29 | c/kWh |
| Average heat cost | 3 | c/ MJ |
| **Total income from electricity** | $8,176,097.72 | |
| **Total income from heat** | $3,301,885.62 | |
| Number of operating days | 335 | per year |
| Operational Hours | 24 | per day |
| Capacity of the electricity generator | 3556 | kWh |
| Capital cost of plant | $7,000.00 | per kWh |
| **Total capital cost** | $ 24,889,835.79 | |
| Operation cost | $0.02 | per kWh |
| **Total operation cost** | $571,755.09 | year |

| | | |
|---|---|---|
| **Total yearly revenue** | $10,906,228.25 | a year (with heat capture facilities) |
| **Total yearly revenue** | $7,604,342.63 | a year (without heat capture facilities) |

## 3.2. Regulatory feasibility of AD in SA

### 3.2.1. Energy security, climate change and renewable energy policy

The availability and price can be interrupted by different factors including global climate change, regional conflicts (wars), and sudden changes in the supply-demand balance, thus, energy security is one of the biggest concerns for every country. Lack of energy security is thus linked to the negative economic and social impacts of either physical unavailability of energy, or prices that are not competitive or are overly volatile (IEA, 2014). Currently Australia has 60 days stock holding capacity which is lower than the IEA's recommended days of 90 days (IEA, 2014). Therefore, energy generations from decentralized and locally sourced systems are important for Australia.

In regards to combating climate change, South Australia has adapted the Climate Change Adaptation Framework (SA-Govt., 2012) which has a 30 years plan for south Australia to reduce GHG emissions, efficient use of resources and sustainable energy generation from alternative energy sources. In addition, South Australia's climate change legislation sets three targets (SA-Govt., 2007):

- reduce greenhouse gas emissions within the state by at least 60% to an amount that is equal to or less than 40% of 1990 levels by 31 December 2050 as part of a national and international response to climate change;
- increase the proportion of renewable electricity generated so it comprises at least 20% of electricity generated in the state by 31 December 2014; and
- increase the proportion of renewable electricity consumed so that it comprises at least 20% of electricity consumed in the state by 31 December 2014.

### 3.2.2. Waste management policy

Waste management policies and strategies are important to promote certain technologies, for instance, bans of organic waste to landfill, the diversion of waste from landfills and the promotion of organic waste recycling and treatment using composting or anaerobic digestion in many European countries. The 'zero waste' target, which aims to divert waste from landfill, also increases recycling and composting. AD promotes zero waste activities by diverting organic waste from landfills and produces renewable energy (Zaman, 2015). Mandatory separate collection systems, landfill tax and pay as you throw (PAYT) etc. systems also have influence in the local waste management systems. Figure 3 shows the key waste management policies that influence AD in different countries.

| Europe | USA | UK | Australia |
|---|---|---|---|
| • Ban on organic waste to landfill<br>• PAYT<br>• Landfill tax | • Zero waste targets<br>• Mandatory separate collection<br>• Landfill tax<br>• Fees/penalties on food waste (Seattle) | • Zero waste targets<br>• Landfill tax<br>• Landfill bans | • Zero waste targets<br>• Landfill levy |

**Figure 3**: Key waste management policies that influence AD

### 3.3. Key challenges and opportunities for AD in SA

Potential challenges of implementing anaerobic digestion in South Australia are to ensure consistent supply of feedstock and to maintain a homogeneous feedstock quality. It is important to have a proper organic waste recycling system in place to implement AD. Separate organic recycling bins are mandatory with a higher percentage of recycling or sorting efficiency and a least proportion of contamination. In the approximate estimation only capital cost and operation cost of the AD plant are considered, therefore, the payback time is very short. However, the overall payback time will be higher if the feedstock cost, collection and transportation cost, manpower cost and other permit cost are considered with the operation and maintenance costs. Government incentives, tipping fees and other economic incentive can significantly reduce the payback time and make AD more profitable source of renewable energy.

Small scale AD plants (Scenario 1) are not eligible for Renewable Energy Target (RET) grants in Australia, therefore, the large scale AD plants (in Scenarios 2 and 3 ) are more viable for South Australia as a waste-to-energy project. In addition, AD should not be treated as only a renewable energy technology, instead it has the potential to manages organic waste and produce bio-fertilizer which also has market value. Therefore, AD should also attract waste management incentives too for instance tipping fees or landfill tax avoidance incentives.

## 4. Conclusion

There is a lack of investment in the renewable energy sector particularly in waste-to-energy using AD technology despite exhibiting various sustainability potentials. Both small scale and large scale AD digestion should be encourage through policy and economic incentives so that the technology can be applied in both centralized and decentralized waste management and renewable energy generation. National and regional climate change is vital for AD as it reduces GHG emissions to the atmosphere and thus climate change incentives are important for implementing and promoting AD in any region. Active community involvement is essential as it requires a high level of organic waste sorting and recycling efficiency.

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