City of Sydney

Renewable Energy Master Plan

Technical Report

206939

Issue | October 2011

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Job number 206939

ARUP

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Background

In April 2008, the City of Sydney released Sustainable Sydney 2030 outlining a series of large visionary projects to transform Sydney into a more sustainable, more liveable, global and connected city by 2030. Sustainable Sydney 2030 also recognised the importance of reducing the City's carbon emissions to both directly contribute to climate change mitigation and to lead by example, setting the standard for other global cities. In this respect, Sustainable Sydney 2030 announced the City's ambition to achieve a 70% reduction in carbon emissions by 2030 based on 2006 levels.

SUSTAINABLE SYDNEY 2030 TARGETS

Carbon Abatement

The City has an overall target of 70% abatement on 2006 levels by 2030. This represents a decrease from 5.4 Mt CO_2e p.a. in 2006 to **1.6 MtCO_2e p.a**. in 2030 compared with business as usual projections of 6.44 MtCO_2e p.a .in 2030.

The target is to be achieved by a range of measures including the renewable energy master plan, Trigeneration Master Plan and other measures targeting waste and transport.

Renewable Energy

Renewable energy will provide a minimum of 30% (4.3 TWh p.a.) of the City's electricity requirement by 2030.

This equates to **1.3 TWh p.a.** to be met or displaced by renewable energy

Renewable Feedstock

Renewable gas resource will replace the natural gas resource supplying the City's trigeneration system by 2030.

This equates to **26.7 PJ** in 2030.

The City also recognised the importance of renewable energy and has set out a separate target of 30% of the City's electricity to be derived from renewable sources by 2030. The City commissioned Arup to prepare this Renewable Energy Master Plan to identify the extent to which renewable energy may contribute to the City's carbon reduction target and the available renewable energy resource to achieve the renewable energy target.

In addition to the renewable energy potential, the City has identified that the prime mechanism for achieving the carbon abatement target is via a Combined Cooling Heating and Power (Trigeneration) Master Plan. The Trigeneration Master Plan outlines a scheme for a 360 MWe network of gas fired cogeneration units to produce electricity and heat. The heat is to be distributed through a pipeline network under the City to provide thermal energy for heating and cooling within 'low carbon zones'. The natural gas requirements for the Trigeneration Master Plan are estimated to be 26.7 PJ per year. The Trigeneration Master Plan also provides an allowance for natural gas to be replaced by renewable fuel feedstocks by 2030. Identification of these feedstocks forms part of the Renewable Energy Master Plan.

The Case for Renewable Energy in the City

Renewable energy has a history in urban environments, typically in the form of building integrated solar photovoltaics, solar hot water and wind turbines. However large scale deployment of both building integrated and stand alone technologies within urban environments has been constrained by the complexity of the built form, availability of suitable land uses, planning constraints, as well as the current structure of energy pricing. Despite these constraints, renewable energy can play a large role in reducing the carbon intensity of cities, increasing energy independence and promotion of a greater awareness of energy consumption within urban communities[1] and decreasing household utility bills.

Recent increases in retail electricity tariffs to households and businesses in NSW are almost entirely due to upgrades to network infrastructure (IPART, 2010) required to meet growing peak demand. In the City of Sydney, this peak typically occurs between 10am and 4pm; times when many building integrated solar energy technologies will be operating at, or near capacity. Any such decentralised energy generation able to reduce peak demand may delay infrastructure upgrades and potentially reduce further escalation of network charges and hence electricity bills for the entire community.

Renewable energy in urban environments offers further benefits compared to conventional fossil fuel generation, including relatively few adverse environmental impacts (generally limited to noise and visual impacts) and health benefits as a result of reduced local air emissions and other pollutants. The renewable energy technology market is relatively immature compared to conventional fossil fuel generation technology. This implies that there is greater potential for innovation in technology, materials and manufacturing methods to occur within the period to 2030 and drive down capital costs of renewable energy technology. This, coupled with the likely advent of a carbon price, will increase the cost competitiveness of renewable energy technologies and remove some of the financial barriers to large scale deployment.

Approach

The Renewable Energy Master Plan provides evaluation of renewable energy resource and renewable technology performance under the following separate categories:

1	Building integrated renewable technologies	Small scale (<100kW) building integrated technologies primarily installed to meet the energy demands of individual buildings within the city
2	Renewable power plants (within the City)	Large scale (>100kW) stand alone technologies primarily exporting energy to the electricity grid and/or district heating network within the city
3	Renewable power plants (Beyond the City)	Technologies operating outside the City of Sydney LGA in optimum resource locations exporting electricity to the grid to be consumed within the city
4	Renewable fuel feedstocks	Waste and other biomass able to be converted to fuel and transported to the city for use in the decentralised energy network

[1] Research from the UK suggests that the intermittent nature of renewable energy makes consumers more aware of their own behaviour. For example Kierstead (2007) found that households decreased their energy consumption after installing solar PV panels on their house.

For building integrated renewable technologies and renewable power plants the objective was to determine the extent to which technologies installed within the city could meet the renewable energy target and the quantity of residual renewable energy which needs to be sourced from beyond the city to meet the target.

For analysis of renewable fuel feedstocks, the objective was to determine the availability of suitable fuel feedstocks within proximity to the City to meet the demand of the decentralised energy network. This demand was estimated to be 26.7 PJ requirement based on the 24 hour operation of a 360MW$_e$ network.

The step wise approach is shown below.

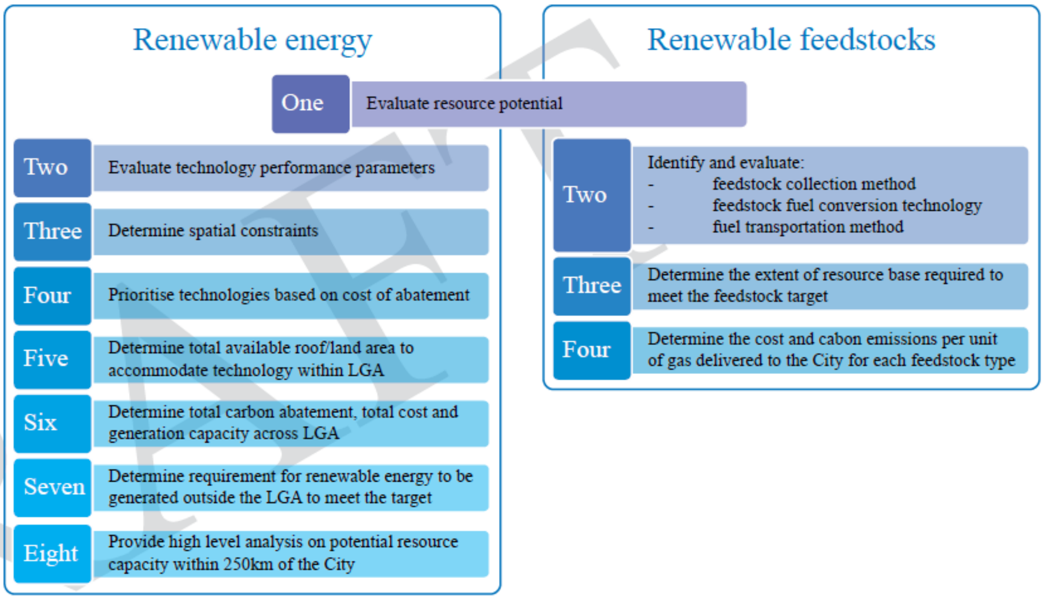

Figure 1 Step wise approach to developing the Renewable Energy Master Plan

Results

Renewable Energy

Renewable energy resources have been identified to meet the 30% renewable energy target (1.3 TWh p.a.). Of this, 46% is provided by building integrated technologies, 8% by renewable power plants within the City and 46% from technologies beyond the City. The contribution of electricity generated or offset by renewable energy to the City's total 2030 electricity consumption is presented in Figure 2 below.

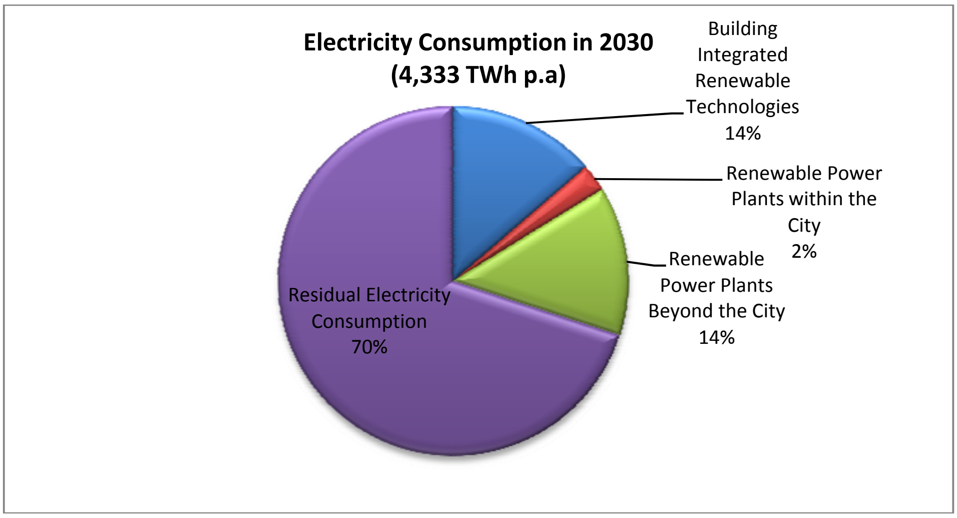

Figure 2 Contribution of electricity generated or offset by renewable energy to the City's total 2030 electricity consumption

Renewable fuel feedstocks

To meet the renewable fuel feedstock target of 26.7PJ, it is estimated that feedstock will be required to be sourced from an area just over 250km from the City. The renewable fuel feedstock within 250km of the City is equivalent to 25.5PJ, estimated to meet 96% of the target.

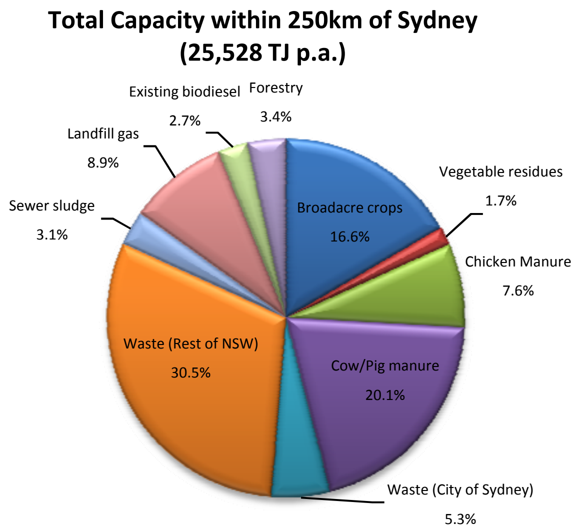

Figure 3 Contribution of primary renewable resource to renewable feedstock target (26.7 PJ p.a.)

Carbon Abatement

Renewable energy technologies are able to achieve 2.16 $MtCO_2e$ abatement per year by 2030 which equates to 45% of the overall target for the City. Of this, 22% is provided by renewable energy technologies both within and beyond the City and 23% from the use of renewable fuel feedstocks to further reduce the emission intensity of the City of Sydney's decentralised energy network.

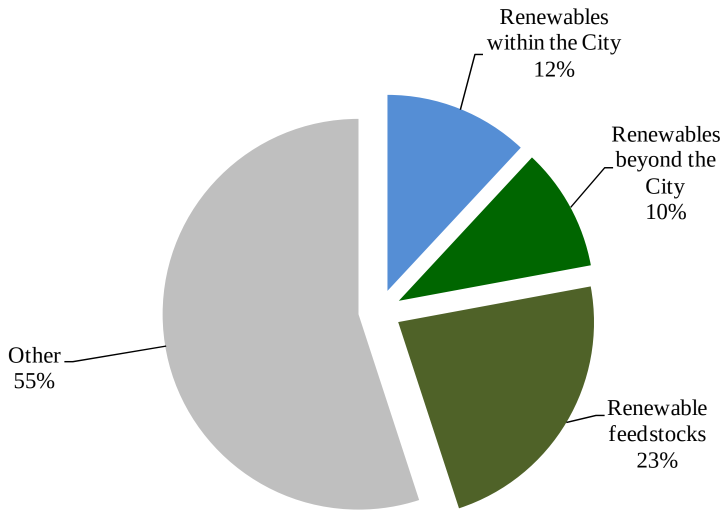

Figure 4 Contribution to carbon abatement in 2030

A cost of abatement curve for all initiatives shows that, with the exception of solar hot water in non residential applications, investment in onshore wind technology beyond the City is currently the most cost effective method of carbon abatement. This is followed by solar hot water on residential buildings. Next in the hierarchy are geothermal and concentrating solar thermal technologies located within the City provided that they are able to export thermal energy to established district heating networks. Building integrated solar photovoltaics, and large scale wind within the City follow along with building integrated wind. However, building integrated wind is only suitable for the tallest of buildings within the CBD such that its contribution to the target is so small that it is not visible on the cost curve. These costs of abatement do not include subsidies. That is, at least part of the cost will be covered by State and Federal Government incentives. Building integrated technologies will attract the greatest subsidies such that the cost of abatement to the City and its residents is further reduced.

The abatement offered by replacement of non-renewable fuel feedstocks with renewable fuel feedstocks is substantial but comes at a high cost. That is, the replacement of natural gas with renewable fuel feedstocks is unlikely to represents the most cost effective method for abatement in 2030.

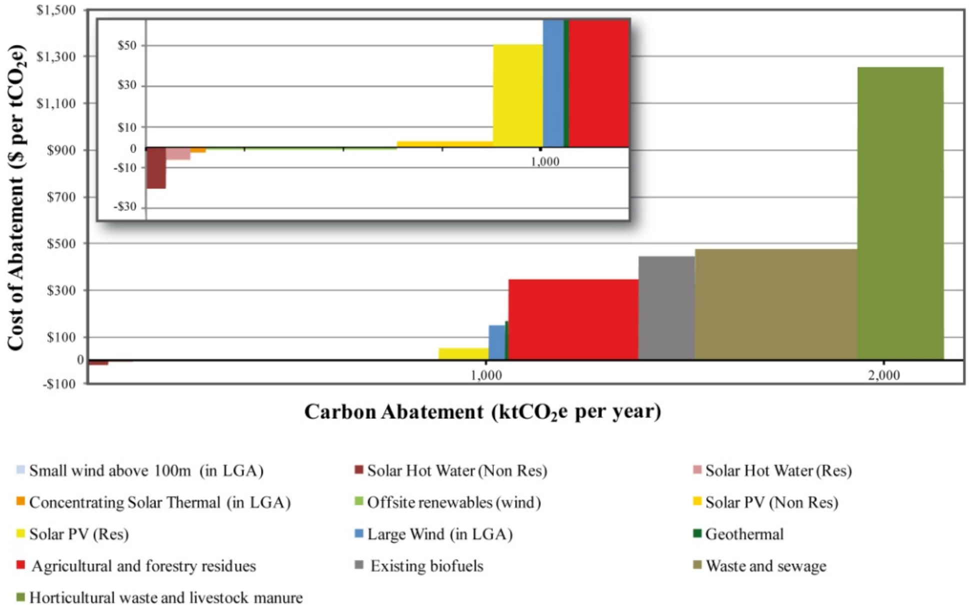

Figure 5 Cost of abatement curve for the Renewable Energy Master Plan

Summary and Next Steps

The Renewable Energy Master Plan presents a summary of the theoretically achievable renewable energy resource available to the City of Sydney to meet its carbon and renewable energy targets. The carbon abatement opportunities identified within this Master Plan can be realised within a few years based on current technology and embraced by the wider community with little or no additional social or physical infrastructure required. Furthermore, the opportunities are currently commercially feasible with no requirement for restructuring of energy pricing or retailing arrangements.

The results represent a best case scenario of theoretically achievable renewable energy generation. In reality, there are likely to be a range of technical, physical, commercial, governance and planning constraints which will limit the degree to which, and the rate at which, the targets can be achieved.

For building scale technologies, the degree and rate of uptake by building owners will be dependent on whether appropriate incentive mechanisms can be developed at all levels of Government, as well as the individual physical constraints of buildings. For renewable power plants within the City, the City of Sydney may be able to directly contribute or incentivise deployment through direct contributions, land offers or rate concessions to proponents. These power plants will also be highly subject to planning controls, especially in parkland areas where there are likely to be conflicting land use issues. These implementation issues are to be explored as a further piece of work.

The use of renewable fuel feedstocks to replace natural gas is likely to offer substantial additional abatement but will likely come at high cost compared to other forms of abatement. Further, the ability of the City to acquire significant volumes of renewable fuel feedstocks will be highly subject to the market for biogas and biomass which is currently in its infancy. Predictions of peak oil in the near future imply that highly competitive markets for these products will emerge to meet demand for transport fuels including LNG. The assumption that the City will be able to acquire 100% of these fuels to service the City's trigeneration system will therefore need to be reviewed in further stages of the Trigeneration Master Plan.

1 Introduction

1.1 Renewable Energy and Sustainable Sydney 2030

In April 2008, the City of Sydney released Sustainable Sydney 2030 outlining a series of large visionary projects to transform Sydney into a more sustainable, more liveable global and connected city by 2030. Sustainable Sydney 2030 also recognised the importance of reducing the city's carbon emissions to both directly contribute to climate change mitigation and to lead by example, setting the standard for other global cities. In this respect, Sustainable Sydney 2030 announced the City's ambition to achieve a 70% reduction in carbon emissions by 2030 based on 2006 levels.

Central to the emissions reduction ambition is the Decentralised Energy Master Plan transforming the way energy is generated in urban environments and setting a benchmark for the rest of NSW, Australia and the world.

The primary aim of the Decentralised Energy Master Plan is to encourage low carbon energy generation in the city to reduce dependence on centralised fossil fuel generation imported via the electricity grid. The prime mechanism to achieve the decentralisation is the Trigeneration Master Plan. The Trigeneration Master Plan outlines a scheme for a network of gas fired cogeneration units producing electricity and heat with the heat distributed through a pipeline network under the city to provide thermal energy for heating and cooling within 'low carbon zones'. The Trigeneration Master Plan also provides allowance for natural gas to be replaced by renewable fuel feedstocks by 2030.

To complement the Trigeneration Master Plan, the City also recognised the importance of renewable energy and has set out a separate target of 30% of the city's electricity to be derived from renewable sources by 2030. The City commissioned Arup to prepare this Renewable Energy Master Plan to investigate the renewable energy technologies and renewable resources available to achieve this target.

SUSTAINABLE SYDNEY 2030 TARGETS

Carbon Abatement

The City has an overall target of 70% abatement on 2006 levels by 2030. This represents a decrease from 5.4 $MtCO_2e$ p.a. in 2006 to 1.6 $MtCO_2e$ p.a. in 2030 compared with business as usual projections of 6.44 $MtCO_2e$ p.a. in 2030 [1].

The target is to be achieved by a range of measures including the Renewable Energy Master Plan, Trigeneration Master Plan and other measures targeting waste and transport.

Renewable Electricity

Renewable electricity will provide a minimum of 30% of the City's electricity requirement by 2030 projected to be approximately 4.3 TWh p.a. This equates to 1.3 TWh p.a. of electricity to be met or displaced by renewable energy

Renewable Fuel Feedstock

Renewable fuel feedstocks will replace the natural gas resource supplying the City's trigeneration system by 2030. This equates to 26.7 PJ in 2030.

1.2 Renewable energy in urban environments

Renewable energy has a history in urban environments, typically in the form of building integrated solar photovoltaics (PV), solar hot water and wind turbines. However large scale deployment of both building integrated and stand alone technologies within urban environments has been constrained by the complexity of the built form, availability of suitable land uses, planning constraints, as well as the current structure of energy pricing. Despite these constraints, renewable energy can play a large role in reducing the carbon intensity of cities, increasing energy independence and promotion of a greater awareness of energy consumption within urban communities[2] and decreasing household utility bills.

Recent increases in retail electricity tariffs to households and businesses in NSW are almost entirely due to upgrades to network infrastructure (IPART, 2010) required to meet growing peak demand. In the City of Sydney, this peak typically occurs between 10am and 4pm; times when many building integrated renewable energy technologies will be operating at, or near capacity. For instance, an investigation into demand management in the Sydney Metropolitan Area by Energy Australia and Transgrid (2009) estimated that solar photovoltaic cell generation is likely to be coincident with peak demand at least 40% of the time. Any such decentralised energy generation able to reduce peak demand may delay infrastructure upgrades and potentially reduce further escalation of network charges and hence electricity bills for the entire community.

The cost of generation of renewable energy in urban environments may be greater than in optimum resource conditions elsewhere. However, where renewable energy is generated in proximity to demand, retail and network charges may be avoided by the consumer such that it becomes cost competitive with grid electricity and optimally located renewable energy plants. For renewable power plants embedded within a distribution network, consumers may avoid the network charge for transmission use of services (TUOS). Further, the consumption of building scale technology, which typically has a greater cost of generation compared to utility scale technology, will offset the total retail rate for electricity (providing it does not exceed the building’s demand), including all network charges and retail margins. Renewable energy in urban environments offers further benefits, compared to conventional fossil fuel generation, including relatively few adverse environmental impacts (generally limited to noise and visual impacts) and health benefits as a result of reduced local air emissions and other pollutants. The renewable energy technology market is relatively immature compared to conventional fossil fuel generation technology. This implies that there is greater potential for innovation in technology, materials and manufacturing methods to occur within the period to 2030 and drive down capital costs of renewable energy technology. This, coupled with the likely advent of a carbon price, will increase the cost competitiveness of renewable energy technologies and remove some of the financial barriers to large scale deployment.

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[2] Research from the UK suggests that the intermittent nature of renewable energy makes consumers more aware of their own behaviour. For example Kierstead (2007) found that households decreased their energy consumption after installing solar PV panels on their house.

1.3 The Renewable Energy Master Plan

1.3.1 Objective

The objective of the Renewable Energy Master Plan is to identify the extent to which renewable energy may contribute to the City's carbon reduction target and the available renewable energy resource both within and beyond the City to achieve the renewable energy target.

1.3.2 Scope of Master Plan

The Renewable Energy Master Plan provides an evaluation of renewable energy resource and renewable technology performance under the following separate categories:

1	Building integrated renewable technologies	Small scale (<100kW) building integrated technologies primarily installed to meet the energy demands of individual buildings within the city
2	Renewable power plants (within the city)	Large scale (>100kW) stand alone technologies primarily exporting energy to the electricity grid and/or district heating network within the city
3	Renewable power plants (Beyond the City)	Technologies operating outside the City of Sydney LGA in optimum resource locations exporting electricity to the grid to be consumed within the city
4	Renewable fuel feedstocks	Waste and other biomass able to be converted to fuel and transported to the city for use in the decentralised energy network

Building integrated renewable technologies are considered within the city only. Renewable power plants have been considered for both within and beyond the City. A detailed assessment of opportunities has been undertaken for renewable power plant sites within the City.

There are a range of technologies which are not considered appropriate for the City of Sydney due to climatic/geophysical characteristics. These technologies may form part of the "Beyond the City" strategy to meet the residual component of renewable energy required to meet the respective targets once opportunities within the City have been explored. It is likely that such a strategy will adopt the most cost effective technology to deliver energy to the grid, which will be ultimately dictated by the energy generation market. A summary of the available wider renewable resource within a 250km radius of the city has been undertaken in the context of this strategy.

For renewable fuel feedstocks, the potential resource base has been considered for an area within a 250km radius of the City of Sydney.

For each category, a range of resources and technologies has been considered and prioritised. The total resource availability was then mapped using Geographical Information Systems (GIS) to determine the total resource availability for comparison against the relevant targets.

A summary of the technologies considered under each of these categories is presented in Appendix A Technology Factsheets.

1.3.3 Scope of Technical Report

This report outlines the technical methodology and assumptions underpinning the evaluation and the results under the following sections:

Section 1	Introduction	Outlines the strategic context for the Plan and the scope of the analysis undertaken by Arup and an overview of the technical approach
Section 2	Resource evaluation	Presents the evaluation of raw renewable resource availability and the rationale for not including certain technologies.
Section 3	Economic Analysis	Details the methodology used in the economic analysis behind the Master Plan.
Section 4	Building integrated renewable technologies	Provides the detailed technical assumptions and methodology for building integrated renewable technologies
Section 5	Renewable power plants (within the city)	Provides the detailed technical assumptions and methodology for renewable power plants within the city
Section 6	Renewable power plants (beyond the city)	Provides the detailed technical assumptions and methodology for renewable power plants beyond the city
Section 7	Renewable fuel feedstocks	Provides the detailed technical assumptions and methodology for renewable fuel feedstocks conversion and transportation
Section 8	Results	Presents the detailed results for all categories of analysis
Section 9	Summary	Presents the overarching findings of the Master Plan and recommendations for next steps

This report should be read in conjunction with the Renewable Energy Master Plan Summary Report.

1.4 Limitations

The Renewable Energy Master Plan presents a summary of the theoretically achievable renewable energy resource available to the City of Sydney to meet its carbon and renewable energy targets. In reality, there are likely to be a range of technical, physical, commercial, governance and planning constraints which will limit the degree to which, and the rate at which, the targets can be achieved.

For building scale technologies, the degree and rate of uptake by building owners will be dependent on whether appropriate mechanisms can be developed at all levels of government, as well as the individual physical constraints of buildings[3]. For renewable power plants within the city, the City of Sydney may be able to directly contribute or incentivise deployment through direct contributions, land offers or rate concessions to proponents. Renewable power plants will also be

[3] Arup has attempted to estimate the extent to which physical constraints may impact the uptake through resource analysis which takes shading into account as well as high level assumptions relating to the likely percentage roof area likely to be available for renewable energy technologies. Other physical constraints such as structural limitations and protection of heritage values have not been considered.

highly subject to planning controls, especially in parkland areas where there are likely to be conflicting land use issues.

Therefore the quantification of the resource available within the City of Sydney presented in this report is considered to be a best case estimate of theoretically available resource subject to the limitations above.

For renewable fuel feedstocks, the ability of the City to acquire significant volumes of renewable fuel feedstocks will be highly subject to the market for biogas and biomass which is currently in its infancy. Predictions of peak oil in the near future imply that highly competitive markets for these products will emerge to meet demand for transport fuels including LNG and bioplastics. The emergence of these markets will increase the price of renewable fuel feedstocks such that the cost to the City will likely become the limiting factor in terms of the volume of fuel able to be purchased to supply the cogeneration units.

The evaluation of the renewable fuel feedstocks presents the total available resource within 250km of the city which will potentially be available within the competitive market to a range of customers, including the City of Sydney.

The assumptions around the financial and technical performance of each technology and feedstock are based on publicly available information. For some technologies, this is well understood as the technology or feedstock has been used at a commercial scale for several years. For other technologies, the data is highly variable and is likely to be subject to some change in the future as technologies develop. Further details with respect to specific technology and feedstock assumptions are presented in Appendix A and details relating to the financial model are presented in Section 3.

2 Resource evaluation

2.1 Overview

The performance of any one renewable energy technology is strongly dependent on the availability of suitable resources in terms of overall resource quantity and daily and seasonal variations. Each resource type is evaluated according to a resource parameter, including wind speed, solar irradiance, subsurface temperatures, wave power levels and tidal variations. Resource parameters can vary considerably from location to location depending on climate, topography and other geophysical conditions.

The resource parameter and fluctuations in the resource parameter over time will impact the fraction of time during which renewable energy can be generated from any given technology. For most technologies, there is a resource parameter threshold value below which the technology is not considered financially viable. These threshold parameters, however, are not static and will reduce over time as innovations in technology and reductions in capital costs mean that renewable energy generation becomes viable in more marginal conditions.

The following section presents an analysis of the raw renewable resource potential available, with particular emphasis on the resource availability within the City of Sydney. The analysis then allows a high level assessment of the viability of renewable energy technologies that rely on these resources.

2.2 Solar

The solar resource at any one site is one of the major determining factors of the viability of installing solar power technology. The diurnal and seasonal characteristics of solar radiation are a major determinant in the energy generated in a year.

Two different measures of solar radiation were considered:

- Direct Normal Irradiance (DNI); and,
- Global Horizontal Irradiance (GHI).

DNI is the direct radiation that comes from the sun and hits a surface perpendicular (or normal) to the sun beam; it is radiation that is not diffused by clouds or reflected off the ground. GHI is the aggregate of DNI, diffuse radiation and reflected radiation.

The relevant parameter depends upon the solar technology, with concentrating solar power technology (solar thermal and concentrating PV) typically dependent on the DNI component and photovoltaic, or PV, based solar power technology dependent on the overall GHI.

Levels of solar radiation measured at the Bureau of meteorology weather station at Observatory Hill within the City show an annual average GHI value 1,652 kWh/m^2/year and DNI of 1,452 kWh/m^2/year.

To estimate the variation in solar radiation across the City, Arup adopted the ArcGIS Spatial Analyst Solar Analysis tool. This tool derives predictions of hourly values for total solar radiation, based on daily and seasonal shifts of the sun angle, along with variations in elevation, orientation (slope and aspect), and shadows cast by topographic features. The tool does not take into account other climatic factors including cloud cover.

A 3D model of the City was developed based on data for building dimensions and base topography supplied by the City of Sydney. The 3D model assumed that all roof tops are flat.

The total annual predicted GHI and DNI values across the City were calibrated by comparing the annual average values for GHI observed at Observatory Hill with the ARcGIS predicted value at the same location to ensure that all climatic factors were considered.

The ratio of annual average DNI to GHI at Observatory Hill of 0.88 was assumed to be consistent across the City and applied to generate a data set for both GHI and DNI for the entire City. An example of the resulting solar mapping is shown in Figure 6 below.

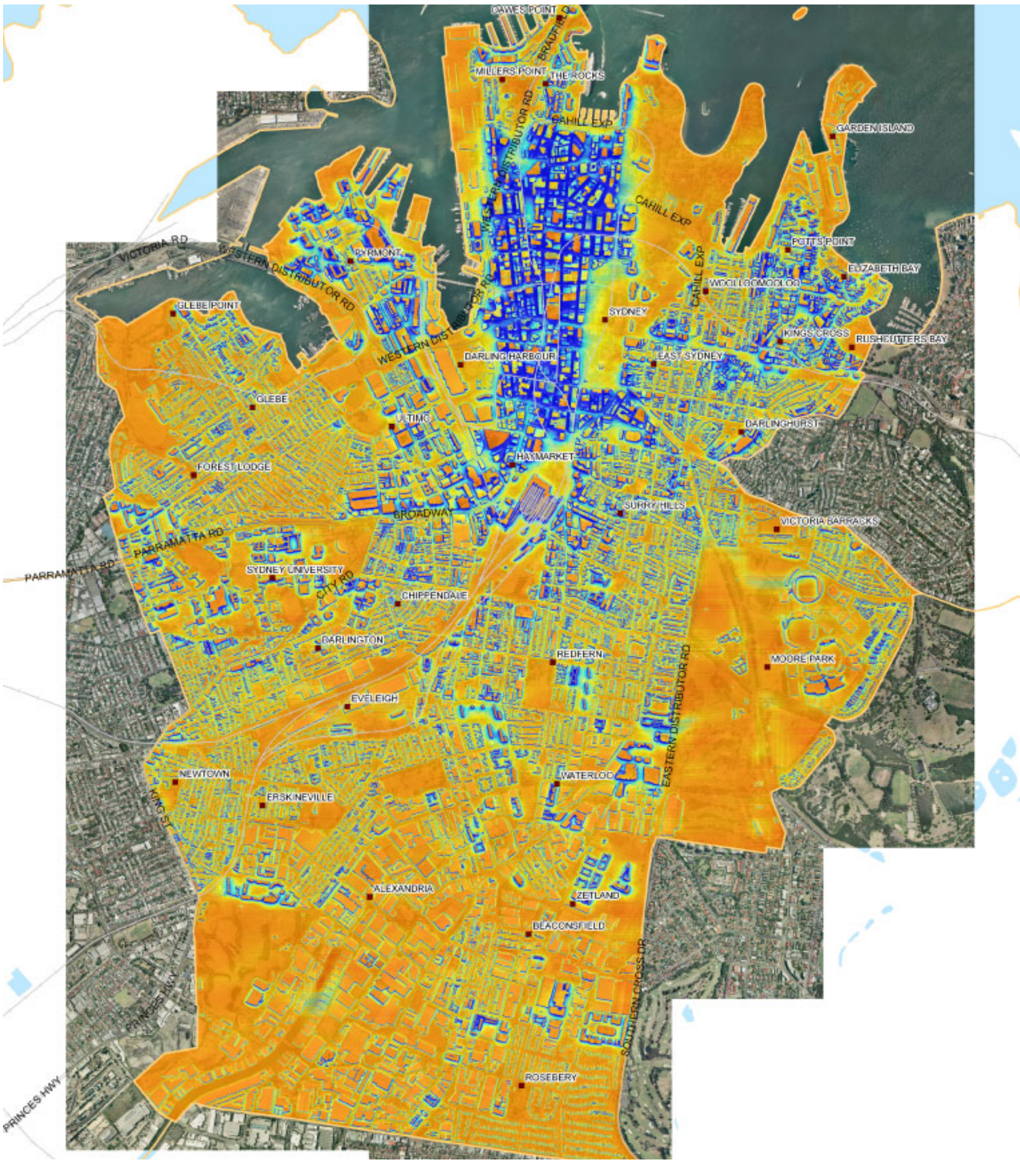

Figure 6 Solar resource mapping

2.3 Wind

Wind resource depends upon the magnitude and frequency of high wind speeds which, in turn, impacts the period of time over which any wind based technology can generate energy (also known as the capacity factor). The relationship between wind speed and power output is determined by a power curve which is specific to individual turbine models.

The speed at which turbines begin to generate electricity (known as the cut-in speed) is typically between 3 to 4 m/s. Turbine power output ratings are typically based on power output when wind speeds are around 12 to 14 m/s. In this sense, a 6kW turbine will typically generate 6kW when the wind speeds are around 12m/s, and produce no electricity at all at 3 m/s and below.

For the purposes of the resource assessment, hourly wind speeds within the City were modelled using CSIRO's The Air Pollution Model (TAPM). TAPM is able to estimate wind speeds at different heights and locations across Australia based on interpolated data meteorology and topographical data. Hourly wind speeds were derived from 2008 weather data for a 1km x 1km grid at 10m, 25m, 50m, 100m, 150m and 200m height intervals spanning the City. The hourly wind speeds were then used to determine annual capacity factors for various types of wind technologies for individual buildings and locations. The figure below shows the capacity factor at various heights and locations across the City.

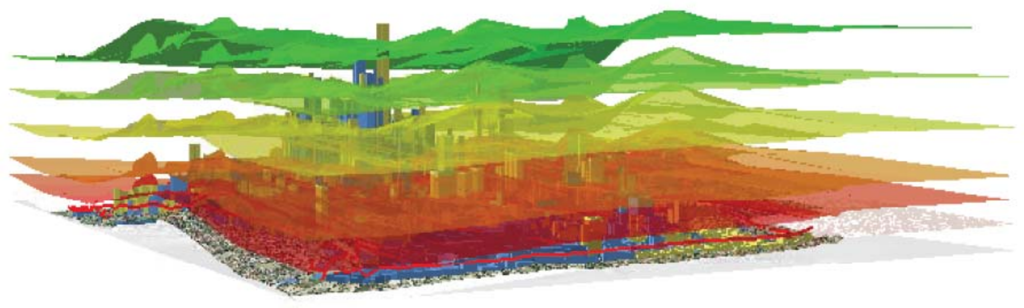

Figure 7 Wind resource mapping

The results of this wind speeds analysis show that the capacity factor at lower heights (less than 100m) increases from south west towards the north east of the City. This pattern is slightly altered at greater heights. At 200m the best locations for wind are in the east of the City near Moore Park.

Having access to this wind resource is a major factor in determining the overall generation potential within the City. Therefore, for large ground mounted turbines, the best locations are likely to be towards the north east, while building integrated technologies will generally perform well at any location, providing the building is greater than 150m high. The major constraint on large wind turbines are the noise and visual impacts and light flicker, such that most locations are likely to be ruled out.

In order to mitigate the effects of noise and flicker on the wider community Arup used the indicative analysis within the NSW Industrial Noise Policy from

DECCW[4]. The policy outlines general rules of thumb for noise limits for certain land uses. The night time recommended maximum noise level for residential and educational property in urban areas is 50dBa. Analysis provided by New Zealand based wind turbine manufacturer Windflow indicates that this would require a 200m buffer distance from a 500kW turbine when installed at a hub height of 50m (see Figure 8 below).

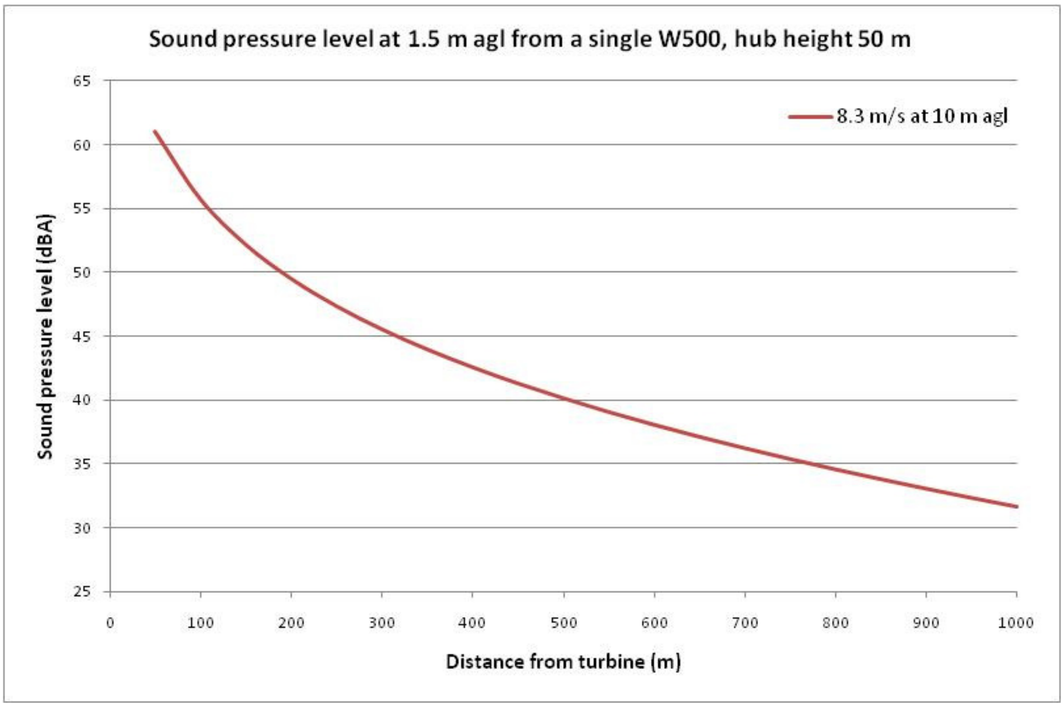

Figure 8 Windflow analysis of a Windflow 500kW turbine

2.4 Geothermal

Geothermal energy refers to the heat stored in the earth's crust from two primary sources:

- Convection and conduction of heat from the earth's magma core, and
- Heat from radioactive decay of substances in the earth's crust such as uranium, thorium, and potassium.

Heat energy from the earth's core largely dissipates, creating a thermal gradient between the core and the surface. Across the world, temperatures increase at an average rate of 17 to 30°C per km, from the surface down. However, the thermal gradient varies depending on location. The presence of radioactive or radiogenic material, such as granites beneath insulating sedimentary layers, can dramatically increase the thermal gradient so that higher temperatures can be encountered closer to the surface in certain areas.

Geothermal power plants (producing electricity) require a geothermal resource of 200°C to 300°C to operate a conventional steam turbine. Organic rankine cycle

[4] Environmental Protection Authority, 1999, NSW Industrial Noise Policy, NSW Government

(ORC) technology can utilise resources at lower temperatures (down to 140°C), but are currently more costly.

Notwithstanding, the most significant cost for geothermal electricity generation is in well installations and drilling. While temperature increases with depth, so too do drilling costs, so in practice there is a depth/cost trade-off. Generally, the deeper you drill, the hotter and harder the rocks and the more costly the well becomes. As a rule of thumb in the oil and gas industry, if you double the well depth, you quadruple the well cost such that wells in excess of 5km become cost prohibitive for electricity generation.

The Renewable Energy Atlas of Australia, produced by the Commonwealth Government indicates that the geothermal resource below the City of Sydney is less than 150°C at 5km depth implying that a geothermal power plant is not likely to be viable, especially when compared to areas in close proximity such as the Hunter Valley where significant geothermal resources have been identified much closer to the surface.

However, geothermal energy can be economically used to supply direct thermal energy at much lower temperatures. Direct Use Geothermal uses the temperature gradient to provide low energy intensive heating and cooling. Circulating Hot Water (CHW) and Ground Source Heat Pumps (GSHP) are the two major direct use applications. Typically, an 80°C geothermal resource is required for CHW, but lower temperatures can be upgraded using a GSHP.

Indicative information from various sources points to a 40°C temperature at achievable depths (500m -1000m) within the City of Sydney. Ground temperatures near the surface, around 17°C, are suitable for cooling only.

In CHW, bore holes or wells are drilled to depths of up to 1km where there is a hot aquifer; no such hot aquifer is present in Sydney. However, an abandoned mine under Goat Island is reported to have a large body of heated water which may be suitable for direct use CHW for low temperature applications (below 40°C), or as a potential thermal storage location.

2.5 Tidal

Tidal resource is a function of the tidal range. Tidal energy is able to be captured via two methods, either in stream or tidal barrage (including tidal pond /lagoons).

Commercial scale tidal barrages and lagoons are typically only installed in areas with a tidal range over 4m[5], whereas the mean spring tidal range in Sydney is around 1.9m. Such commercial scale installations are very large in terms of capacity and area that they occupy which is likely to have prohibitively significant environmental, social and economic impacts if installed in Sydney Harbour.

Notwithstanding, if significant barrage or lagoon structures were to be installed for other purposes such as crossings or climate change adaptation[6] measures, there may be an opportunity to capture this resource.

[5] Pelc, Robin and Fujita, Rob. 2002, Renewable Energy from the Ocean, Marine Policy Volume 26, Issue 6

[6] It should be noted however, that as a climate change adaptation measure a barrage would reduce the tidal range even further in order to prevent flooding impacts at high tide.

Tidal resources have, therefore, not been further considered for application within the City. However, there may be opportunities beyond the City.

2.6 Wave

Wave energy is a form a solar energy, whereby the air above ocean waters is heated by the sun and the subsequent wind that is created drags across the surface of the ocean and, through friction, forms swells and waves. The viability of wave energy technology is dependent on the wave power level measured in units of Watts per length of coastline which is a function of the wave height and the wave speed.

Wave energy varies within oceans over the world, with the most potential available within the north and south temperate zones. In any one location, wave energy can also be highly irregular, although relatively predictable over longer periods. The viability of wave energy technologies is therefore assessed in terms of average wave power levels. Applying current technology, it is generally considered that there is the potential to generate wave energy at competitive prices within any coastal zone with an average wave power level of a threshold value of between 15 and 30kW/m.

Peak wave power is generally achieved in deeper offshore waters. However increased distance from the coast typically means a number of difficulties in construction and maintenance, and connection to the power grid using underwater marine cables over long distances. As a result, there is a trade off between locating wave devices closer or further away from the coast.

A nationally consistent wave resource assessment for the Australian shelf (<300m depth) was undertaken in 2008 by Geoscience Australia, Marine and Coastal Environment Group, derived from data for the period 1 March 1997 to 29 February 2008 inclusive. The assessment found that wave power is greatest on the southern Australian shelf (Tasmania, Victoria, southern Western Australia and South Australia), with an average value of 25 to 35kW/m. New South Wales, on the other hand, has a mean wave power level of 12kW/m, with the most viable sites to the north of Forster (some 220km to the north east of Sydney) where mean power levels in the order of 16kW/m were recorded.

In the Sydney region, wave climate is reported to be dominated by moderate waves, but both extreme waves (>4m) and/or low swell occurred in any month.

In summary, the City itself is unlikely to offer sufficient wave energy for commercially attractive opportunities for generation technologies in the near future, with better resources available further north of the state, and even greater resource potential in the southern states.

The potential for wave energy to meet the City of Sydney targets has therefore been considered as part of the “Beyond the City” component of the Master Plan only.

2.7 Hydro

Hydro is a very cost effective form of electricity generation, with close to 10% of the nation’s electricity already derived from this source. The opportunities for further large scale installations are limited within NSW with the major dams incorporating electricity generation already. The Snowy Mountains hydroelectric power scheme is the largest hydroelectric system in Australia, with a generating capacity of nearly 3,800 MW. It includes seven power plants, 145km of tunnels and 416 dams. The largest dam, Lake Eucumbene, can hold nine times the water volume of Sydney Harbour.

Opportunities still exist in Australia for small hydro electricity generators where there are regular water flows. The cost of producing electricity from small hydro, where a new dam is not needed, is similar to that of wind generation. Within urban environments, these are likely to be limited to town water supplies. In Sydney, Sydney Water has capitalised on these opportunities already, installing small scale hydro electricity plants at their North Head Sewage Treatment Plant, with other hydro-electric generators soon to be installed at Woronora Water Filtration Plant and on the Warragamba to Prospect Reservoir Pipeline. Sydney Water has not identified any further significant hydro resource within their network and, in particular, considers the resource potential from mains water to have been exhausted.

If the growth in mini hydro over the past 20 years is mirrored into the next 20 years, the additional resource is limited.

2.8 Renewable fuel feedstocks

Renewable fuel feedstocks include non fossil derived energy dense mass which is able to be converted into a fuel suitable for combustion in vehicles or stationary engines. For the purposes of the Renewable Energy Master Plan, the renewable feedstock resource was evaluated in terms of its potential to provide a fuel source for the Trigeneration Master Plan from 2030 to replace natural gas. The City of Sydney has made a strategic decision that the Renewable Energy Master Plan is to focus on waste feedstocks, rather than those feedstocks which could be grown specifically for fuel, known as energy crops (e.g. oilseeds, algae or mallee eucalypts), to avoid any land use conflicts including adverse impacts on the potential food resource within NSW. The renewable resource feedstock appraisal therefore focused on all waste within NSW, including waste from agriculture, forestry, and human settlements.

The renewable feedstock resource appraisal was based on several different sources and follows the methodology developed in 2002 for the Bioenergy Atlas of Australia[7]. The primary difference within the City of Sydney Renewable Energy Master Plan is that information was analysed at the scale of Statistical Local Area rather than the much more detailed data in the Bioenergy Atlas.

The waste streams assessed were:

- Pasture and broadacre crop (under the ABS definitions[8]) harvesting and processing residue;
- Vegetable processing residues (under the ABS definitions[9]);

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[7] A. L. Bugg et al, 2002, *Bioenergy Atlas of Australia: An Online Geographic Information System and Decision Support System*, a report for the Joint Venture Agroforestry Program and the Australian Greenhouse Office.

[8] ABS, 2008, *71250DO004_200506 Agricultural Commodities: Small Area Data, Australia, 2005-06 (Reissue)*

- Animal manure including manure from:
  - Dairy and meat cattle;
  - Meat chickens and laying hens;
  - Pigs;
- Forestry residue from plantations;
- Municipal solid waste;
- Commercial and industrial waste;
- Sewage;
- Existing landfill; and,
- Waste oil (existing biodiesel)

Pasture and broadacre crops, vegetable and animal commodity numbers were estimated using data collected by the Australian Bureau of Statistics as part of their Agricultural Commodities survey in 2005/2006. Although there is more recent data from 2008, it was not available by statistical local area. The amount of waste available from broadacre and vegetable crops was estimated by using the crop to stubble and crop to processing residue factors from the Bioenergy Atlas. The amount of manure produced by farm animals was estimated using factors from Australia's Biomass Resource Appraisal[10]. These assumptions include:

- 1.78 stubble to crop ratio for wheat, barley, oats, rice, oilseeds and legumes;
- 0.1 processing residue to crop ratio for vegetable wastes;
- 0.8 stubble to crop ratio for sugar;
- 40kg of manure per laying chicken;
- 20kg of manure per meat chicken;
- 9.13t of manure per head of dairy or meat cattle; and
- 1.22t of manure per head of dairy or meat cattle.

Additional assumptions include that only 80% of the broadacre crop is harvested, 90% of vegetable processing residue is harvested, and manure is only harvested in Statistical Local Areas that produce 2kt of manure per annum.

Estimates of timber harvesting and processing waste from plantations were supplied by Forests NSW, who own and operate a large timber plantation to the West of Sydney near Oberon. Forests NSW estimated that there were 150,000t of waste available per annum that had no current beneficial use. It was assumed that 50% of this resource would be made available to the City of Sydney based on advice from Forests NSW that it would be costly to collect any more than this.

Municipal solid waste and commercial and industrial waste volumes were estimated using figures reported by the NSW Department of Environment, Climate Change and Water. These figures are around 2,000,000 tonnes of

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[9] ABS, 2008, *71250DO005_200506 Agricultural Commodities: Small Area Data, Australia, 2005-06 (Reissue)*

[10] Clean Energy Council, 2009, *Biomass Resource Appraisal*, Department of Environment, Water, Heritage and the Arts

municipal solid waste and 2,700,000 of commercial and industrial waste disposed of to landfill per annum. The figures were attributed to statistical local areas based on employment and population for C&I and MSW respectively. These factors are 0.287t of MSW per person per annum and 1.206t of C&I per employee per annum.

Sewage volumes were estimated using a factor per head of population, derived from total biosolid figures handled by Sydney Water. The figure for effluent treated by Sydney Water in 2008/09 was 462GL. The amount of sludge within this effluent was estimated using the historical relationship between dry biosolids and effluent (around 0.25mg/L). The sewage sludge per head factor (0.03t per person per annum) was then attributed to statistical local areas based on population distribution.

Although there is an implicit assumption above that the MSW and C&I waste resource is captured, existing landfills will still be generating gas. The biodegradation of organic material that generated landfill gas can occur over a number of decades, so waste disposed to landfill today is likely to still be producing gas in 2030. The landfill gas resource was estimated by using the installed capacity of engines at existing landfills. The generation capacity was assumed to grow and shrink, based on the amount of waste going to the landfill. It was assumed that, as more MSW and C&I are treated by bioreactor landfill and anaerobic digesters, there would be less waste disposed of to landfill and organic waste disposed of to conventional landfill will cease by 2020. The reduction in gas generation was estimated to be 15% from today by 2030 using the NGERS emissions from waste methodology. This resource was attributed to the statistical local areas where the landfills are currently located.

3 Economic analysis

To evaluate the various technologies, two economic criteria were considered:

- the long run marginal cost (LRMC); and
- the cost of abatement.

The methodology for determining these parameters is presented below and explained in more detail in Section 3.1 and Section 3.2.

Long Run Marginal Cost

$$LRMC = \frac{NPV_{(no\ income)}}{NPGQ_{Elec}}$$

Where:

LRMC	=	Long Run Marginal Cost ($ per MWh)
$NPV_{(no\ income)}$	=	Net Present Value of Capital and Operational Expenditure over lifespan of technology not including any income from the sale of electricity ($)
$NPGQ_{Elec}$	=	Net Present Electrical Generation Quantity over lifespan of technology (MWh)

Cost of Abatement

$$Cost\ of\ Abatement = \frac{NPV_{Elec\ rev}}{NPCQ_{Elec} + NPCQ_{Th}}$$

Where:

Cost of Abatement	=	Cost of carbon abatement over lifespan of technology ($/t$CO_2$e
$NPV_{Elec\ Rev}$	=	Net Present Value of cash flow including capital and operating expenditure, electricity sales and/or electricity savings over lifespan of tech ology ($)
$NPCQ_{Elec}$	=	Net Present Carbon abatement Quantity from offset of Electricity over lifespan of technology (tCO_2e per MWh)
$NPCQ_{Th}$	=	Net Present Carbon abatement Quantity from offset of Thermal energy over lifespan of technology (tCO_2e per MWh)

3.1 Long Run Marginal Cost

The LRMC represents the cost per unit of electricity generated over the lifetime of the technology. In this sense, the LRMC can be considered the price that must be received, or avoided, in order for the technology to have a net present value (NPV) of zero.

For renewable power plants operating outside of the distribution network (beyond the city), the LRMC must be comparable with the wholesale cost of electricity in the National Energy Market (NEM) in order to be cost competitive. This generation will also attract transmission use of services, distribution use of services charges (TUoS and DUoS), some environmental and administrative charges and retail charges to make up the overall price of retailed electricity.

For renewable power plants operating within the local distribution network (within the city), it may be possible for the electricity generated to avoid transmission use of services (TUoS) charges, and some distribution use of service (DUoS) charges reflecting the value of generating electricity close to the demand. In this case, the LRMC must be comparable with the wholesale cost plus the avoided network charges. This implies that while, renewable power plants within the City may cost more per unit generation due to less than ideal resource conditions, they may become cost competitive where network charges can be avoided.

For building scale technologies, the LRMC only needs to be comparable with the retail cost of electricity as the owner is able to offset the entire retail cost by providing their own electricity. Therefore, building scale technologies, while typically more expensive than utility scale technologies which achieve economies of scale, may be financially viable especially as electricity prices rise into the future.

This concept is explained in Figure 9 below.

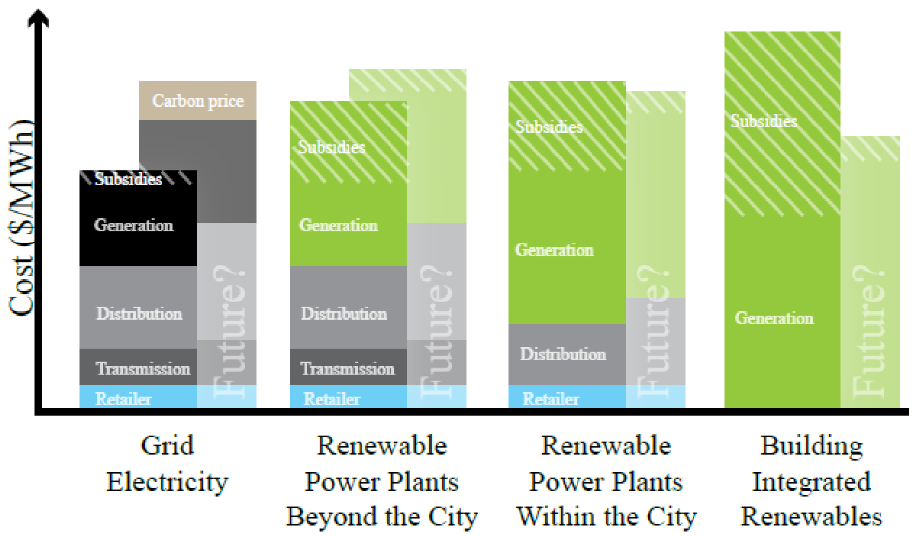


Figure 9 Indicative breakdown of electricity prices now and in the future

An example of how such increases in electricity prices and decrease in technology prices are likely to impact the financial viability of building integrated solar photovoltaic is shown in Figure 10 below.

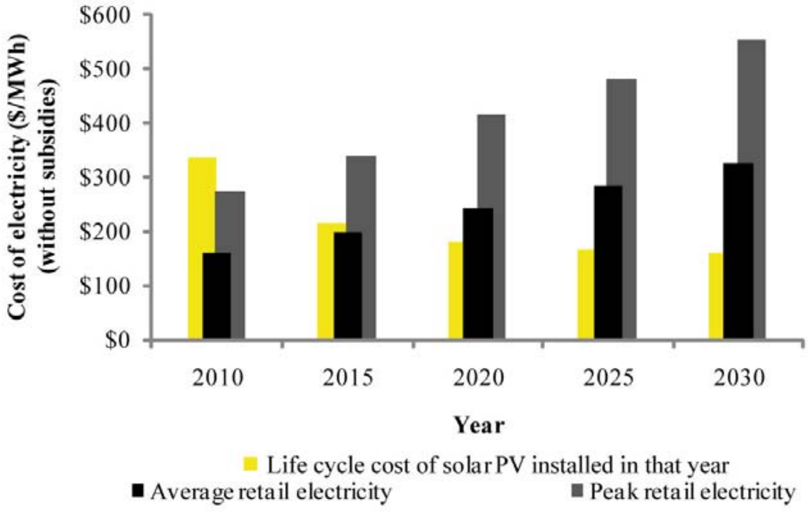


Figure 10 Improved business case for building integrated solar PV to 2030

This shows that the building integrated solar PV is likely to become cheaper than peak grid electricity, if installed in 2015. Building integrated solar PV installed in 2020 is likely to be cheaper than average retail electricity. It should also be noted that this does not include any allowance for government subsidies which would further improve the business case for building owners.

3.2 Cost of Abatement

While the LRMC is important in terms of business case, the cost of abatement has been used as the ultimate determinant of which technologies to preferentially adopt in the Master Plan. The cost of abatement is similar to the LRMC but values the energy generated in terms of its potential to abate carbon compared to business as usual, and therefore allows both thermal and electrical energy to be considered in terms of their relative abatement potential. This improves the case for technologies which generate both electrical and thermal energy, particularly where the thermal energy is able to offset electricity (such as electric hot water systems, air conditioning and electric induction heating).

The concept of cost of abatement is shown in Figure 11 below.

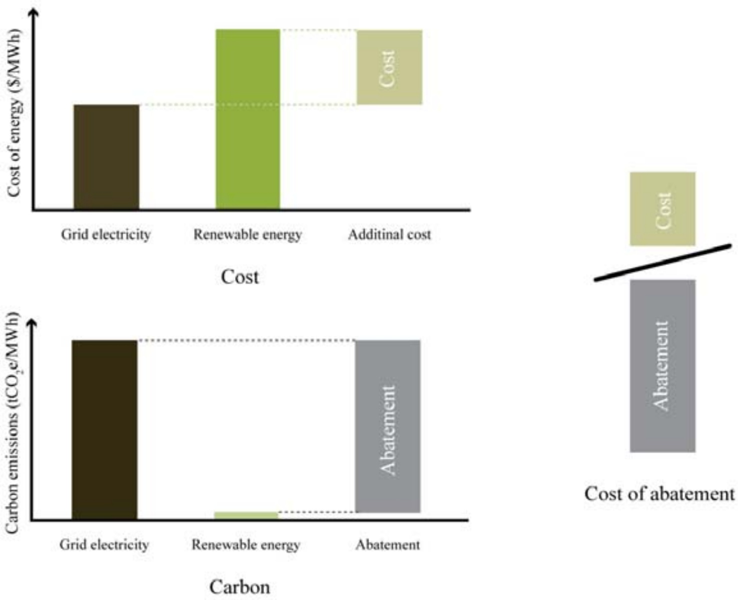


Figure 11 Cost of abatement explained

The cost of abatement has been presented both with and without subsidies. The 'with subsidies' case represents the cost to the owner of the generation technology. The 'without' subsidies case represents the overall cost to the economy (both public and private sector). The 'without' subsidies cost has been used to prioritise the technologies in order to determine the best outcomes for the economy as a whole.

3.3 Financial Model

To determine the LRMC and cost of abatement, a detailed financial model was prepared incorporating annual analysis of costs, energy generation and carbon abatement over a 30 year period to 2040. The model assumes that all technologies are implemented in 2011 and do not need replacement until after 2040. This is considered conservative for the following reasons:

- the cost of technology is likely to decrease into the future; and
- the cost of offset electricity is likely to increase into the future.

The financial model incorporates
a number of assumptions as detailed below.

3.3.1 Capital costs

Capital costs for plant and equipment for all technologies were based on quoted costs for technologies in commercial operation at similar scales. Where possible, costs were obtained for Australian applications. For building and renewable power plants, a minimum of three examples were used to give rise to a range of values for cost of abatement and LRMC, with the median cost of abatement adopted for the purposes of generated overall results. Details of individual capital costs of technologies can be found in Appendix A

3.3.2 Operational Costs

Operational costs were also obtained from reported values for technologies in commercial operation. For building scale technologies, these are typically negligible with the exception of heat pumps.

3.3.3 Generation Quantity

The generation quantity represents the total generation of electricity or thermal energy over the life of the technology. For each technology, the generation quantity is based on an annual generation model taking into account:

- the quoted technology efficiency (including a derate factor to account for efficiency losses over time); and
- capacity factor adjusted to reflect the resource conditions within the City.

The generation quantity is then discounted to provide a net present generation quantity, using a factor of 7% (in line with the weighted average cost of capital), to account for potential risks of reduced generation over the lifetime of the technology.

3.3.4 Carbon Quantity

The carbon quantity represents the total carbon abated over the life of the technology. For each technology, the carbon quantity is based on an annual carbon flow model taking into account:

- the grid electricity offset per unit of electricity generated each year; and
- the thermal energy offset per unit of thermal energy generated over the life of the technology each year.

The carbon quantity has then been discounted to provide a net present annual generation quantity, using a weighted average cost of capital of 7%, to account for potential risks of reduced generation over the lifetime.

It is assumed that the emission intensity of the grid electricity offset varies over the 20 year period, as shown in Figure 12.

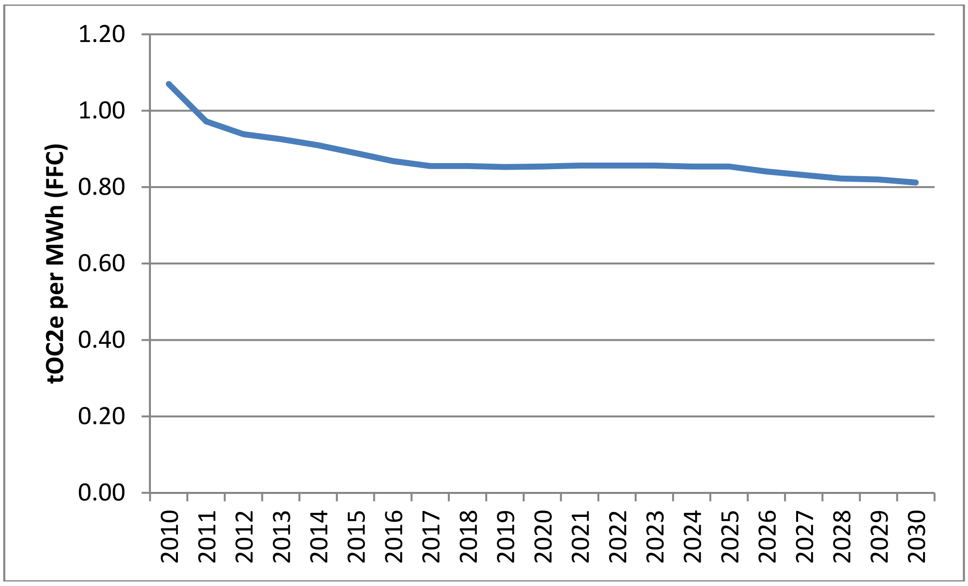


Figure 12 Projections of emission intensity of electricity grid used in financial model

For technologies generating thermal energy, it has been assumed that the heat will offset energy depending on end use. That is, for each building type and each end use, thermal energy will offset a different mix of fuels and efficiencies. For renewable power plants, thermal energy is assumed to offset the average thermal energy mix across the city.

These assumptions for thermal offsets are presented in Table 1 below.

Table 1 Assumptions for current thermal energy consumption by building type and end use

Parameter	Residential	Commercial	Industrial	Power Plants (End Use Not Specific)
Hot water				
COP Elec	0.7	0.7	0.7	na
% Electricity	60%	50%	25%	na
COP Gas	0.8	0.8	0.8	na
% Gas	40%	50%	75%	na
Heating				
COP Elec	1.0	1.0	na	na
% Electricity	33%	20%	na	na
COP Gas	0.8	0.8	na	na
% Gas	67%	80%	na	na
Cooling				
COP Elec	3.5	5.0	na	na
% Electricity	100%	100%	na	na
COP Gas	na	na	na	na
% Gas	na	na	na	na

Parameter	Residential	Commercial	Industrial	Power Plants (End Use Not Specific)
Average of Thermal End Uses				
COP	0.74	1.10	0.77	2.2
% Electricity	50%	94%	25%	72%
% Gas	50%	6%	75%	28%

3.3.5 Electricity Revenue

As discussed above, technologies exporting to the grid outside of the City are assumed to receive wholesale prices for electricity, while technologies within the City are assumed to receive wholesale prices plus a saving for avoided TUoS charges. Building integrated technologies are assumed to receive a saving for avoidance of the entire retail cost of electricity. The sale or saving for each technology has been applied on an annual basis to produce a cash flow model.

We have assumed price increase for electricity based on IPART determinations (without a carbon price) to 2013. From 2014, we have assumed wholesale electricity prices increase according to the Treasury model for CPRS-5[11] and that network prices increase by 3% per annum in real prices. All revenue has been discounted to 2010m based on a 4.5% pre-tax real weighted average cost of capital (WACC) (or in other words, a 4.5% discount rate before inflation and 7% including inflation).

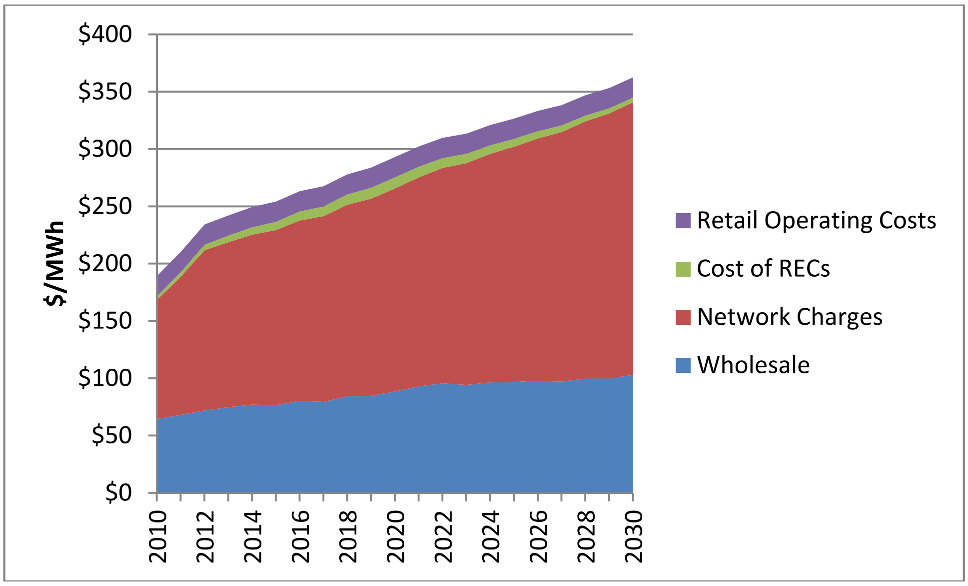


Figure 13 Projections of electricity prices used in financial model

[11] Treasury model representing a cap and trade scheme designed to achieve a 5% reduction in Australia's carbon emissions by 2020.

3.3.6 Thermal Energy Revenue

For technologies generating thermal energy, it has been assumed that savings will depend on the end use of thermal energy. That is, for each building type and each end use, thermal energy will offset a different mix of energy and efficiencies, and therefore costs. For renewable power plants, thermal energy is assumed to offset the average thermal energy mix across the city. The assumptions for thermal energy end use are presented in Table 1 in Section 3.3.4.

The revenue for thermal energy is therefore dependent on both the cost of electricity (see Section 3.3.5 above) and cost of mains gas as presented in Figure 14 below. The cost projections for mains gas are based on IPART determinations (without a carbon price) to 2013. From 2014, we have assumed mains gas prices according to the Treasury model, as well as an additional cost of carbon derived from the Treasury model for CPRS-5. Network prices for gas are assumed to increase by 3% per annum (real prices, in addition to a 2.5% escalation factor). All revenue has been discounted to 2010, based on a 4.5% pre-tax real weighted average cost of capital (WACC) (or in other words, a 4.5% discount rate before inflation and 7% including inflation).

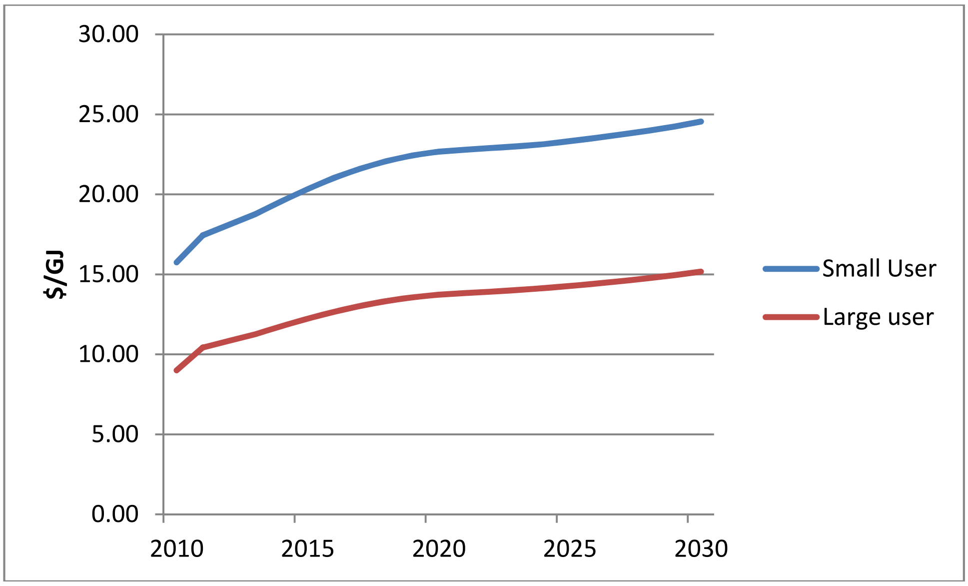


Figure 14 Projections of retail gas prices used in financial model

3.3.7 Revenue from Subsidies

While technologies have been evaluated without subsidies, we have also evaluated the technologies with subsidies to show how the business case would likely be improved for individual building owners and utility proponents. The explanation of the subsidies is presented below.

Renewable Energy Certificates

Renewable energy generators must compete directly with fossil fuel electricity generators in the NEM. Due to the relatively cheap capital cost and fuel costs, fossil fuel generation generally out prices renewable energy in the NEM. The Commonwealth Government has proposed two market mechanisms for increasing the financial viability of renewable energy generation; a carbon price and the Renewable Energy Target (RET).

The RET has been legislated with the objective of ensuring that 20%, or around 45,000GWh of Australia's electricity, is supplied by renewable sources by 2020. The RET provides an additional payment in the form of a Renewable Energy Certificate (REC) per unit of energy generated (MWh) from renewable sources. Where the REC price is sufficient, the RET will improve the cost competiveness of renewable energy compared to fossil fuel generation.

For each technology, it has been assumed that revenue is received from REC's revenue per unit energy generated. The price of RECs is predicted to decrease to 2020 until the Renewable Energy Target is met and then further reduce as renewable energy becomes cost competitive with the grid, and subsidies are no longer required.

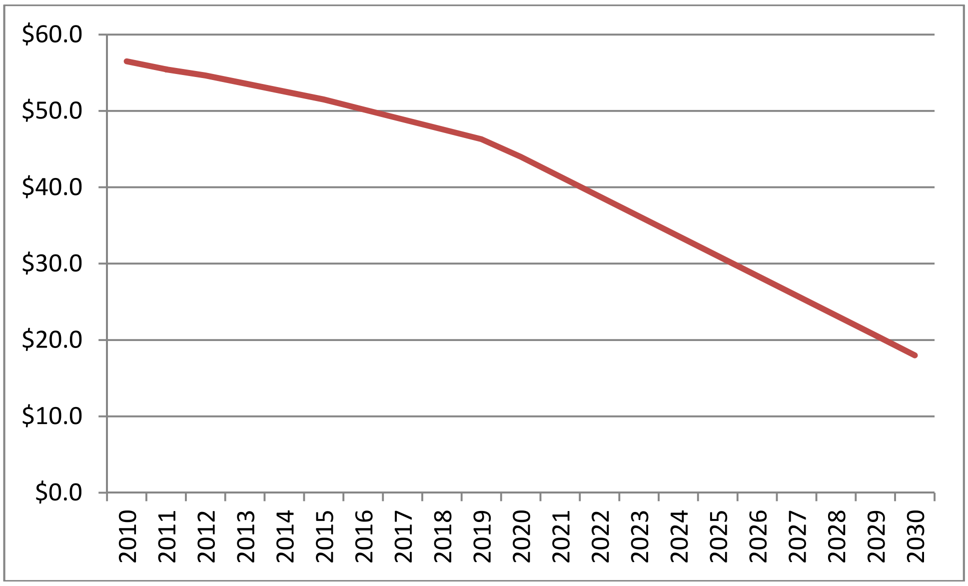


Figure 15 Projections of REC prices used in financial model

Carbon Price

While a carbon price does not provide additional revenue for renewable energy generators, it has been included as additional revenue from the correlated increase in wholesale cost of electricity. In contrast to the RET, a carbon price penalises fossil fuel generators for each tonne of carbon emitted and does not directly affect renewable energy generators. A carbon price will increase the bid price of fossil fuel generators who will seek to pass on the cost of carbon to the market. An increased price of wholesale electricity will generate more income for all participants in the NEM who are not affected by the carbon price, including renewable energy generators. It should however, be noted that the introduction of the carbon price will likely be delayed until 2012 at the earliest. The form of the carbon price, either as a tax or emission trading scheme, is also yet to be decided. Without such certainty, the price of carbon is estimated based on the Treasury model for CPRS-5 representing a cap and trade scheme designed to achieve a 5% reduction in Australia's carbon emissions by 2020.

Solar Credits

In addition to renewable energy certificates, the expanded RET scheme includes the ‘Solar Credits’ mechanism to boost the support to households and businesses that install small scale solar PV, wind and hydro electricity systems (less than 100kW). The scheme’s current rules allow owners of small-scale solar photovoltaic (PV) systems, small wind turbines and micro-hydro systems to create at the time of installation, RECs equivalent to the output of up to 15 years operation. The solar credits mechanism increases the number of RECs available for a single eligible installation by multiplying the number of tradeable RECs by up to 5 times. Solar credits will apply to the first 1.5 kW of capacity installed. Generation above 1.5 kW will still be eligible for the standard 1:1 rate of RECs creation. The credits will only apply to the first small-scale generation system installed at an address.

On 1 December 2010 the Commonwealth Government announced its intention to scale back the solar credits scheme. The solar credits multiplier would be reduced effective 1 July 2011 and phased out completely by 2014, with incremental reductions taking place over the coming four years. The “with subsidies” analysis includes a solar credits multiplier of 5 in applicable buildings.

Feed-in Tariff

The NSW Government implemented its feed-in tariff, known as the Solar Bonus Scheme NSW, in January 2010. The feed-in tariff is payable to energy customers with solar PV systems up to 10 kW in size and with a maximum of 160 MWh of electricity consumed per annum. The Scheme originally payed the owners of eligible solar PV systems 60c per kWh for all renewable energy generated (gross metering) and fed into the national electricity grid, but has recently been reduced to 20c per kWh. There is also an overall cap of 300 MW of installation.

The revised level means that it will be not cost effective to sign up for the tariff for many installations. Instead it may be more beneficial for building owners to offset their own retail electricity via net metering as the regulated retail price is likely to be greater than the 20c per kWh FiT, especially during peak times.

Where installations on buildings generate significantly more than their consumption, the feed-in tariff may be more cost effective than net metering. Under current arrangements, Aus Grid would only have to pay the building owner a wholesale rate for the electricity fed back into the grid, despite the fact that this electricity will almost certainly satisfy demand from a neighbouring building being charged a retail rate. In effect, this means that buildings subscribing to the NSW solar bonus scheme are subsidising coal fired power plants and the transmission and distribution networks they require to remain cost competitive.

Given the marginal benefit of the reduced feed-in tariff level and the uncertainty over the policy in general, it has been excluded from the analysis.

3.3.8 Other Externalities

There are a range of other externalities which have not been considered in the economic analysis. These include:

- Avoided cost of human health impacts from reduced emissions to air compared to combustion technologies;
- Avoided cost environmental impacts from reduced pollutant loads compared to combustion technologies;
- Avoided cost of reduced water consumption compared to combustion technologies requiring cooling towers;
- Avoided cost of reduced resource depletion compared to fossil fuel based technologies;
- Avoided costs of future network upgrades.

These would all have direct and indirect economic impacts which would improve the business case for renewable energy compared to other technologies on a whole of economy basis.

3.4 Summary of Inclusions and Exclusions in Financial Model

A summary of the items that have been incorporated into the financial model are presented in Table 2 below.

Table 2 Summary of financial model inclusions and exclusions

Item	Building Integrated	Renewable Power Plans within the City	Renewable Power Plants Beyond the City
Cost of capital	✓	✓	✓
Cost of maintenance	✓	✓	✓
Cost of district heating network	×	×	×
Revenue from sale of electricity or electricity savings	✓	✓	✓
Revenue from sale of heat or savings from heat from supplied by existing source	✓	✓	✓
Cost of district heating network	×	×	×
Carbon price	✓	✓	✓
Transmission Use of Service Charges and projected increases	×	×	✓
Distribution Use of Service Charges and projected increases	×	✓	✓
RECs	× (except where explicitly stated that subsidies are included)	× (except where explicitly stated that subsidies are included)	× (except where explicitly stated that subsidies are included)
Solar Credits	× (except where explicitly stated that subsidies are included)	×	×
Feed-in tariff	×	×	×
Externalities	×	×	×

4 Building Integrated Renewable Technologies

4.1 Overview

Building integrated renewable technologies include those technologies which harness available renewable resources primarily to meet the energy demands of individual buildings. These installations are typically less than 100kW in capacity and may include technologies that generate both electrical energy and thermal energy. Building integrated technologies must be considered in the context of the building's energy demand.

For technologies that generate electricity, the building owner is able to directly offset the electricity consumed within the building that would otherwise be supplied by the grid at full retail prices and grid emission intensity. Electricity generated in excess of the building's demand at any point in time will be exported to the grid and will receive only the wholesale rate for electricity, plus any available subsidies. Further, exported electricity generated within the City is likely to receive concessions in terms of reduced charges for use of transmission and distribution infrastructure which are not available to technologies beyond the City.

However, since retail rates are unlikely to be received, exported electricity has a reduced financial benefit for the building owner compared to electricity consumed within the building. As a result, technologies with output matching building demand profiles perform better financially than those that do not match demand profiles. Notwithstanding, the same carbon abatement is achieved whether the electricity is exported or not. The Master Plan, therefore, does not limit the size of renewable electricity generation to match building demand, it maximises generation within the physical and infrastructural constraints of the building meaning that many buildings will export a portion of renewable electricity to the grid.

For technologies that generate thermal energy, the building owner is able to directly offset any grid electricity or mains gas that would otherwise be consumed to meet thermal demand, including space heating and cooling and hot water. The offset for thermal technologies includes the financial and carbon offset from grid electricity and mains gas which would otherwise supply the thermal demand, taking into account the efficiency (or coefficient of performance) of relevant building equipment in end use. Any thermal energy generated in excess of the building's demand is not able to be exported and is effectively wasted achieving neither a financial or carbon abatement benefit. Therefore, the Master Plan sizes thermal technologies to ensure that little to no thermal energy is wasted.

4.2 Step wise Approach

The objective of the Stage 2 detailed analysis is to further refine and prioritise the shortlist of building and utility scale technologies under each category to apply to the Master Plan to achieve the greatest and most cost effective carbon reductions. Figure 16 below displays the process used to prioritise application of renewable technologies, which then informed City wide mapping and macro outcomes.

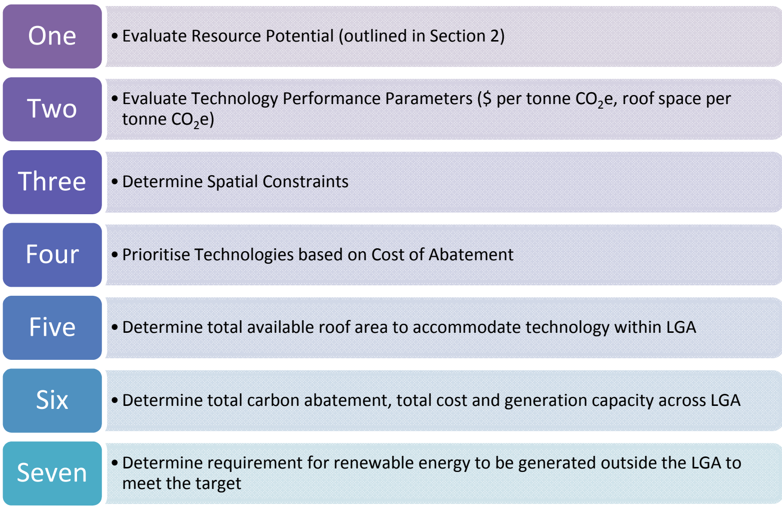


Figure 16 Stepped process for building integrated renewable technologies

The following sections present the generic assumptions that were applied to each building type. Arup acknowledge that variations from assumptions made will influence predicted outcomes for any particular building. However, the assumptions are considered both reasonable and conservative, such that outcomes are considered appropriate to guide policy and program direction for the City of Sydney now and in future.

4.3 Commercial Buildings

Commercial buildings pose a number of opportunities for renewable energy generation. The commercial building stock is both large and varied, in size, age, HVAC plant, use and location and as such not all technologies listed herein will be applicable to every commercial building. There are, however, a great number of similarities and trends within the building stock which guide technology inclusions based on their performance in building integrated applications.

For the purposes of this analysis, the Master Plan considers commercial buildings to represent retail, entertainment, accommodation and commercial office buildings and applies the same general methodology. The abatement for the thermal offsets differs depending on the emission intensity of current thermal energy supplied to the various typologies. Assumptions relating to current demand and fuel use types for these buildings are shown in Figure 17 below.

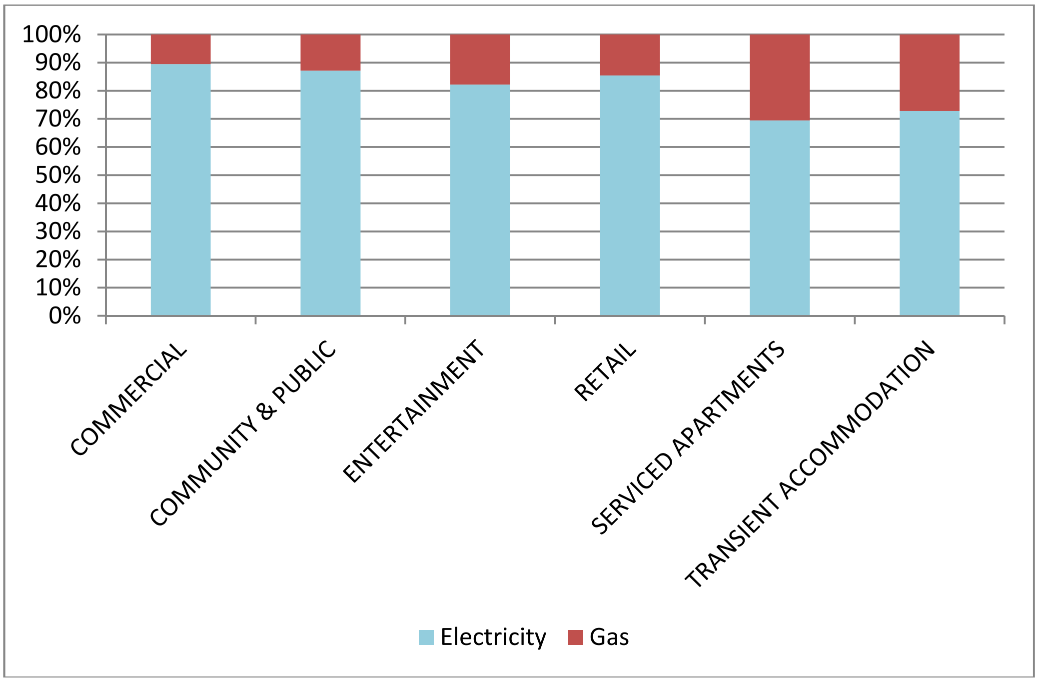


Figure 17 Proportion of energy supplied by gas and electricity in 'commercial' building typologies based on Trigeneration Master Plan assumptions

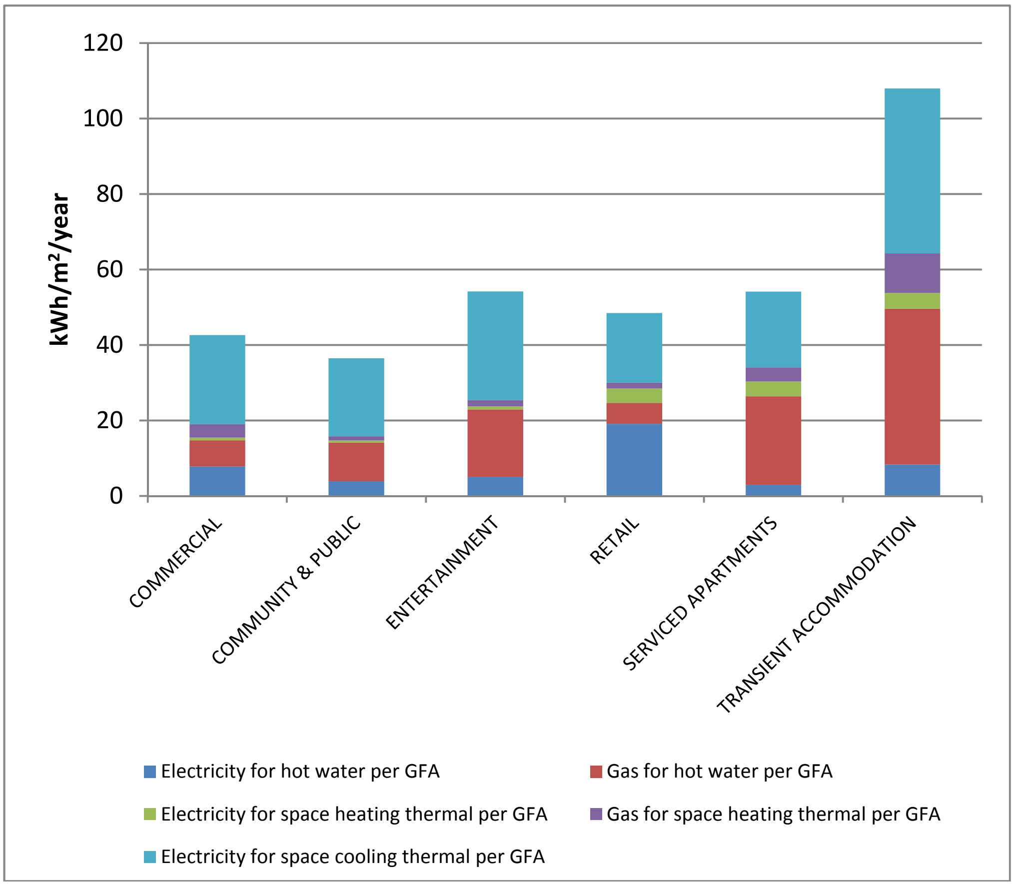


Figure 18 Thermal energy by fuel type and end use in non-residential building types

An assessment of the cost of abatement using different technologies was conducted for commercial, community, public, entertainment and retail buildings. The findings for each building type were not significantly different (although the solar hot water sizing for building type varied according to internal demand).

The cost of abatement and technology hierarchy, based on commercial buildings are presented below. These are indicative of all non-residential or industrial building types.

4.3.1 Cost of Abatement

A comparison between the costs of abatement for each technology is outlined below. A negative cost of abatement indicates that the technology provides a return on investment over its lifetime such that there is a net benefit per tonne of carbon abated.

Table 3 Commercial buildings cost of carbon abatement by technology ($/tCO$_2$e)

Range	**PV**	**CPV**	**OPV - Future thin film**	**Micro wind (@150m height)**[12]	**Solar Cooling (SCOOL)**	**SHW**	**Heat Pump**
No subsidies							
Low	-$54	$136	-$161	$2	$277	$34	$342
Median	$3	$226	-$102	$7	$654	$81	$443
High	$13	$256	-$63	$20	$1084	$110	$482
Subsidies included (Solar Credits where applicable)							
Low	-$105	$77	-$222	-$28	$277	-$1	$314
Median	-$47	$192	-$163	-$24	$504	$40	$414
High	-$43	$216	-$124	-$10	$913	$76	$453

These results show that solar photovoltaics (PV) are currently the most cost effective renewable electricity generation technology to achieve carbon abatement in commercial buildings. It should be noted that, with rapid reduction in the cost of printed thin film and organic photovoltaic technologies (OPV), in future this may become the most cost effective carbon abatement technology at a building scale. Installation costs create some inertia to this price reduction shift, however as local markets mature this is expected to reduce somewhat.

Although OPVs have a reduced cost of abatement compared to conventional PV, they will achieve less carbon abatement per unit area and so, for the purposes of this Master Plan, have not been prioritised over conventional PV where roof space is likely to be limited.

Micro-wind turbines can be a cost effective renewable energy measure, however their effectiveness is entirely dependent on local site wind resource. It is evident that low lying buildings do not have the wind resource for micro-wind turbines.

[12] Performance of micro wind differs depending on building height and location within the City. Data presented is based on 150m building within the CBD. Appendix B presents costs of abatement for grid locations across the City for various building heights.

At heights of around 150m above ground level they start to become cost competitive with solar PV.

Concentrated photovoltaic (CPV) systems are generally associated with utility scale application. There are technologies available at building scale, however these do not have the economies of scale or broad readymade suppliers and solutions of utility CPV.

Solar cooling does not perform well on a cost of abatement basis when compared with electrically based renewable energy generation technologies. Additionally, systems will only be applicable to larger commercial buildings with heavily centralised plant and a significant amount of open roof space.

4.3.2 Effect of Thermal Energy Supply on Cost of Abatement

The thermal technologies, including solar hot water and ground source heat pump, above show a relatively poor cost of abatement in Table 3 due to the proportion of thermal energy already supplied by natural gas within the commercial sector.

However, for solar hot water, the cost of abatement improves significantly where it offsets thermal energy currently supplied by electricity as shown in Table 4 below.

Table 4 Effect of fuel type offset on cost of carbon abatement for low temperature solar thermal in commercial buildings

Range	**Low temperature solar thermal for hot water (solar hot water)**		**Low temperature solar thermal for space heating**	
	Offsetting Electricity	**Offsetting Gas**	**Offsetting Electricity**	**Offsetting Gas**
No subsidies				
Low	-$49	$463	-$160	$438
Median	-$20	$612	-$116	$572
High	-$2	$702	-$84	$670
Subsidies included (RECs and Solar Credits where applicable)				
Low	-$71	$366	-$193	$338
Median	-$45	$498	-$154	$457
High	-$21	$608	-$116	$574

Therefore, solar hot water will have the lowest cost of abatement where it replaces space heating and hot water supplied by electricity. For the purposes of this resource appraisal it has been assumed that 50% of current commercial buildings utilise electricity to meet thermal energy demands. In the modelling, this is reflected by assuming *every* building has 50% of hot water supplied by gas and 50% supplied by electricity and that only the portion supplied by electricity is offset with solar hot water.

Utilising an electric heat pump to offset existing gas heating systems does not currently achieve an environmental benefit a standalone swap. High grid electricity carbon content means that even with COP of up to 5, electric heat pumps are only marginally better than gas heating on a tCO_2e per MWh basis.

This factor, combined with a much higher price point for electricity on per kWh basis, makes this the least attractive abatement option available.

However, many solar hot water systems come equipped with an electric heat pump. Therefore, where a solar hot water unit is installed to meet a portion of the building's thermal demand, the remaining portion of thermal demand will be met by the heat pump.

A summary of the relative cost of abatement for each technology (depending on thermal offset) is presented in Figure 19 below.

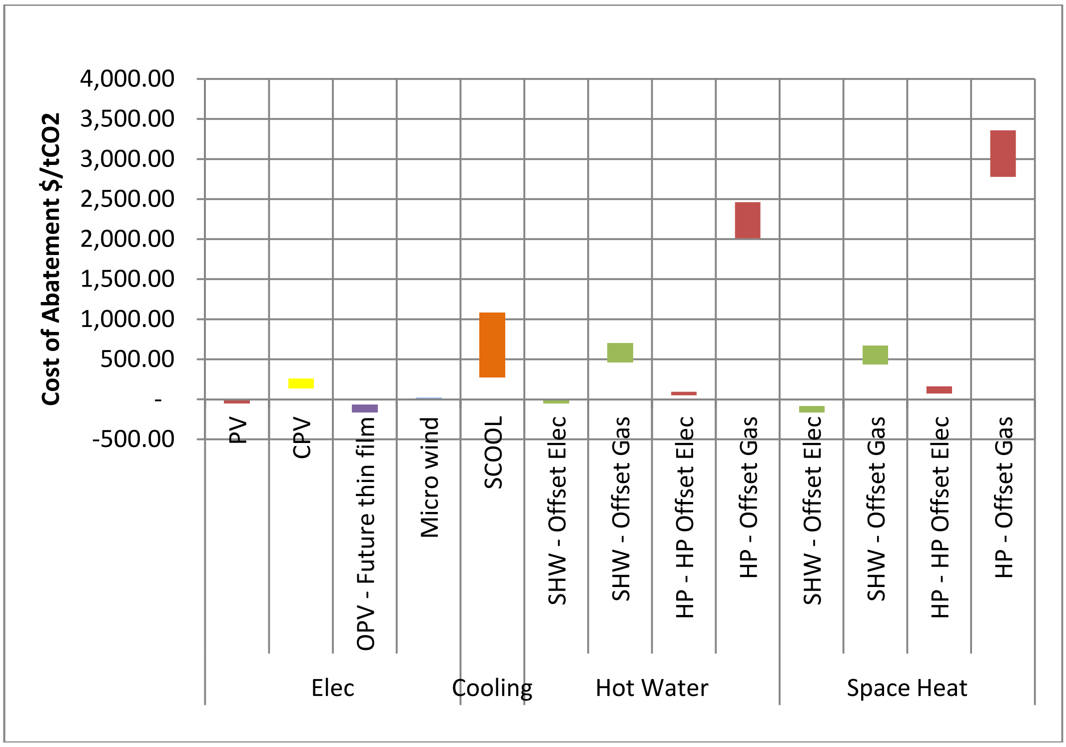


Figure 19 Cost of abatement (no subsidies) for commercial buildings

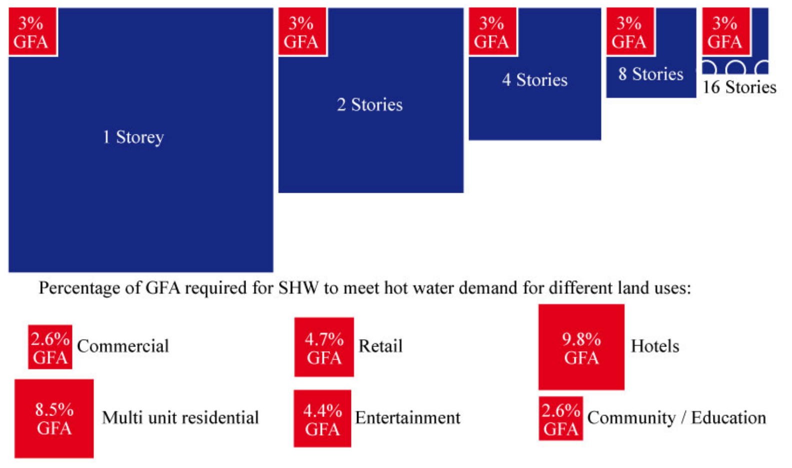
4.3.3 Commercial Buildings Hierarchy

Typically, multi storey commercial buildings have a low roof area to energy ratio. Therefore, for most commercial buildings, the entire thermal and electrical demand is unachievable with the limited roof space available.

The Master Plan aims to use the limited roof space optimally by applying a renewable energy technology hierarchy based on lowest cost of abatement. The hierarchy is then applied to commercial buildings across the City to determine the total renewable energy generation and carbon abatement available from commercial buildings.

The hierarchy first aims to meet the thermal demand currently supplied by electricity through solar hot water technologies. The residual thermal demand in these buildings is met by an electric heat pump replacing electric induction boilers. Existing gas boilers in buildings are not replaced.

Sizing Solar Hot Water



The Master Plan compares the generation profile of an evacuated tube solar thermal system in Sydney against hot water demand profiles to estimate the annual consumption. The result of this comparison is a set of factors for roof area required for a solar thermal system[13] as a proportion of GFA for the different land use types. These land use factors, and an indicative illustration of the relationship of the space requirements to the number of stories are shown in the figure above.

The remaining roof space is then used to meet the electrical demand of the building through solar photovoltaic technology and/or wind turbines for tall buildings.

For the vast majority of commercial buildings the entire demand is not able to be met. However, for some buildings the demand is exceeded and this electricity is assumed to be exported to the grid.

A summary of the hierarchy is presented in Figure 20 and a worked example in Table 5 below.

[13] It should be noted that this space requirement is based on a 38.7% land use efficiency for the solar thermal system. This is to allow for the access space, supporting structures and supporting infrastructure such as pumps and tanks that are required with each system.

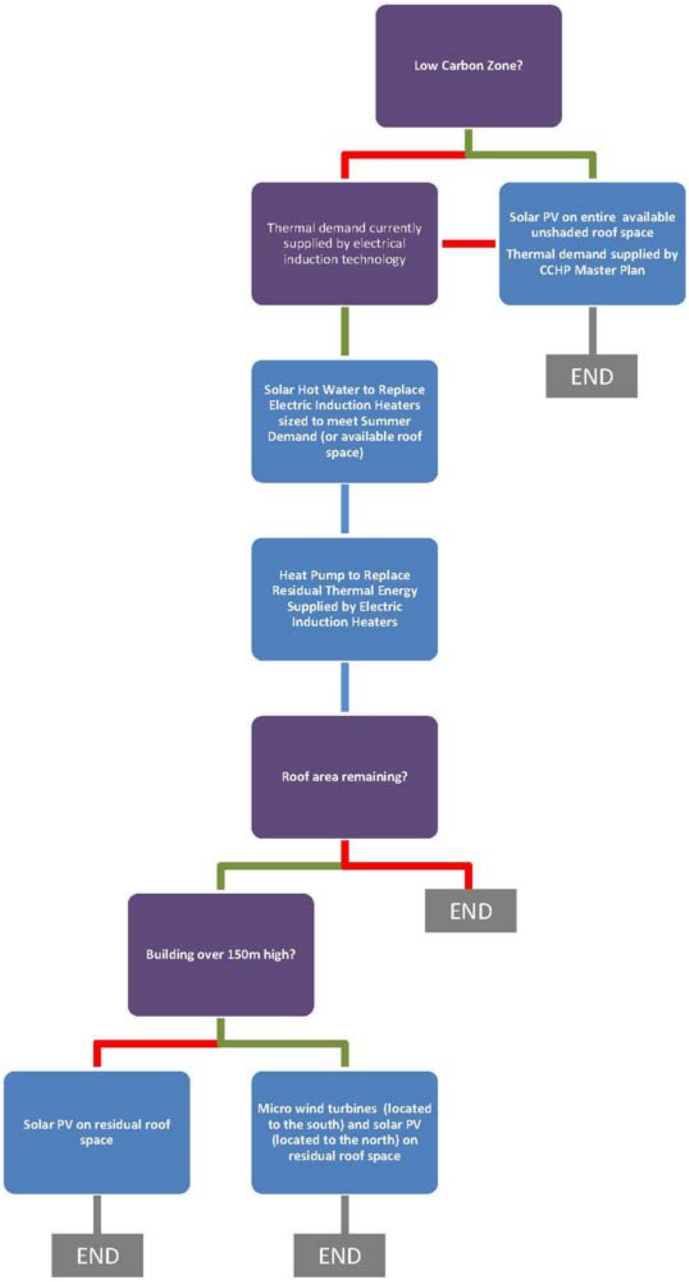


Figure 20 Hierarchy for commercial buildings

Table 5 Example of analysis used to calculate renewable energy potential of a commercial building

Land use type	**Commercial**
Gross Floor Area (m^2)	5,000
Number of storeys	3
Approximate available roof area (m^2)	1,000
Proportion of GFA required for SHW on roof	2.6%
Solar Hot Water roof area (m^2)	130
Collector area based on a 38.7% space efficiency (m^2)	50
PV area based on remainder of roof (m^2)	870
Panel area based on a 38.7% land efficiency (m^2)	341
Installed capacity based on 5.2m^2/kWp, DC or 19.3% efficient (kWp, DC)	65
Annual heat generation, based on 775kWh_{th} / m^2 collector area (kWh_{th} p.a.)	39,120
Annual electrical generation based on 1480kWh/kWp (kWh_e p.a.)	96,316
Proportion of hot water supplied by renewables	70%
Proportion of gas avoided	48%
Proportion of electricity (electrical and cooling demand) avoided	11%
Renewable energy percentage achievable	15%
Emissions reduction	12%

The methodology above can be used to establish relationships between the use of a building, the number of storeys and the total proportion of renewable energy it would be possible to generate. This relationship is shown below in Figure 21.

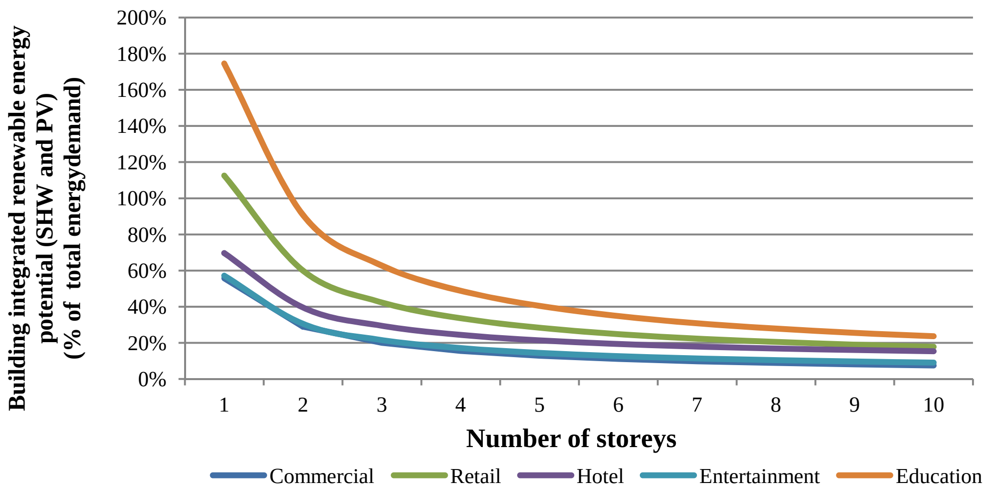


Figure 21 Potential percentage of power supplied by building integrated renewables as a function of number of stories in a building

This shows that typical commercial and hotel buildings are not able to meet demand with renewable energy, only single storey retail and education buildings have the opportunity to meet demand. In reality, any one building may achieve a significantly greater percentage contribution of renewable energy, especially where energy efficiency options are just as aggressively pursued.

Due to the lower price point and carbon content of gas, solar hot water has a significantly poorer cost of abatement if offsetting gas boiler for domestic hot water or heating applications.

4.4 Residential Buildings

Residential buildings may be categorised into two major groups; single dwellings and multi-unit buildings. Single dwellings typically have a relatively large roof space area available for renewable energy generation compared to a relatively low energy consumption. Therefore, single dwellings have significant opportunity to offset on site energy use, as well as to export to the grid to offset peak load, and carbon emissions in the broader City. Additionally, the type of technology appropriate for individual residential buildings will be unique based on building design and integration with existing systems.

Multi-unit residential buildings have slightly different requirements, and are one of the more challenging building typologies with regard to renewable energy. This is largely due to space requirements, as well as the number of stakeholders involved in decision making. Multi-residential developments are traditionally space poor, with little roof space or plant room space. Where space is available, it is generally common space under body corporate control. Likewise, plant room and reticulation space for hot water systems is typically very tight, compounding issues for solar hot water and heat pump solutions. Notwithstanding, resources are available for those buildings where these issues can be overcome.

Residential buildings in Sydney use a relatively equal proportion of both gas and electricity. Due to the higher retail price of electricity, and high carbon content of grid electricity, technologies that address this portion offer greater potential for carbon abatement. Assumptions relating to current demand and fuel use types for these buildings are shown below.

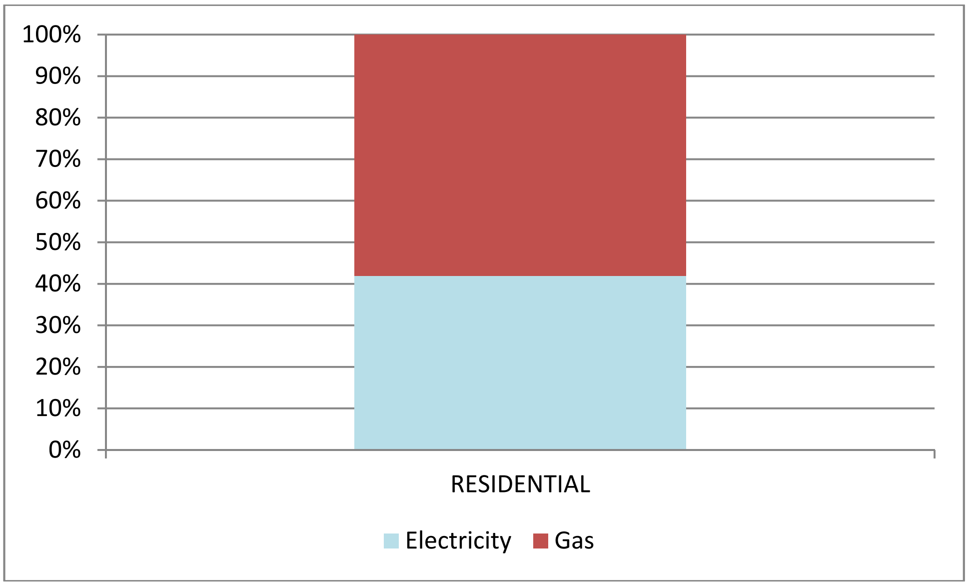


Figure 22 Average proportion of energy supplied by gas and electricity in residential buildings

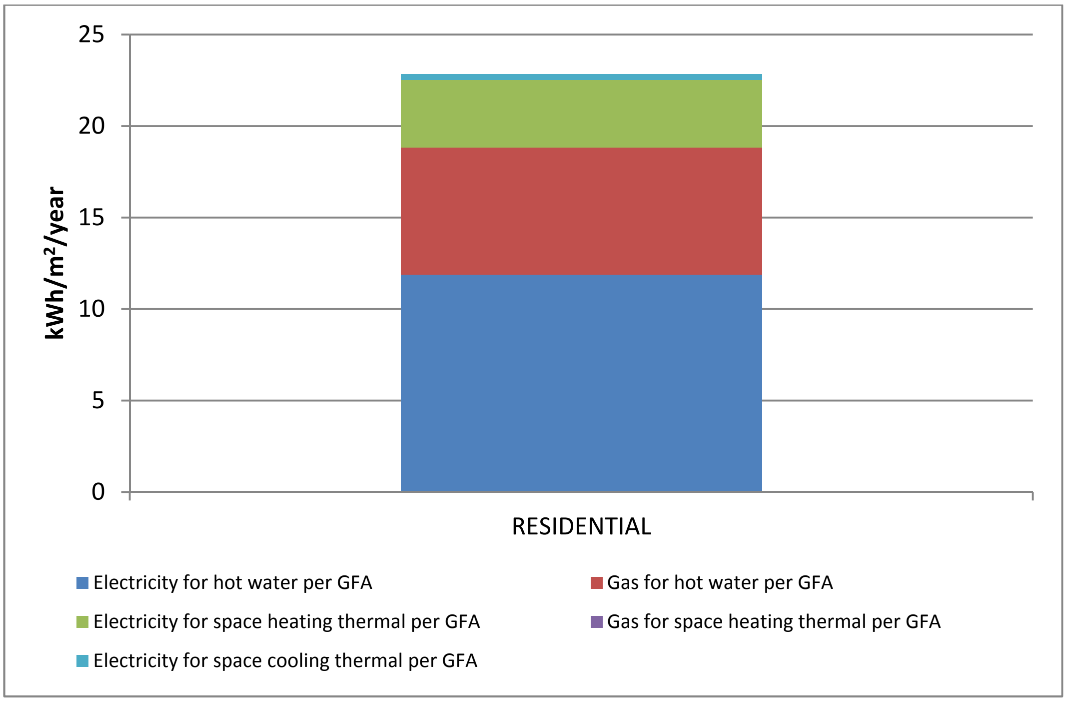


Figure 23 Average thermal energy by fuel type and end use in residential buildings

It should be noted that thermal demands are not always met using gas in the existing building market. A portion of thermal loads will be met by electric boilers, heating elements, etc. The existing building stock containing electric heaters will achieve different environmental and economic benefits from that currently using gas. Additionally, the efficiency of existing equipment will influence the improvements possible using renewables.

4.4.1 Cost of Abatement

A comparison between the costs of abatement for each technology is outlined in Table 6 below. A negative cost of abatement indicates that the technology provides a return on investment over its lifetime resulting in a net benefit per tonne of carbon abated.

Table 6 Residential buildings cost of carbon abatement by technology ($/t$CO_2$e)

Range	PV	OPV - Future thin film	Micro wind (@25m height)[14]	SHW	Heat Pump
No Subsidies					
Low	-$6	-$115	$956	$112	$2,040
Median	$51	-$57	$973	$176	$2,380
High	$61	-$18	$1,026	$216	$2,511
Subsidies included (RECs and Solar Credits where applicable)					
Low	-$129	-$196	$891	$36	$1,915
Median	-$73	-$137	$962	$88	$2,256
High	-$65	-$98	$909	$143	$2,387

Results in Table 7 show the effect of the existing fuel use type on cost of abatement. Although grid electricity and gas carbon contents remain consistent for all building types, the efficiency of equipment and retail price of utilities is different for smaller scale residential users. This difference in electricity pricing will affect the cost of abatement and subsequently the proposed hierarchy.

Table 7 Effect of fuel type offset on cost of carbon abatement for low temperature solar thermal in residential buildings

Range	Low temperature solar thermal for hot water (solar hot water)		Low temperature solar thermal for space heating	
	Offsetting Electricity	Offsetting Gas	Offsetting Electricity	Offsetting Gas
No subsidies				
Low	-$35	$454	-$53	$427
Median	-$6	$602	-$86	$561
High	$12	$692	-$130	$660
Subsidies included (RECs and Solar Credits where applicable)				
Low	-$71	$285	-$185	$260
Median	-$47	$405	-$149	$369
High	-$22	$530	-$107	$498

A summary of the cost of abatement for each technology is presented Figure 23 below.

[14] Performance of micro wind differs depending on building height and location within the City. Data presented is based on wind turbine at height of 25m above ground level within the CBD. Appendix B presents costs of abatement for grid locations across the City for various building heights.

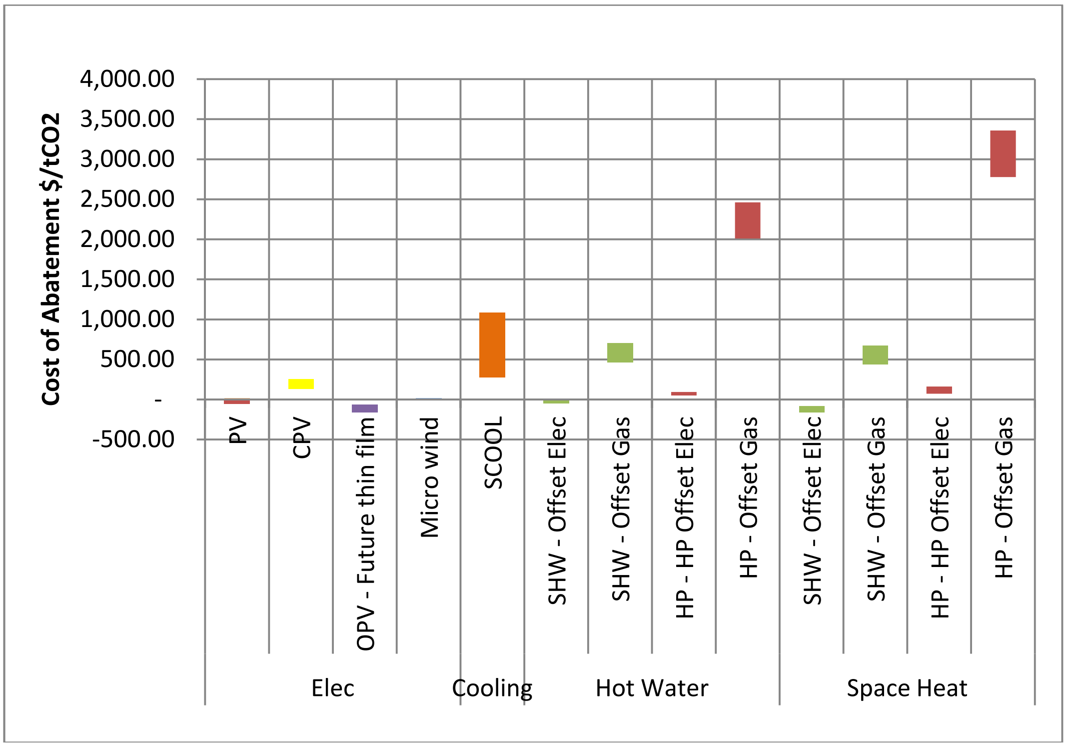


Figure 24 Cost of abatement (no subsidies) for residential buildings

4.4.2 Residential Buildings Proposed Hierarchy

The Master Plan aims to use the residential roof space optimally by applying a renewable energy technology hierarchy based on lowest cost of abatement. The hierarchy is then applied to residential buildings across the City to determine the total renewable energy generation and carbon abatement available from residential buildings.

The hierarchy first aims to meet the thermal demand currently supplied by electricity through solar hot water technologies which is assumed to be the case for 60% of dwellings. Solar hot water is sized to meet summer demand. This is achieved in the majority of single dwelling buildings with left over roof space. For many multi-unit residential buildings, solar hot water dominates the roof space.

The remaining roof space is then used to meet the electrical demand of the building through solar photovoltaic technology. Organic Photovoltaics (OPVs) have the lowest cost of abatement and are therefore prioritised where they are able to meet the entire building’s electrical demand. However, where the entire electrical demand cannot be met based on a limited roof area, conventional PV is considered instead.

Micro wind turbines are not applied to residential buildings for carbon abatement purposes. There are no residential buildings of sufficient height to access the wind speeds micro wind turbines need to compete favourably with solar technologies, based on equivalent roof areas.

A summary of the hierarchy is presented in Figure 25 and a worked example in Table 8.

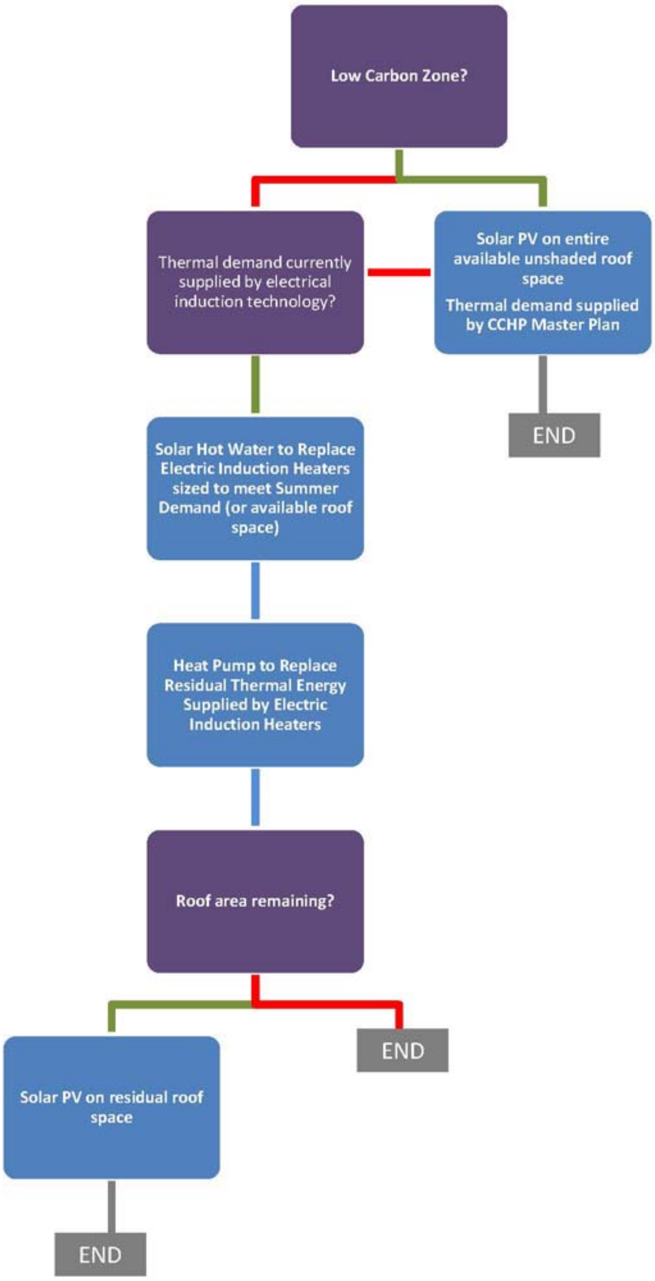


Figure 25 Hierarchy for residential buildings

Table 8 Example of analysis used to calculate renewable energy potential of a residential building[15]

Land use type	Residential Building
Gross Floor Area (m^2)	200
Number of storeys	1
Approximate roof area (m^2)	150
Proportion of GFA required for SHW collectors	3.6%
Solar Hot Water area (m^2)	7
Collector area based on a38.7% space efficiency (m^2)	3
PV area based on remainder of roof (m^2)	143
Panel area based on a 38.7% land efficiency (m^2)	56
Installed capacity based on $8m^2$/kWp (kWp)	10
Annual heat generation (based on 300 kWh_{th} / m^2 (kWh_{th} p.a.)	900
Annual electrical generation based on 1,480 kWh/kWp (kWh_e p.a.)	14,818
Proportion of hot water supplied by renewables	70%
Proportion of gas avoided	11%
Proportion of electricity (electrical and cooling demand) avoided	304%
Renewable energy percentage achievable	107%
Emissions reduction	201%

[15] Note that this is an example of an unshaded single story residence that has the potential to be both energy and carbon positive on a net-basis.

4.5 Industrial Buildings

The types of industrial buildings across the City vary in uses and energy profiles. The majority of industrial buildings in the City utilise larger proportions of electricity compared to gas, as shown in Figure 26. This is due to the lack of centralised heating and cooling equipment, and often the absence of any need for space heating or cooling.

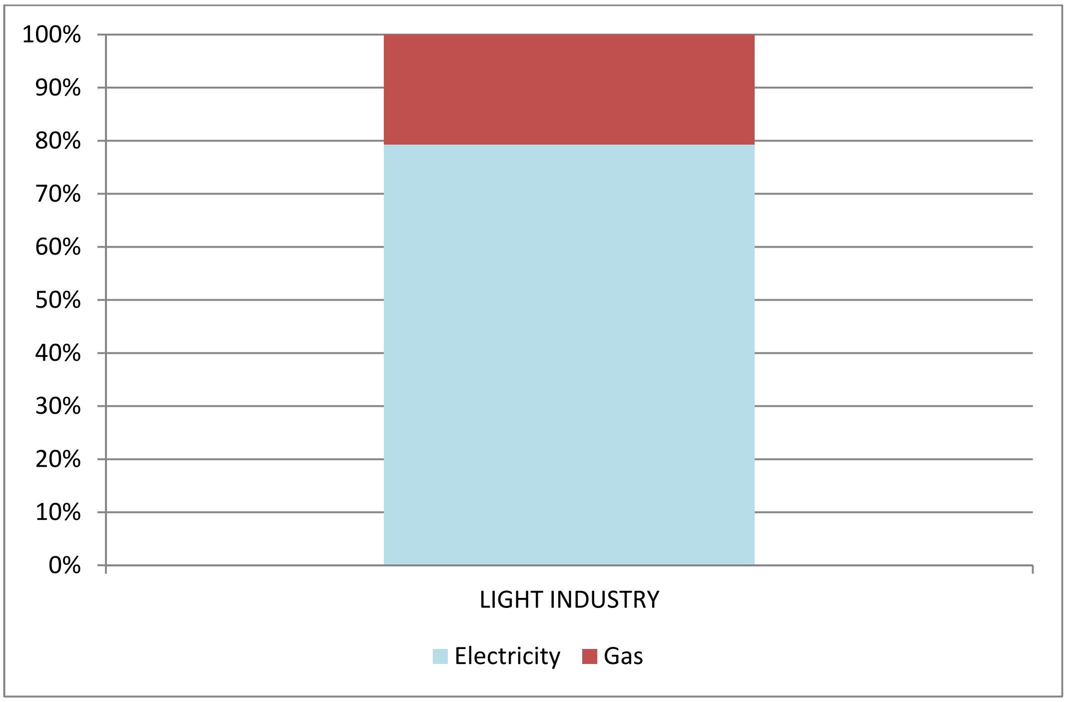


Figure 26 Average proportion of energy supplied by gas and electricity in industrial building typologies

Thermal energy use in industrial buildings is divided between hot water and space heating, the remaining portion devoted to process heat. Thermal energy from process heat consumption is considered in this renewable energy review.

Thermal loads are low on a per m^2 basis compared with other building typologies. Most industrial buildings contain relatively large, open, unconditioned spaces, often with some smaller conditioned office space.

Aside from the gas/electrical heating equipment split and efficiency of equipment, industrial buildings often do not have load for space heating or cooling technologies. This reduces the applicable technologies compared to commercial and residential buildings.

In the demand data adopted in the Master Plan it is assumed that the heating and cooling demands from the industrial sector are negligible and that thermal energy is required for water heating only as shown in Figure 27.

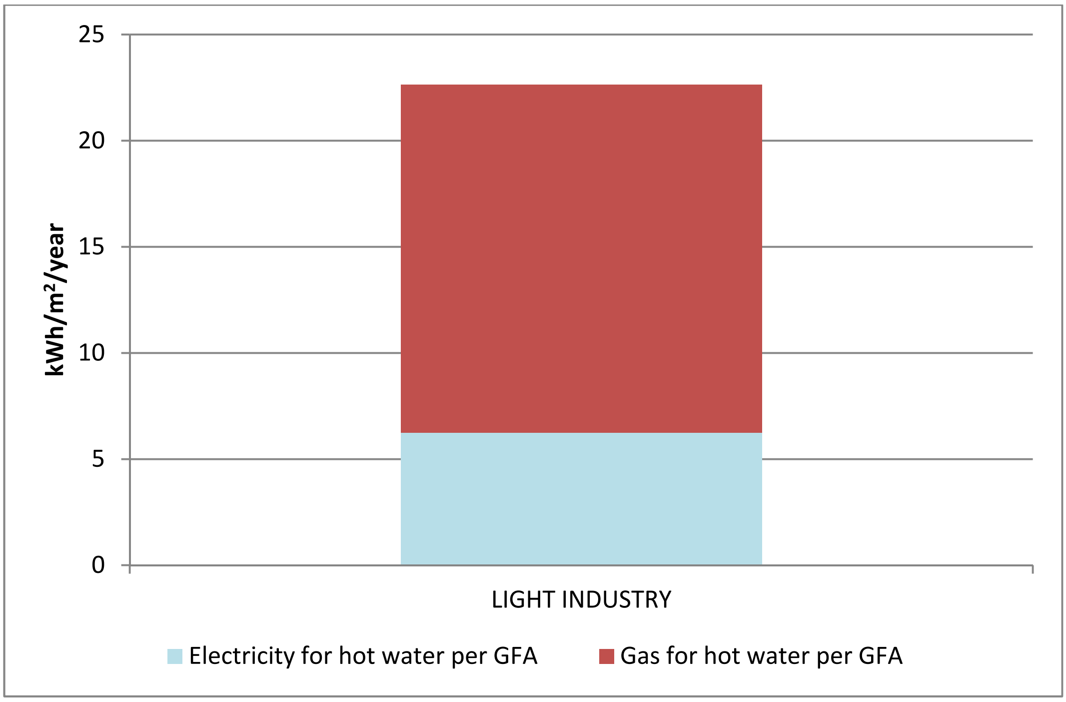


Figure 27 Thermal energy by fuel type and end use in industrial building typologies

There are also opportunities for larger scale renewable applications – often touted as “big roof” projects. Some buildings may be large enough that they may induce a third party energy company to use the roof space for a large scale renewable energy facility. Issues with regard to grid integration and local electrical infrastructure would need to be considered in these applications. However, economies of scale and the potential for significant carbon and peak load reduction make these projects attractive. “Big Roof” projects greater than 100kW are presented in Section 5.

4.5.1 Cost of Abatement

A comparison between the costs of abatement for each technology is outlined in Table 9 below. A negative cost of abatement indicates that the technology provides a return on investment over its lifetime and that there is a net economic benefit per tonne of carbon abated.

Table 9 Industrial buildings cost of carbon abatement by technology (\$/tCO_2e)

Range	PV	CPV	OPV - Future thin film	Micro wind (@25height)[16]	SHW	Heat Pump
No Subsidies						
Low	-$54	$136	-$161	$926	$258	$1,289
Median	$3	$226	-$102	$943	$355	$1,493
High	$13	$256	-$63	$996	$414	$1,610
Subsidies included (RECs and Solar Credits where applicable)						
Low	-$105	$77	-$222	$896	$184	$1,190
Median	-47	$192	-$163	$913	$270	$1,511
High	-43	$216	-$124	$966	$344	$1,395

Results in Table 10 show the effect of the existing fuel use for hot water use on cost of abatement.

Table 10 Effect of fuel type offset on cost of carbon abatement for low temperature solar thermal in residential buildings

Range	Low temperature solar thermal for hot water (solar hot water)	
	Offsetting Electricity	Offsetting Gas
No Subsidies		
Low	-$72	$399
Median	-$48	$528
High	-$33	$606
Subsidies included (RECs and Solar Credits where applicable)		
Low	-$94	$304
Median	-$72	$417
High	-$53	$515

A summary of the cost of abatement for each technology is presented in Figure 28 below.

[16] Performance of micro wind differs depending on building height and location within the City. Data presented is based on 150m building within the CBD. Appendix B presents costs of abatement for grid locations across the City for various building heights.

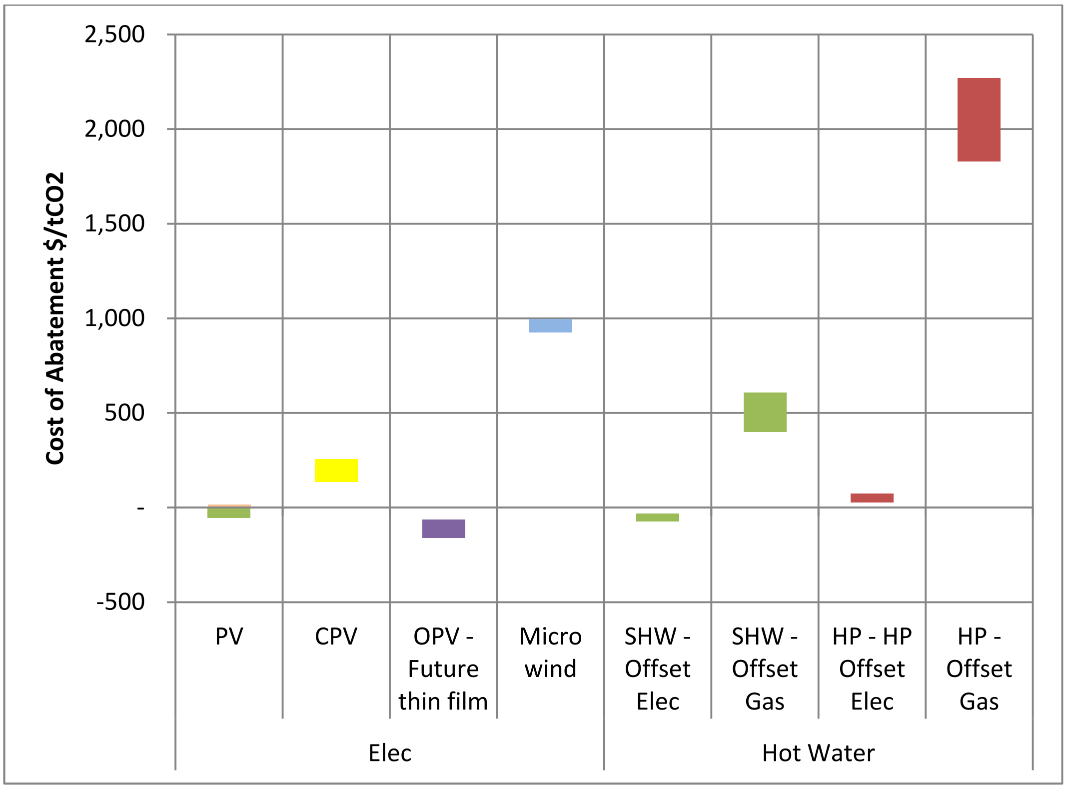


Figure 28 Cost of abatement (no subsidies) for industrial buildings

Solar photovoltaics (PV) with peak output of less than 10kW DC receive the feed in tariff (FiT)[17], as well as capital support through the renewable energy credits (RECs) scheme. As such they are currently the most cost effective renewable electricity generation technology if applied to industrial buildings in the City of Sydney. These systems will be the most cost effective and applicable to industrial buildings.

Solar hot water is estimated to have low to no net cost of abatement, whether or not government subsidies are included. Where centralised electric hot water systems are present, and allow integration with solar hot water systems, this is a cost effective option for carbon abatement.

Lightweight warehouse structures will have issues with structural loading. Thin film technology may be considered a possible solution to these issues. Note that with the rapid reduction in the cost of printed thin film and organic photovoltaic technologies, in future this may become the most cost effective carbon abatement technology at a building scale. Installation costs create some inertia to this price reduction shift, however, as local markets mature this is expected to reduce somewhat.

Concentrated photovoltaics (CPV) are generally associated with utility scale application. Big roof applications are potentially of a size that would make this technology more viable, with regard to standard systems, components and more competitive costing. Roof mounting may be an issue for lightweight warehouse type structures.

[17] The revised feed-in tariff of 20c per kWh means that the effect of this subsidy is currently minimal for new installations (See Section 3.3.7).

In addition to the high level figures listed above, there are a number of practical building and renewable technology considerations that need to be understood. Industrial buildings are very different in design and usage to other building typologies. Building energy loads and industrial building design and scale lend to slightly different technology choices.

4.5.2 Industrial Buildings Proposed Hierarchy

Industrial buildings have significant potential to become large producers of renewable electricity. This is due to the relatively large roof space of this building type, compared with total building floor area. Prospects for thermal technologies are reduced due to lack of heating and cooling load.

The Master Plan aims to use the industrial roof space optimally by applying a renewable energy technology hierarchy based on lowest cost of abatement. The hierarchy is then applied to industrial buildings across the City to determine the total renewable energy generation and carbon abatement available from industrial buildings.

The hierarchy first aims to meet the thermal demand currently supplied by electricity through solar hot water technologies which is assumed to be the case for 30% of industrial buildings. This is achieved in the majority of buildings with vacant roof space.

The remaining roof space is then used to meet the electrical demand of the building through solar photovoltaic technology. Organic Photovoltaics (OPVs) have the lowest cost of abatement and are therefore prioritised where they are able to meet the entire building's electrical demand. However, where the entire electrical demand cannot be met, based on a limited roof area, conventional PV is considered instead. If systems are smaller than 10kW DC peak output, they receive assistance of a feed in tariff (FiT), as well as capital support through the renewable energy credits (RECs) scheme.

To take into account potentially unusable roof areas due to suboptimum roof pitch variations and structural limitations, it was assumed that thin film PV technology is used without any supporting structure to reduce weight.

Micro wind turbines are not applied to industrial buildings for carbon abatement purposes. There are no industrial buildings of sufficient height to access the wind speeds micro wind turbines need to compete favourably with solar technologies, using equivalent roof areas.

A summary of the hierarchy is presented in Figure 29 and a worked example in Table 11.

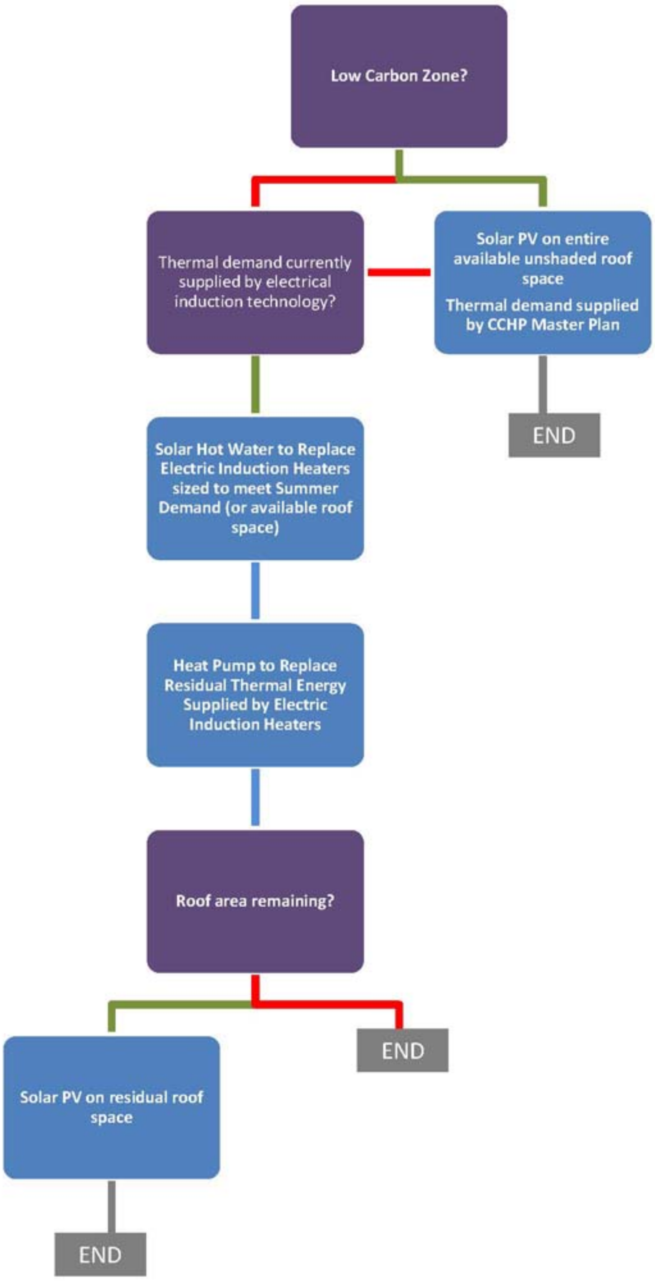


Figure 29 Hierarchy for industrial buildings

Table 11 Example of analysis used to calculate renewable energy potential of an industrial building

Land use type	**Industrial**
Gross Floor Area (m^2)	1,000
Number of storeys	1
Approximate available roof area (m^2)	700
Proportion of GFA required for SHW collectors	4.14%
Solar Hot Water roof area (m^2)	41
Collector area based on a 38.7% space efficiency (m^2)	16
PV area based on remainder of roof (m^2)	660
Panel area based on a 39.2% land efficiency (m^2)	260
Installed capacity based on 5.2m^2/kWp, DC or 19.3% efficient (kWp, DC)	50
Annual heat generation, based on 775kWh_{th} / m^2 collector area (kWh_{th} p.a.)	4,838
Annual electrical generation based on 1480kWh/kWp (kWh_e p.a.)	74,089
Proportion of hot water supplied by renewables	71%
Proportion of gas avoided	24%
Proportion of electricity (electrical and cooling demand) avoided	77%
Renewable energy percentage achievable	66%
Emissions reduction	74%

5 Renewable Power Plants (within the City)

5.1 Overview

Renewable power plants (within the City) include stand alone utilities which generate electricity and/or thermal energy from the City's resource base. The electricity is exported to the electricity grid and thermal energy to the thermal network established as part of the Trigeneration Master Plan. The technologies receive wholesale rates for electricity and thermal energy (as well as any subsidies, including renewable energy certificates) and abate carbon equivalent to grid emission intensity for electricity and the average City of Sydney thermal energy emission intensity for thermal energy.

To achieve economies of scale and minimise capital costs, plants are typically greater than 100kW and generally located on low value land and in close proximity to transmission and distribution infrastructure. These technologies take up significant areas of land and may require buffer distances to protect nearby residences against amenity impacts.

Large scale renewable energy power plants have typically been deployed outside of urban locations where optimum resource conditions are identified, land values are lower and land use conflicts can be avoided. However, there are significant benefits associated with locating renewable energy plants within the City including:

- potential to offset transmission and partial distribution use of service charges where the plant is embedded within the city's distribution network;
- potential for the city to manage land use conflicts within its own jurisdiction and fast track planning applications where appropriate;
- opportunity to export waste heat to the district heating network improving financial return and carbon abatement potential; and
- educational and community value with potential subsequent influence on demand management.

5.2 Step wise Approach

A step wise approach was undertaken to evaluate the contribution of renewable power plants within the City to the renewable energy and carbon targets as shown below.

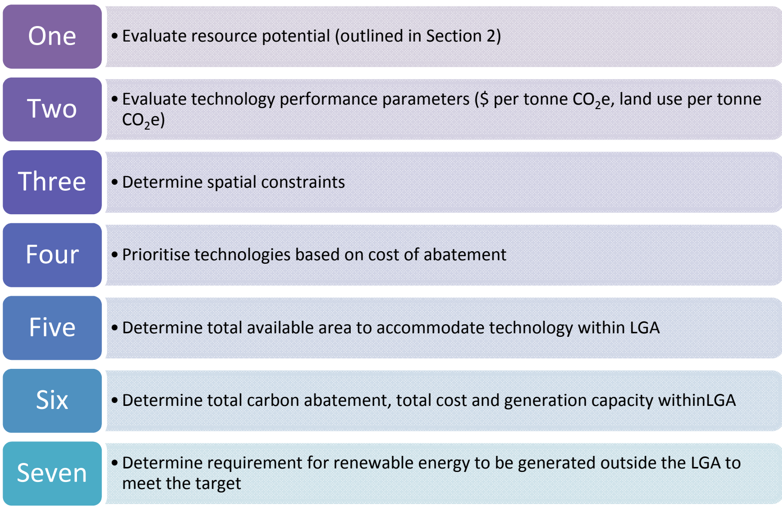


Figure 30 Methodology for renewable power plants within the City

5.3 Technology Evaluation

Each technology type was assessed to determine the long run marginal cost and cost of abatement using performance and cost data for existing technologies (commercially operating within Australia where possible) and adjusted to suit the conditions in Sydney.

In some instances, including concentrated photovoltaic cell and wave power, the available information on costs was not considered reliable as the technologies are still under development and are yet to be commercialised. With photovoltaic cell and wave power technologies, the bottom of the cost range was taken to be indicative of the price in the future, once the technology is commercially developed.

The range of prices for tidal power is dependent on the type and scale of the power plant. These prices are significantly higher than elsewhere in the world because of a relatively low tidal range. The low end of the price spectrum is a barrage type tidal power plant which is also likely to have considerable impediments for approval through the planning system due to environmental and practical considerations.

Table 12 below shows the LRMC of electricity for the technologies. This rate is indicative of the average price the renewable energy generator would require in order to be profitable. When compared to the wholesale rate for electricity in NSW, which is currently around $50/MWh, it becomes apparent that under current market conditions subsidies are required to make renewable energy generation a profitable business.

Table 12 LRMC renewable power plants within the City ($/MWh)

Range	Technology								
	Solar Photovoltaic	Concentrated solar PV	Concentrated solar thermal	Onshore Wind (within the City)	Onshore e Wind (beyond the City) [1]	Offshore Wind (in proximity to the City) [2]	Wave power	Tidal power	Direct use geothermal[3]
No Subsidies									
Low	$265	$282	$283	$196	$85	$134	$265	$334	na
Median	$322	$289	$348	$216	$91	$147	$265	$832	na
High	$366	$485	$375	$223	$111	$195	$687	$3,712	na
Subsidies included (RECs)									
Low	$226	$244	$144	$156	$45	$102	$208	$297	na
Median	$284	$251	$207	$172	$51	$108	$225	$795	na
High	$334	$452	$232	$181	$80	$108	$751	$3,675	na

1 Assumes a site is found that has wind speeds high

Onshore wind beyond the City has been included for reference as the current most commercially viable renewable energy technology within Australia and becomes almost cost competitive with grid based electricity where subsidies are considered. On shore wind within the City does not perform as well due to the lower wind speeds.

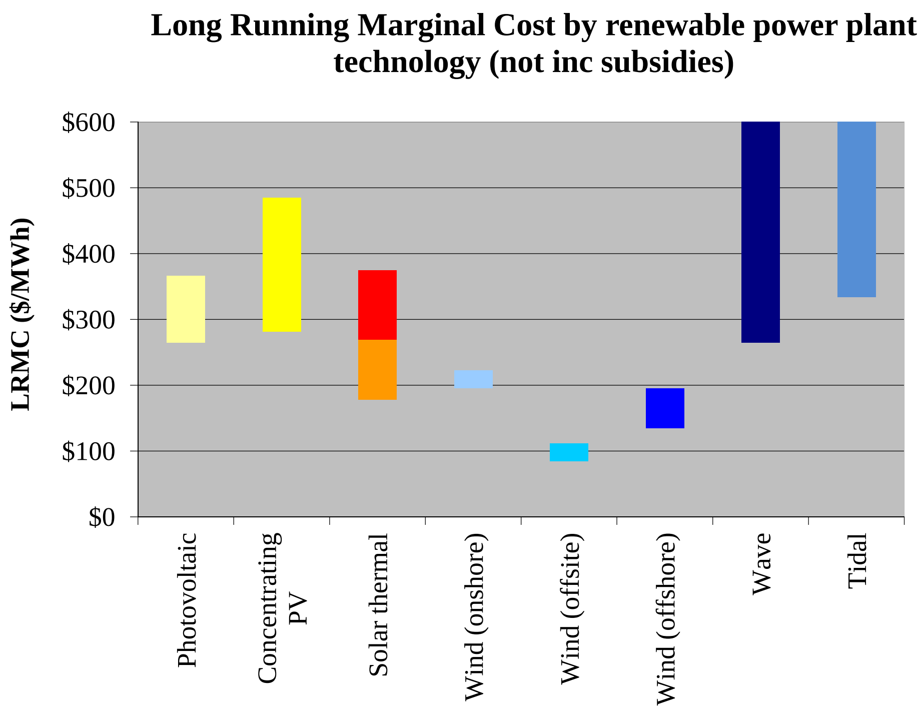


Figure 31 Long Running Marginal Cost by renewable power plant technology

The geothermal resource within the city of Sydney is not considered sufficient for electricity generation. Direct use geothermal has been considered where it can be exported directly to the proposed distributed heating network. LRMC calculation methodology is suitable for electricity generation only and has therefore not been applied for direct use geothermal.

When the cost of abatement methodology is applied, those technologies producing thermal energy (concentrated solar thermal and direct use geothermal) receive additional benefit for carbon abated from offsetting current thermal energy consumption based on the average emission intensity for thermal end use within the City.

Table 13 Cost of abatement for renewable power plants ($/t$CO_2$e)

Range	Technology								
	Solar Photovoltaic	Concentrated solar PV	Concentrated solar thermal	Onshore Wind (within the City)	Onshore Wind (Beyond the City)	Offshore Wind	Wave power	Tidal power	Direct use geothermal
No Subsidies									
Low	$125	$142	-$28	$78	-$8	$48	$194	$270	$113
Median	$190	$151	-$2	$99	-$1	$63	$195	$840	$168
High	$240	$374	$4	$109	$22	$116	$669	$4,138	$242
Subsidies included (RECs)									
Low	$81	$99	-$40	$34	-$52	$4	$131	$228	$113
Median	$146	$108	-$27	$55	-$35	$15	$150	$798	$168
High	$197	$331	-$9	$62	-$22	$19	$741	$4,096	$242

The technologies with the lowest cost of abatement are concentrated solar thermal, wind power and offshore wind beyond the City.

The cost of abatement for the concentrated solar thermal is improved due to the assumption that the waste heat generated by the power plant is used by the Trigeneration Master Plan's heating network. The value of heat within the City of Sydney is significant when replacing heat currently supplied by electricity. This increases the revenue of the CST plant and the carbon abated. The majority of hot water and space heating within the City are fuelled by electricity which is both more expensive than gas on a pure energy basis, and more carbon intensive.

In Figure 31, the grey bars below photovoltaic, concentrating photovoltaic, solar thermal and onshore wind indicate the reduction in cost of abatement if taking into account the reduction in transmission charges which may be available where the technology is located within the City of Sydney.

The subsidies available to the various technologies are all based on Renewable Energy Certificates. Table 13 above shows that offsite wind has a negative cost of carbon abatement. This means that with the readily available subsidies it is possible to make a profit with wind powered generation outside the City. The other technologies are not as financially viable without additional financial support.

If the negative costs of avoiding Transmission Use of System (TUoS) changes are included, solar thermal approaches financial viability at the lower end of the price spectrum. This also includes the sale of waste heat produced by the generator and a scale of at least 1MW. If the scale were below this level the electrical efficiency of the power plant would drop, reducing the overall carbon offset and increasing the cost of abatement.

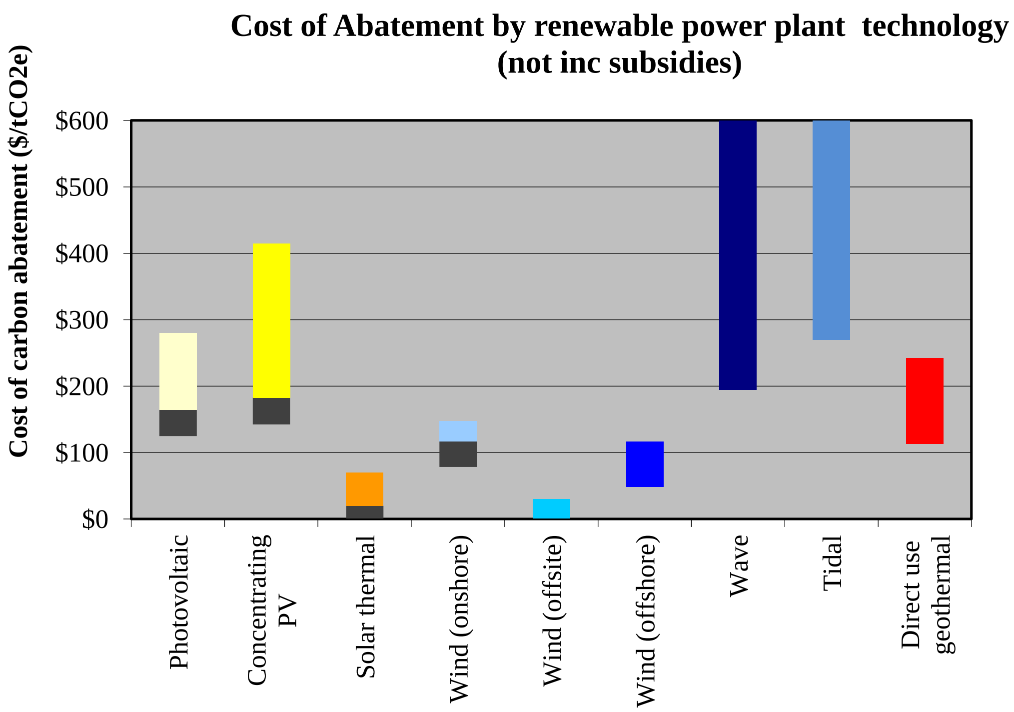


Figure 32 Cost of abatement by renewable power plant technology (including TUoS discount indicated in grey)

5.4 Spatial Constraints

The total generation potential of renewable power plants within the City will depend upon the available land area. The land area required per unit generation for each technology is shown in Figure 33 below.

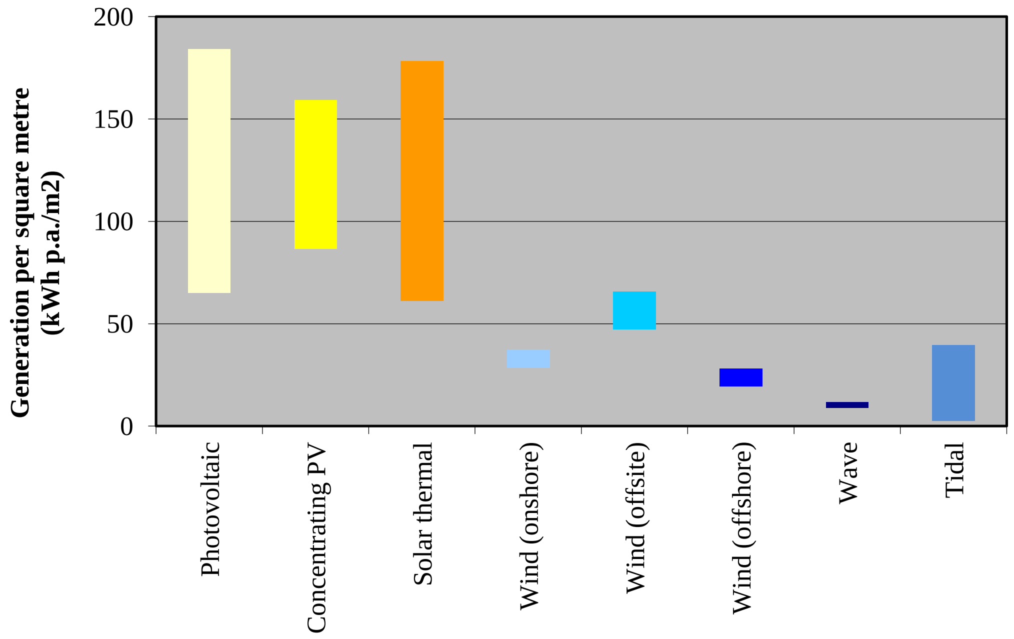


Figure 33 Generation potential by area for renewable power plants

The technologies with the greatest potential for electricity generation per unit area are solar technologies. Solar PV, laid flat on a north facing roof pitched at 30 degrees presents the greatest potential for energy generation per square metre. Where this is not possible, it is likely that certain forms of solar thermal, like the small solar towers developed by the CSIRO, or the linear Fresnel type systems, would generate more energy given the same space.

Direct use geothermal is extremely energy dense in terms of land use but was not included in the above chart as it does not generate electricity.

Of the non-solar technologies, wind presents the greatest potential energy generation by land use. Offshore wind turbines are typically much larger and so require greater distances between turbines, decreasing the overall spatial generation potential.

Onshore wind turbines are also constrained within urban settings due to noise impacts. Typically a buffer distance of 200m from residential areas is required for large wind installations

Tidal power has more potential generation, in terms of area than offshore wind and wave power, but only in very large installations (e.g. multi GW scale).

Notwithstanding, each technology will be subject to particular land use constraints in terms of proximity to sensitive land uses, topography, conflict with other land uses and requirements to link to the low carbon zones thermal networks. Ultimately, these land use constraints have defined the extent to which renewable power plants will be deployed within the City. These are outlined for each technology below.

5.4.1 Concentrating Solar Thermal

There are several major types of concentrating solar thermal, including linear Fresnel, parabolic trough, and solar towers. All use mirrors to focus sunlight and heat a fluid. Most technologies either use steam turbines (working fluid is water), sterling engine (working fluid is air), organic rankine turbines (working fluid is refrigerant) or a combination of the above to generate electricity and heat.

For the purposes of the Master Plan, it was assumed that the minimum plant size would be 500kWe which is the threshold capacity to enable medium efficiency organic rankine turbines to be used. This required a minimum site area of between 0.5 ha for linear Fresnel and trough technologies and 1.8 ha for a parabolic trough or large solar tower.

A buffer distance of 20m from all non-car parking buildings was also applied to avoid light pollution onto neighbouring properties. Sites with a gradient of greater than 1% were also excluded for linear Fresnel technologies which required a flat terrain.

The suitable sites remaining included car park roof top areas, some industrial areas as well as a number of parks as shown in Figure 34 below.

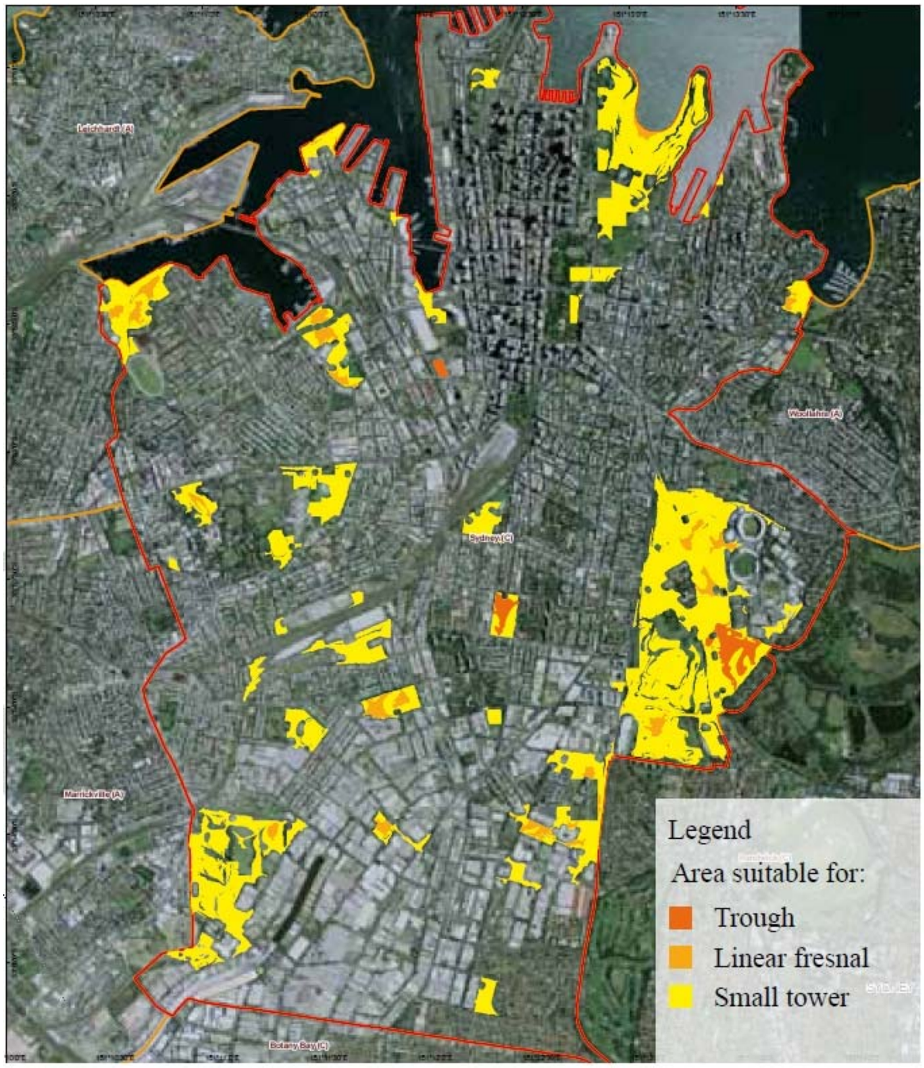


Figure 34 Sites potentially suitable for CST technology

Many of these sites are likely to have competing land uses, particularly the park land areas. For this reason, it was assumed that 5% of the area above would be available for this technology.

5.4.2 Large Wind Turbines

Large wind turbines are currently the most cost effective type of renewable energy technology (excluding hydro) in optimum wind conditions. Large wind turbines within the City may not perform as well due to less than ideal conditions, but provide an iconic component of the Renewable Energy Master Plan. Wind speeds are higher in the north and east of the City, making the sites identified in these locations the priority for development.

The noise and flicker effect generated by these large turbines means there are potential issues for siting them near residential and educational buildings.

A 200m buffer from these buildings leaves several opportunities around the outer edges of the City boundary, mostly in parkland and industrial areas.

Although the largest area for wind turbines is to the South West of the City, wind speeds in these locations are much lower making them less suitable for development. The locations and the corresponding capacity factor for wind turbines under the Renewable Energy Master Plan are shown in Figure 35 below.

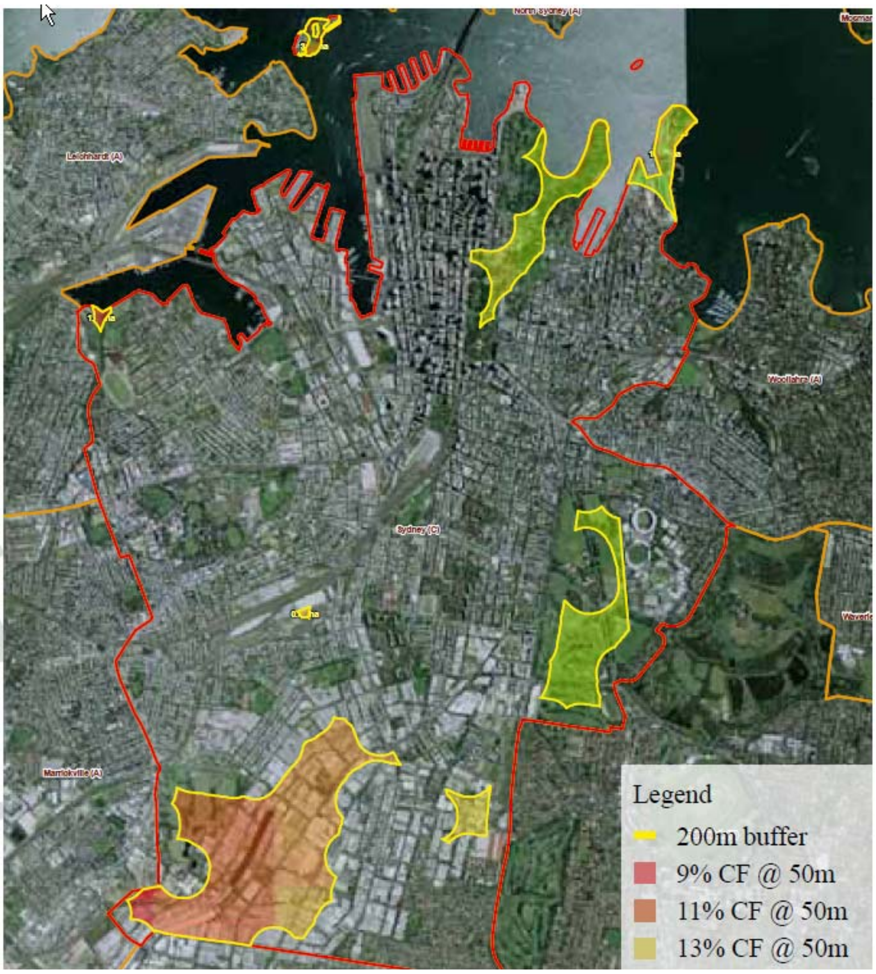


Figure 35 Sites potentially suitable for large wind turbines

A land use factor for large wind turbines, based on five blade diameters between turbines, was used to determine the number of turbines within each of the areas identified above. The capacity factors are based on wind speeds at 5m above ground level and power curves for large turbines designed for low wind sites.

5.4.3 Direct Use Geothermal

For direct use geothermal, it was assumed that the technology would directly input into the Trigeneration Master Plan's district heating network and would therefore be located within 1km of the low carbon zones in unused land or road reserves. Each direct use geothermal power plant was assigned 300m^2 to accommodate access and ancillary equipment. The actual land required by the well is very small relative to other technologies. The potential locations are shown in Figure 36 below.

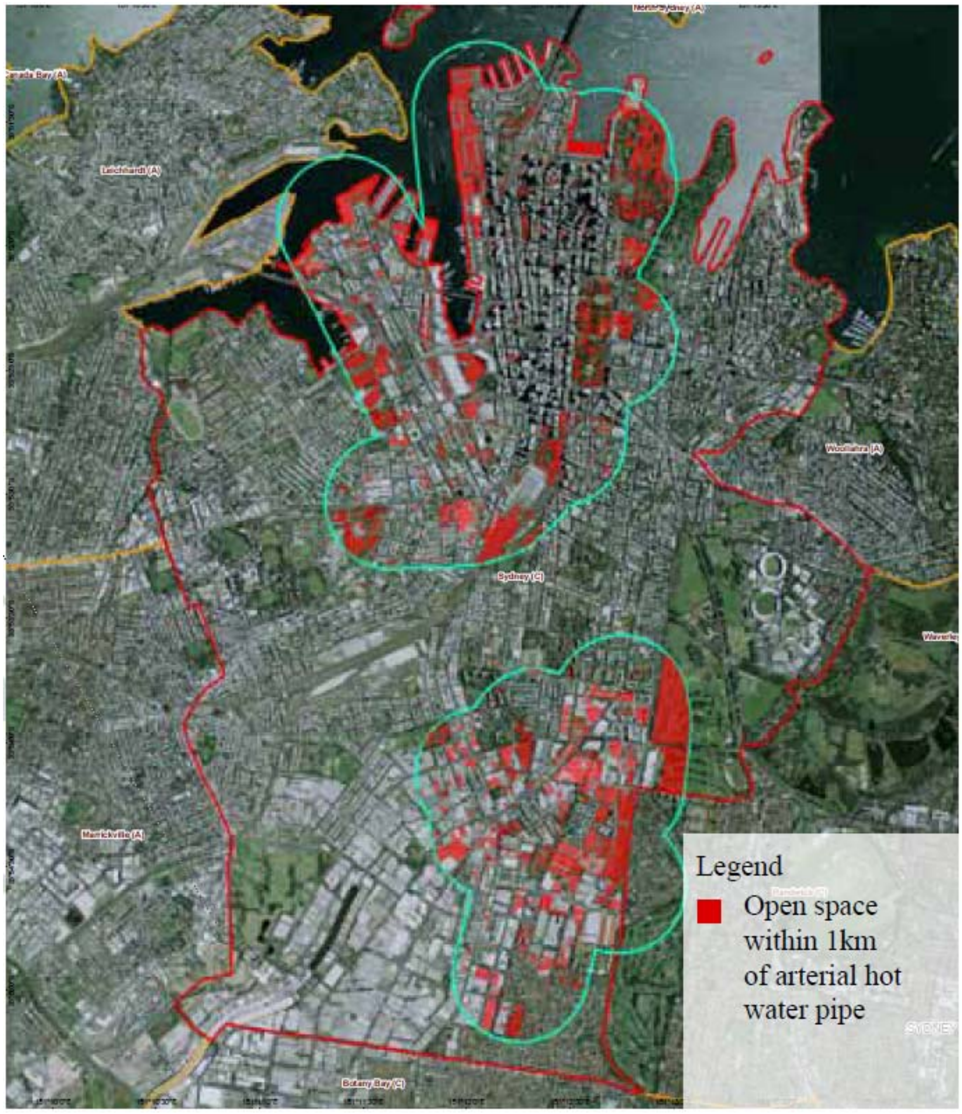


Figure 36 Sites potentially suitable for direct use geothermal

For the purposes of the Master Plan, it was assumed that one 1.2 MWth plant would be located in each low carbon zone.

6 Renewable Power Plants (Beyond the City)

6.1 Overview

There are abundant renewable resources across NSW which the City may investigate in order to meet any shortfall in the targets. Renewable power plants located beyond the City may take advantage of improved resource conditions, reduced land values and land use conflicts to achieve greater commercial returns than investments within the City. However, appropriate governance and implementation issues will need to be explored for the City to claim that renewable energy generated has offset consumption within the City of Sydney and to ensure that the renewable energy generated is additional to business as usual.

If the City is to explore such a strategy there will be a range of resources and technology options which are not viable within the City itself. The aim of the analysis of the Renewable Energy Master Plan is to highlight the extent to which resources are likely to be available within proximity (a nominal 250km radius) of the City to meet the residual target.

In reality, the technology option, or options, taken is likely to be guided by the implementation mechanism adopted by the City, such as a direct investment or a power purchase agreement and the willingness of other businesses and residents within the City to contribute. The ultimate choice will also depend upon the City's objectives and criteria in supporting the development and commercialisation of various technology options.

The analysis therefore presents a high level summary of the likely available resource to indicate:

- Whether a renewable resource base is available to meet the City's target;
- The size of the resource base that the City would need to utilise to meet its target; and
- The potential investment which would be required by the City.

6.2 Step wise Approach

A step wise approach was undertaken to evaluate the contribution of renewable power plants beyond the City to the renewable energy and carbon targets as shown in Figure 37 below.

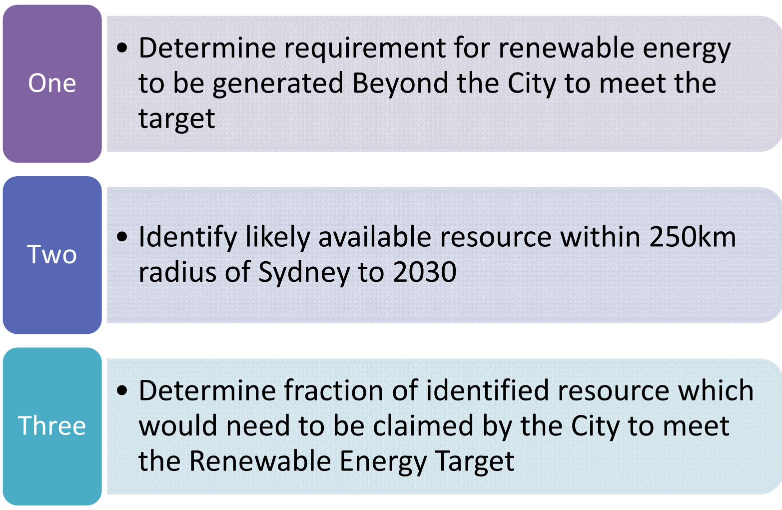


Figure 37 Methodology for renewable power plants beyond the City

6.3 Available Resource

The City has developed some initial objectives for the investment in renewable energy power plants beyond the City. They include:

- a project in a location with a credible geographical link to the city (e.g. within 250km);
- a project that would proceed without the City's investment; and,
- a project that requires little additional transmission infrastructure.

There are likely to be vast amounts of renewable resources within a 250km radius of the City and it is not the purpose of this study to map this resource across such a wide area. Identification of the optimum location of these resources has already been undertaken by the NSW Government and renewable power plant proponents seeking to establish and who have already established commercially viable power plants. If the City is to invest in a power plant beyond the City, it is likely that this would be located at either an existing plant, a power plant already being planned, or a future power plant located in the renewable energy precincts identified by the NSW Government. The review of resources beyond the City has therefore focussed on the available resource from power plants likely to be established to 2030, based on current publically available information.

The NSW Government has developed a series of policies under the banner of the NSW Renewable Energy Precincts. The existing policies focus on fast tracking the development of wind farms across Wind Precincts, areas with good resource and electrical infrastructure as identified by the NSW Government. Figure 38 below shows the locations of the Wind Precincts, as well as the specific locations of wind farms, that have either received planning approval or are awaiting assessment. Figure 38 shows that there are significant areas of the Wind Precinct within 250km of the City.

Figure 38 Potential locations for wind based renewable energy power plants Beyond the City

Apart from hydroelectricity and biomass cogeneration facilities, wind power is currently the cheapest source of renewable electricity on a commercial power plant scale. Wind power has a limited capacity for growth, but it is likely to meet the bulk of the Commonwealth Government's 2020 Renewable Energy Target, with few commercially viable sites available after this. This implies that there may be a lack of wind investment projects in the renewable energy sector for the City in order to claim the RECs and associated carbon benefits.

Technologies that are expected to experience growth in the period to 2020 are landfill of Sydney's gas and biomass cogeneration. However, since it is part of the City's strategy to divert these fuels to the City as part of the Trigeneration Master Plan it seems unlikely that the City would invest in them for electricity generation beyond the City.

Other technologies that have the potential to be commercially feasible after hydro, wind, landfill gas and biomass gasification are:

- hot fractured rock geothermal;
- large scale concentrating solar thermal;
- large scale PV;
- wave power; and,
- offshore wind.

Figure 39 below shows the areas under geothermal exploration licence in NSW. The map shows that they are concentrated around Greater Metropolitan Sydney. The licences do not necessarily indicate that the resource is viable in these locations, or that there will be geothermal power plants, but they do give an indication of the possible locations if hot fractured rock technology proves to be technically feasible at depths where energy can be harvested.

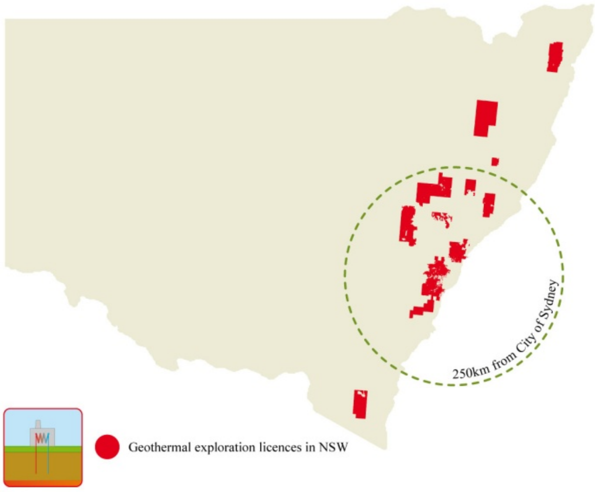


Figure 39 Geothermal exploration licence areas in NSW

NSW has a great solar resource by world standards; this is especially the case when looking at areas west of the Great Dividing Range. However, much of NSW is not suitable for solar power plants because of the distance to the electricity transmission infrastructure. The Victorian and NSW High Temperature Solar Thermal Roadmap[18] identified several locations that had good solar resource and access to transmission lines. More recently, a series of planning applications have been submitted as part of the Australian Government's Solar Flagship program for large scale solar PV power plants. These areas are shown in Figure 40 below. Only one of the locations is within the 250km radius identified by the City of Sydney as preferential for offsite investment.

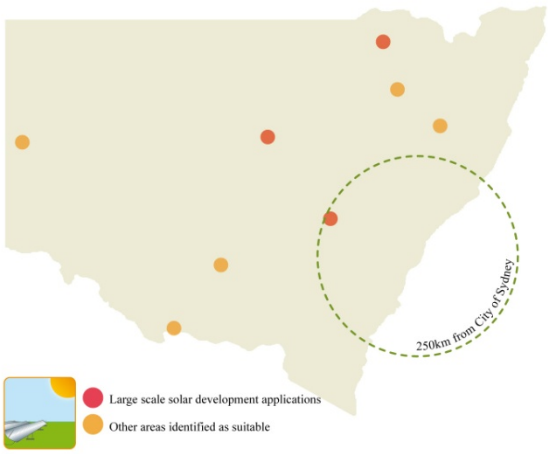


Figure 40 Potential locations for solar based renewable energy power plants Beyond the City

Other technologies which have some possibility of becoming viable within 250km between now and 2030 include offshore wind and wave power. Until recently an offshore wind farm in NSW was unlikely because the infrastructure required to install the foundations and turbines (heavy lift vessels) are not present in NSW.

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[18] Wyld Group and MMA, 2008, *High Temperature Solar Thermal technology Roadmap*, Prepared for the NSW and Victorian Governments

However recent plans to explore the natural gas reserves off the coast of NSW make the chances of having the vessels more probable.

Another constraint on offshore wind within 250km from the City is the depth of the ocean. Conventional foundations are typically only possible at shallow depths with many of the existing Northern European offshore wind farms sited in water less than 20m deep[19]. The coastal area close to Sydney is only less than 100m within 5km of the shoreline where the wind resource is relatively low and a range of planning constraints exist. Foundations, which typically make up around 20% of the capital cost, would be significantly more expensive for an offshore wind farm greater than 5km from the shoreline. Nevertheless, turbine foundation technology, including floating turbines[20], is being developed that could reduce these costs in the future.

Wave energy is a less developed technology that also has potential to become cost effective by 2030. There are numerous technology developers around the world with several standouts in the Australian industry. According to several sources[21,22] the wave resource in NSW as a whole is not as good as in other states. However, wave resource is highly dependent on the specific environmental surroundings (e.g. coastal form, sea floor depth and grade) and there are some sites within NSW that have potential for wave power plants. This is evidenced by the wave energy developer Oceanlinx choosing Port Kembla as the location for their demonstration plant and by Carnegie exploring the wave resource around Eden on the South NSW coast.

Figure 41 Potential locations for ocean based renewable power plants Beyond the City

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[19] Deutche WindGuard GmbH et al, 2006, *Case Study: European Offshore Wind Farms – A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms*, POWER

[20] Statoil have been conducting a trial of a turbine that has a floating base and is anchors to the sea floor off the coast of Norway. See http://www.statoil.com/en/TechnologyInnovation/NewEnergy/RenewablePowerProduction/Onshore/Pages/Karmoy.aspx accessed on the 1/12/2010

[21] M. G. Hughes and A. D. Heap, *National-scale wave energy resource assessment for Australia*, Renewable Energy xxx (2009) 1-9

[22] ABARE and Geoscience Australia, *Australian Energy Resource Assessment*, Department of Resources, Energy and Tourism

7 Renewable Fuel Feedstocks

7.1 Overview

Renewable fuel feedstocks include biomass and biogas derived from waste products including agricultural wastes, horticultural wastes, livestock manure, sewage, commercial and industrial waste and municipal solid waste. Purpose grown energy crops are not included in the assessment. The renewable biomass and biogas resources may be converted into fuels which can replace natural gas in combustion engines through technologies including:

- Anaerobic digestion to produce biogas (which can be upgraded to synthetic natural gas); and
- Pyrloysis of gasification to produce syngas (which can be upgraded to synthetic natural gas or methanol).

The evaluation of the renewable fuel feedstocks has been undertaken to determine the extent of resource which would be required to fuel the City's proposed 360 MWe decentralised energy network under the Trigeneration Master Plan.

In order to estimate the total feedstock availability we have made a series of assumptions based on the most likely technology and fuel conversion process for feedstocks in 2030 from a review of current industry trends.

Where the City of Sydney has control over a feedstock (such as the City's own waste) the technology and fuel conversion process will be able to be dictated by the City to maximise the gas able to be produced. For other feedstocks already collected, the City will unlikely be able to influence the technology (for example other waste treatment facilities across NSW, existing landfills, wastewater treatment facilities). Other feedstocks which are not currently collected are assumed to be processed and transported using the most economic means likely to be available.

While these assumptions have been used to derive the estimate, in reality any one of these technologies or transport methods could be feasible.

It should also be noted that the ability of the City to acquire significant volumes of renewable fuel feedstocks will be highly subject to the market for biogas and biomass which is currently in its infancy. Predictions of peak oil in the near future imply that highly competitive markets for these products will emerge to meet demand for transport fuels, including LNG. While biomass has an important role to play in the renewable energy future, the assumption that the City will be able to acquire 100% of these fuels to service the Trigeneration system will need to be reviewed in the future. This also highlights the need to aggressively implement renewable energy technologies identified in the preceding sections to minimise the City's reliance on renewable fuel feedstocks and to ensure availability to other sectors of the economy.

7.1.1 Stepwise Approach

From Stage 1 the following potential feedstocks were identified:

- Municipal solid waste;
- Sewer gas;
- Sewerage sludge;
- Landfill gas;
- Forestry waste;
- Agricultural waste – broad acre crop residue;
- Agricultural waste – fruit and vegetable;
- Chicken manure;
- Cow manure;
- Pig manure;
- Existing biodiesel production; and,
- Existing ethanol production.

These sources have the potential to produce a gas which may then feed into the City of Sydney's Trigeneration systems in the future.

Arup undertook an analysis of the available primary fuel resource base within Greater Sydney using statistics provided by ABS, potential suppliers and GIS analysis. In most cases, the primary fuel resource is unlikely to be available in its entirety due to commercial reasons where there is an existing competing market for the feedstock; or practical reasons associated with collection or transportation. In these cases the limitations are highlighted and an assumed reduction factor has been applied.

For each resource, Arup have determined the potential renewable feedstock able to be delivered to Sydney. This is dependent on the following:

- Physical properties of the feedstock;
- Fuel conversion technology; and
- Fuel transportation technology.

It should also be noted that the final estimate of available feedstock is subject to significant error associated with agricultural and waste production rates in 2030. Given this error, the variation in technology or transport type is not likely to be material to the overall result.

7.2 Physical Properties of Feedstock Types

The physical properties of renewable fuel feedstocks are the determining factor for how the feedstock is collected, which fuel conversion technology is most suitable and how much energy can be harvested. Table 14 below shows the assumptions made about each feedstock type in order to calculate the energy potential of the feedstock.

Table 14 Assumptions used for the physical properties of feedstock

Feedstock type	Dry matter (% as received)	Calorific value (GJ/t dry basis, MJ/Nm3 or GJ/kL)	Volatile solids (% as received)
Broadacre crops	40%	17.9 GJ/t	Not applicable to the method used
Forestry residue	60%	19.6 GJ/t	Not applicable to the method used
MSW (CoS)	63%	12.2 GJ/t	Not applicable to the method used
MSW (rest of NSW)	Not applicable to the method used	Not applicable to the method used	Various
C&I (CoS)	63%	11.8 GJ/t	Not applicable to the method used
C&I (rest of NSW)	Not applicable to the method used	Not applicable to the method used	Various
Vegetable crop processing waste	Not applicable to the method used	Not applicable to the method used	20%
Landfill gas	Not applicable	22.62 GJ/kL	Not applicable
Biodiesel	Not applicable	34.6 GJ/kL	Not applicable
Laying chicken manure	Not applicable to the method used	Not applicable to the method used	24%
Meat chicken manure	Not applicable to the method used	Not applicable to the method used	48%
Pig manure	Not applicable to the method used	Not applicable to the method used	6%
Dairy cattle manure	Not applicable to the method used	Not applicable to the method used	10%
Meat cattle manure	Not applicable to the method used	Not applicable to the method used	10%
Biosolids from sewage sludge	Not applicable to the method used	Not applicable to the method used	100%

7.3 Fuel Conversion Technology

In order to estimate the total feedstock availability, Arup have made a series of assumptions to arrive at a final number. The assumptions are based on the most likely technology and fuel conversion process for feedstocks in 2030 from a review of current industry trends. Where City of Sydney has control over a feedstock (such as the City’s own waste), the technology and fuel conversion process will be able to be dictated by the City to maximise the gas able to be produced. For feedstocks that are already collected for other purposes, the City is unlikely to be able to influence the technology choice other than through advocacy (for example other waste treatment facilities across NSW, existing landfills, wastewater treatment facilities). Feedstocks which are not currently collected are assumed to be processed and transported using the most economic means likely to be available.

The fuel conversion technologies included in the analysis were:

- Anaerobic Digestion (AD);
- Mechanical biological treatment (MBT) with AD;
- Gasification;
- Bioreactor landfill.

7.3.1 Anaerobic Digestion

Anaerobic digestion uses bacteria in a vessel with a limited supply of oxygen to break down the volatile solids in organic material and create a gaseous fuel, usually called biogas. The vessel can be in the form of a sealed and covered ditch or a large vat. Biogas is a mixture of gases made up primarily of methane and carbon dioxide.

Feedstocks that are assumed to be converted to fuel by anaerobic digestion include:

- Chicken manure;
- Cow manure;
- Pig manure;
- Vegetable processing waste;
- Biosolids from sewage sludge.

Table 15 below shows the assumptions made around the biogas yield from different renewable fuel feedstocks[23].

Table 15 Assumptions used for fuel conversion by anaerobic digestion

Feedstock type	Gas yield (Nm^3/t volatile solids)	Methane content of biogas (% vol)	Calorific value of biogas (MJ/Nm^3)	Fuel potential (GJ/t as received)
Vegetable crop processing waste	186	60%	22.6	0.84
Laying chicken manure	350	60%	22.6	1.9
Meat chicken manure	350	60%	22.6	3.8
Pig manure	250	70%	26.4	0.42
Dairy cattle manure	200	55%	20.7	0.42
Meat cattle manure	200	55%	20.7	0.42
Biosolids from sewage sludge	150	60%	22.6	3.39

Costs for anaerobic digestions were based on medium to large scale anaerobic digestion plants in Europe as estimated by Tsilemou et al (2006)[24] and Clarke

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[23] R. Steffen, O. Szolar and R. Braun, 1998, *Feedstocks for Anaerobic Digestion*, Institute of Agrobiotechnology Tulln, University of Agricultural Sciences Vienna

(2000)[25]. Arup inflated estimates to today's prices and took an average of the two sets of estimates. These average prices were then used in Arup's financial model to calculate the price per GJ of gas output per ktonne of capacity for different feedstocks as shown in Figure 42 below. These costs are based on anaerobic digestion plants treating solid waste and are therefore likely to be higher than smaller scale farm digestors. However, given that the farm would need to be of a sufficient scale to export gas, this was deemed appropriate.

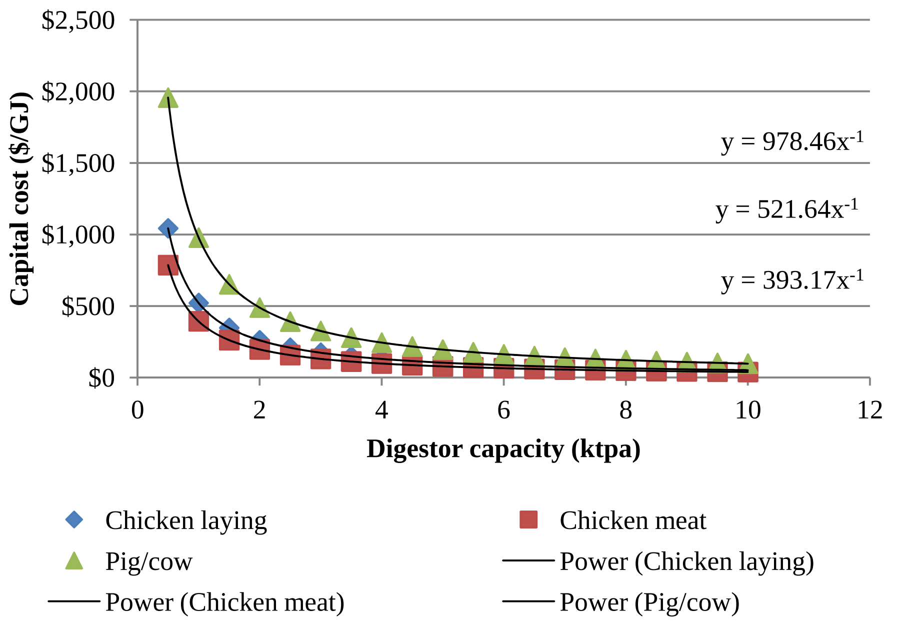

Figure 42 Assumed costs per GJ of biogas produced

7.3.2 Mechanical Biological Treatment with AD

Mechanical biological treatment (MBT) with AD is an example of Alternative Waste Treatment (AWT) technology that has several existing examples operating in Sydney (i.e. UR3R, Earthpower and Macquarie Resource Recovery Park). The energy conversion technology is still anaerobic digestion, but is preceded by a process of sorting the waste stream into recyclable material, material suitable for AD and rejects that are redirected to landfill.

It is assumed that municipal solid waste from outside of the City provides the feedstock for MBT using AD. In this instance Arup used modelling from the City of Sydney Alternative Waste Treatment Business Case to estimate the amount of gas that can be captured. The rule of thumb of 4.7% was based on analysis of the waste composition in NSW. Verified data at WSN's UR3R facility at Eastern Creek in Western Sydney would make this amount only 3.8%[26].

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[24] Tsilemou, K. and D. Panagiotakopoulos, *Approximate cost functions for solid waste treatment facilities.* Waste Management & Research, 2006. **24**(4): p. 310-322.
[25] Clarke, W.P., *Cost-benefit analysis of introducing technology to rapidly degrade municipal solid waste.* Waste Management & Research, 2000. **18**(6): p. 510-524
[26] AEA, 2007, *Mechanical Biological Treatment Case Study 2: Eastern Creek UR3R Sydney*, IEA Bioenergy Taskforce

Table 16 Assumptions used for MBT with AD

Feedstock type	Amount of waste captured as methane by weight	Fuel potential (GJ/t as received)
MSW outside of City of Sydney	4.7%	3.3

The costs associated with purchasing biogas from an MBT-AD plant were assumed to be the price the plant would otherwise receive for generating electricity with the gas (i.e. wholesale electricity plus RECs in the year 2030).

7.3.3 Bioreactor landfill

A bioreactor landfill is similar to a conventional landfill, except that leachate is circulated within the waste to produce greater quantities of landfill gas. In some instances additional bacteria are added to help the process of biodegradation. The gas that is given off by the additional and/or naturally occurring bacteria is captured and typically used in reciprocating engines to generate electricity.

It is assumed that commercial and industrial (C&I) waste from outside the City of Sydney provides the feedstock for bioreactor landfill. As with MBT using AD, a factor was developed to estimate the amount of gas that could be captured from C&I waste based on the composition of C&I waste in NSW. This rule of thumb was developed using NGERS methodology and DECCW composition data to calculate the gas production and assumptions from Grant et al 2003[27] for gas capture.

Table 17 Assumptions used for bioreactor landfill

Feedstock type	Amount of waste captured as methane by weight	Fuel potential (GJ/t as received)
C&I outside of City of Sydney	2.1%	1.15

The costs associated with purchasing biogas from a bioreactor landfill were assumed to be the price the landfill would otherwise receive for generating electricity with the gas (i.e. wholesale electricity plus RECs in the year 2030).

7.3.4 Gasification

Gasification is a process that heats combustible material to between 800°C and 1000°C in a low oxygen environment. The lack of oxygen means that instead of combusting, the material breaks down into an unrefined gaseous fuel, called syngas, and a slag like material. The syngas, a mixture of hydrogen, nitrogen and carbon monoxide and a series of other gases, can be refined into a hydrogen rich gas suitable for fuel cells, or converted into other fuels such as Substitute Natural Gas (SNG) or Methanol.

Feedstocks that are assumed to be converted to fuel by gasification include:

- Municipal Solid Waste from within the City of Sydney;

[27] T. Grant, K.L. James and H. Partl, 2003, *Life Cycle Assessment of Waste and Resource Recovery Options (including energy from waste)*, Nolan ITU and RMIT Centre for Design

- Commercial & Industrial waste from within the City of Sydney;
- Broadacre crops; and
- Forestry residue.

The energy conversion efficiency from feedstock to syngas was assumed to be 75%, including the energy required for gas cleaning[28].

Table 18 Assumptions used for gasification

Feedstock type	Calorific value of syngas (MJ/Nm^3)	Renewable proportion of energy	Fuel potential (GJ/t as received)
Broadacre crops	5.1	100%	3,510
Forestry residue	5.1	100%	5,760
MSW (CoS)	5.1	45%[29]	5,750
C&I (CoS)	5.1	45%	6,440

Costs for harvesting and processing the feedstock into a renewable fuel are based on those estimated in Stucley et al 2004[30].

7.4 Fuel Transportation

The method by which the fuel is transported to the City of Sydney was incorporated into the analysis to gauge both the cost impacts of delivering renewable fuel to the City, and the associated greenhouse gas emissions. There are two main transportation methods considered as part of the Master Plan. They are:

- Road freight (tanker truck); and,
- Pipeline.

Whether a fuel is transported by road freight or pipeline is primarily a function of whether it can be upgraded to be compliant with AS 4564, which typically means a 90% methane gas. Fuels converted by gasification would have to undergo methanation[31], or in other words conversion to Substitute Natural Gas (SNG) in order to be piped. An alternative to this method is to convert the syngas into methanol, a liquid hydrocarbon. Both of these processes require large scale infrastructure which would require centralised plant to obtain economies of scale.

Arup's assumptions for transportation of fuel are shown in Table 19 below.

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[28] E. Rensfelt and A. Ostman, 1996, *IEA Bioenergy Agreement: Task X Biomass Utilization: Biomass Thermal Gasification and Gas Turbines Activity: Sub Task 6 Gasification of Waste: Summary and Conclusions of Twenty Five Years of Development*, IEA Bioenergy Taskforce

[29] Based on modelling for the City of Sydney Alternative Waste Treatment Facility Business Case only a proportion of the fuel generated could be considered renewable under the *Renewable Energy (Electricity) Act 2000*

[30] C.R. Stucley, S.M. Schuck, R.E.H. Sims, P.L. Larsen, N.D. Turvey and B.E. Marino, *Biomass Energy Production in Australia: Status, Costs and Opportunities for Major Technologies*, Rural Industries Research and Development Corporation, An Australian Government Initiative

[31] Methanation is an exothermic process that converts a hydrogen based gas into a methane based gas. Typically, methanation is around 75% to 80% efficient in terms of the fuel energy, although much of the lost energy can be captured as high grade heat.

Table 19 Feedstock transportation assumptions

Feedstock type	Conversion	Fuel treatment required for transport	Transportation method
Broadacre crops	Gasification	Converted to methanol	Truck
Forestry residue	Gasification	Converted to methanol	Truck
MSW (CoS)	Gasification	Injected as syngas	Dedicated pipeline
MSW (rest of NSW)	MBT-AD	Upgrade to SNG	Pipeline
C&I (CoS)	Gasification	Injected as syngas	Dedicated pipeline
C&I (rest of NSW)	Bioreactor landfill	Upgrade to SNG and inject	Pipeline
Vegetable crop processing waste	Anaerobic digestion	Upgrade to SNG and compressed	Truck
Landfill gas	NA	Upgrade to SNG and inject	Pipeline
Biodiesel	NA	NA	Truck
Laying chicken manure	Anaerobic digestion	Upgrade to SNG and compressed	Truck
Meat chicken manure	Anaerobic digestion	Upgrade to SNG and compressed	Truck
Pig manure	Anaerobic digestion	Compresses biogas	Truck
Dairy cattle manure	Anaerobic digestion	Compresses biogas	Truck
Meat cattle manure	Anaerobic digestion	Compresses biogas	Truck
Biosolids from sewage sludge	Anaerobic digestion	Upgrade to SNG and inject	Pipeline

While these assumptions have been used to derive the estimated renewable fuel resource, Arup considers that any one of these technologies or transport methods could be feasible.

7.4.1 Tanker

The costs and carbon emissions of transporting renewable fuels by tanker truck are based on the following assumptions:

- 24t and 38.5m^3 capacity truck;
- Compression of gaseous fuels to 150kpa;
- 12 hour day for the truck driver;
- An average speed of 40km / h in urban areas and 80km /h in regional areas (30km outside the City of Sydney); and
- 15 minutes to load and unload the fuel on either end of the trip.

The above assumptions were cross referenced with the fuel properties shown in Table 20 below to estimate the energy carrying capacity of a tanker truck.

Table 20 Fuel properties and tanker truck capacity assumption

Fuel	Calorific value	Density	Calorific value	Capacity of truck
	MJ/kg	kg/Nm^3	MJ/Nm^3	GJ / truckload
Syngas	6.4	0.8	5.1	29
Biogas	30.8	1.0	29.9	172
Methanol	23	691	15,900	552
SNG	50.2	0.75	37.8	218
Biodiesel	39.3	880	34,600	943
Ethanol	25	936	23,400	600

The remaining assumptions are related to the cost and emissions of transporting fuel. One of the major costs of transporting fuel is the labour involved in driving the truck. The relationship between the number of trips per day, distance from the City of Sydney and average speed is shown in Figure 43 below.

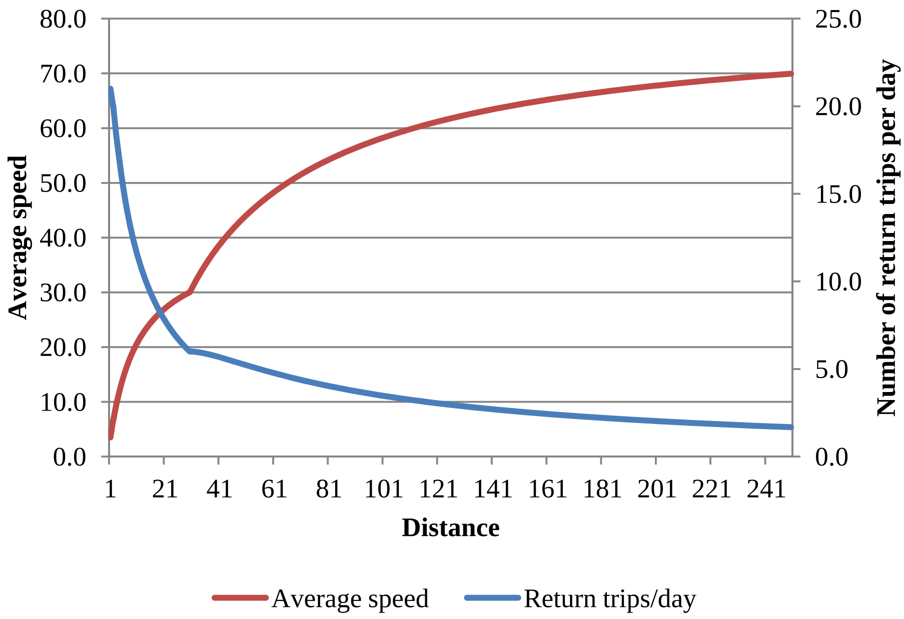

Figure 43 Assumed relationship between speed, distance and number of trips per day

Arup used an online freight cost estimating tool to estimate the costs involved in transporting the fuel[32]. This data was then used to estimate the trucking costs for each fuel type and in each statistical local area in the NSW. These costs range from less than a $1/GJ in inner Sydney to $15/GJ in western NSW.

[32] Freight metrics road calculator available at: http://www.freightmetrics.com.au/CalculatorsRoad/TruckOperatingCost/TruckOperatingCostwithFuelLevyTable/tabid/506/Default.aspx accessed on 20/6/2010

7.4.2 Pipeline

As mentioned earlier, the main criteria for transporting a renewable fuel by pipeline is the ability to meet AS4564-2005, the Specification for General Purpose Natural Gas.

For biogas, this involves an upgrading process where the gas is purified to increase the methane content. This typically involves absorbing or separating the carbon dioxide from the rest of the gas, thereby increasing the methane content. There are several technologies available that can achieve this; one of the most widely used is Pressure Swing Absorption (PSA).

Costs associated with piping gas to the City of Sydney are assumed to be the difference between the commodity price of natural gas and the large user retail rate for natural gas without a carbon price. In the year 2030 this equates to $3.59 per GJ.

In line with the City of Sydney Alternative Waste Treatment Facility Business Case, it is assumed that waste collected within the City of Sydney will be converted into syngas using gasification treatment. It is very unlikely that a syngas (which is hydrogen based) would be allowed to be injected into the existing natural gas network as AS4564-2005 specifies that the Wobbe Index (related to calorific value) is much higher than is possible to achieve with a hydrogen based gas. One possibility is methanating the syngas into a synthetic natural gas, however this would mean the overall energy potential would reduce by around 20% due to an exothermic reaction. For this reason it is assumed that a purpose built gas pipeline[33] will be incorporated as part of the Trigeneration Master Plan to transport this syngas. The costs of this pipeline are attributed to the Trigeneration Master Plan and are not included in the financial analysis within the Renewable Energy Master Plan.

[33] It should be noted that Arup has not investigated the feasibility of piping syngas and that this assumption was from City of Sydney.

8 Results

8.1 Building Scale

8.1.1 Solar Thermal – Hot Water

SOLAR THERMAL – HOT WATER

Total installed Capacity: 62 MW

Total Roof Area Required: 26.9 ha

Total Capital Cost: $289M

Cost of Carbon Abatement (no subsidies): -$6 per tCO_2e (Residential), -$20 per tCO_2e (Non residential)

Cost of Carbon Abatement (with subsidies): -$47 per tCO_2e (Residential), -$45 per tCO_2e (Non residential)

Additional subsidy required for cost neutrality: None (better than cost neutral even without subsidies)

Total renewable electricity generated/grid electricity displaced: 138 GWh p.a.

% of 2030 BaU Electricity: 3.2%

Total carbon abated p.a. in 2030: 112 $ktCO_2$ p.a.

% reduction on 2006 carbon emissions: 1.6%

Solar thermal hot water systems can make a significant contribution to the City's carbon abatement. It is estimated that by installing 62 MW of solar thermal hot water to replace electric systems across all building types within the City, up to 138.4 GWh p.a. of electricity could be displaced, representing an abatement of 112 $ktCO_2e$ p.a. in 2030. This assumes that systems are not installed within the low carbon zones where thermal energy requirements are met by the trigeneration system. Further abatement may be available if this is not the case.

The potential locations and the electricity potentially displaced by these systems are shown in Figure 43 below.

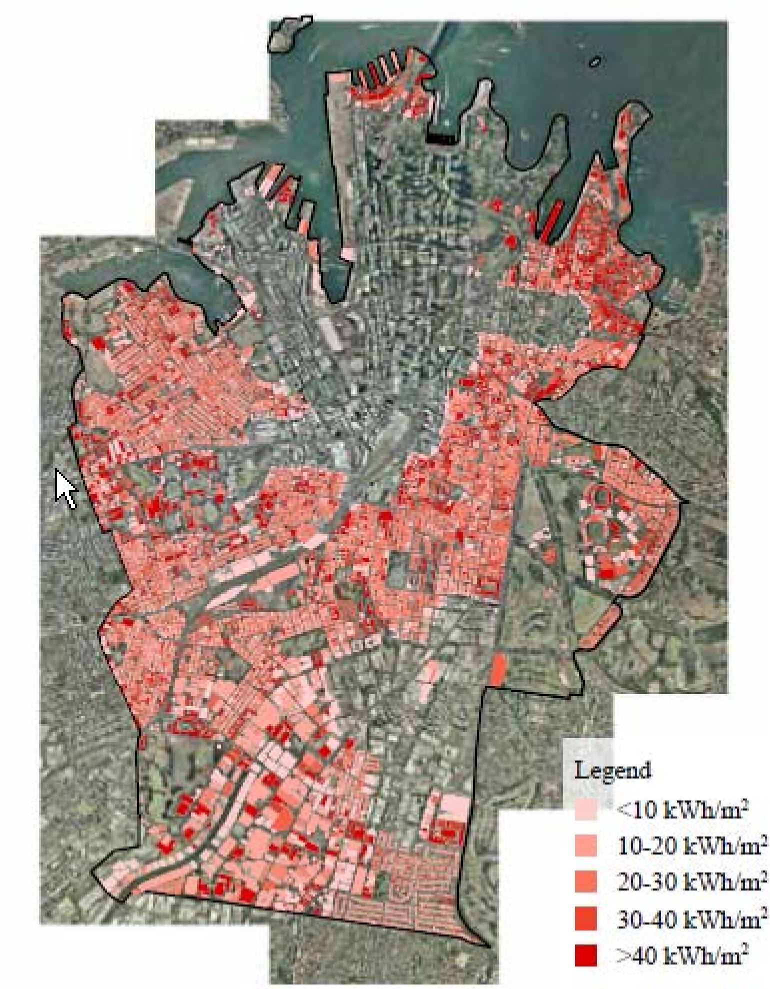

Figure 44 Solar thermal –hot water results

8.1.2 Solar photovoltaic

SOLAR PHOTOVOLTAIC

Total installed Capacity: 395 MW

Total Roof Area Required: 49.3 ha

Total Capital Cost: $2,059M

Cost of Carbon Abatement (no subsidies): $51 per tO_2e (Residential), $3 per tCO_2e (Non residential)

Cost of Carbon Abatement (with subsidies): -$73 per tO_2e (Residential), -$47 per tCO_2e (Non residential)

Additional subsidy required for cost neutrality: None (Existing subsidies are sufficient)

Total renewable electricity generated/grid electricity displaced: 455 GWh p.a.

% of 2030 BaU Electricity: 10.5%

Total carbon abated p.a. in 2030: 369 $ktCO_2$ p.a.

% reduction on 2006 carbon emissions: 5.4%

Solar photovoltaic technology also makes a significant contribution with approximately 394.6 MW installed by 2030 generating 454.6 GWh p.a. The potential locations for the systems and the associated electricity generation are presented in Figure 45 below.

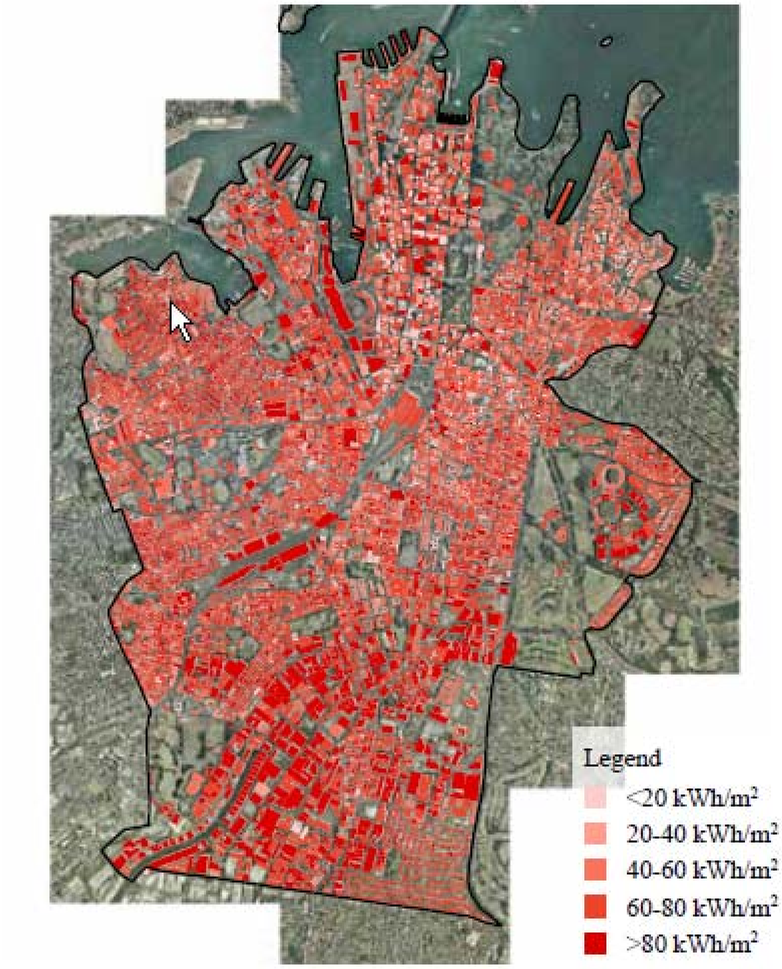

Figure 45 Solar Photovoltaic results

There is large generation potential on industrial buildings in the south of the City. The buildings within the low carbon zones also have a high generation per unit area. It is assumed that the thermal energy in these buildings is provided from the Trigeneration Master Plan so that the majority of the roof space can accommodate solar photovoltaics.

8.1.3 Building Integrated Wind Turbines

BUILDING INTEGRATED WIND

Total installed Capacity: 0.5 MW

Total Roof Area Required: 0.1 ha

Total Capital Cost: $4M

Cost of Carbon Abatement (no subsidies): Depends on height and building location. Ranges from $286 per tCO_2e to -$45 per tCO_2e for individual buildings or $61 per tCO_2e across portfolio of buildings where wind is recommended.

Cost of Carbon Abatement (with subsidies): Depends on height and building location. Ranges from $82 per tCO_2e to -$294 per tCO_2e for individual buildings or -$157 per tCO_2e across portfolio of buildings where wind is recommended.

Additional subsidy required for cost neutrality: None (Existing subsidies are sufficient)

Total renewable electricity generated/grid electricity displaced: 0.7 GWh p.a.

% of 2030 BaU Electricity: 0.02%

Total carbon abated p.a. in 2030: 0.6 $ktCO_2e$ p.a.

% reduction on 2006 carbon emissions: <0.01%

Building integrated wind performs better than solar photovoltaic on only the tallest buildings. For the purposes of the Master Plan this is assumed to be all buildings greater than 100m as shown in Figure 46 below.

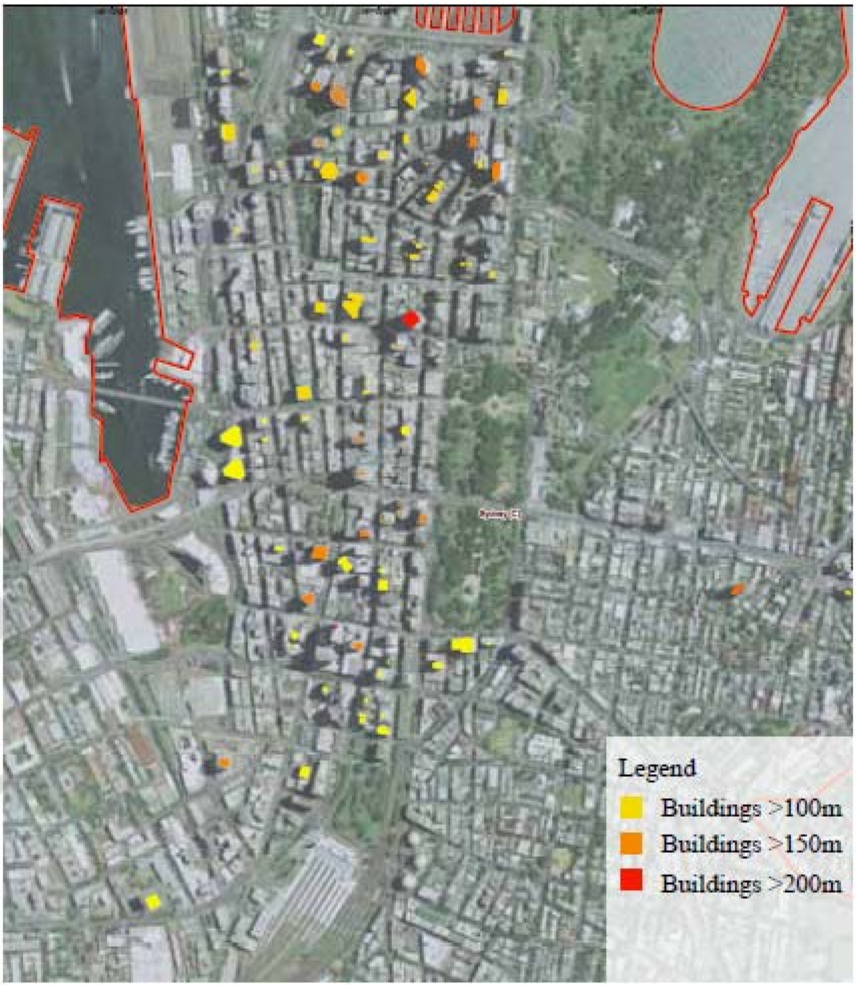

Figure 46 Building integrated wind results

The relatively small number of buildings results in a relatively small contribution of building integrated wind to the City's targets. However, for the tallest buildings (greater than 200m) building integrated wind is likely to significantly outperform solar photovoltaic in terms of cost of abatement.

8.1.4 Summary of Building Scale Results

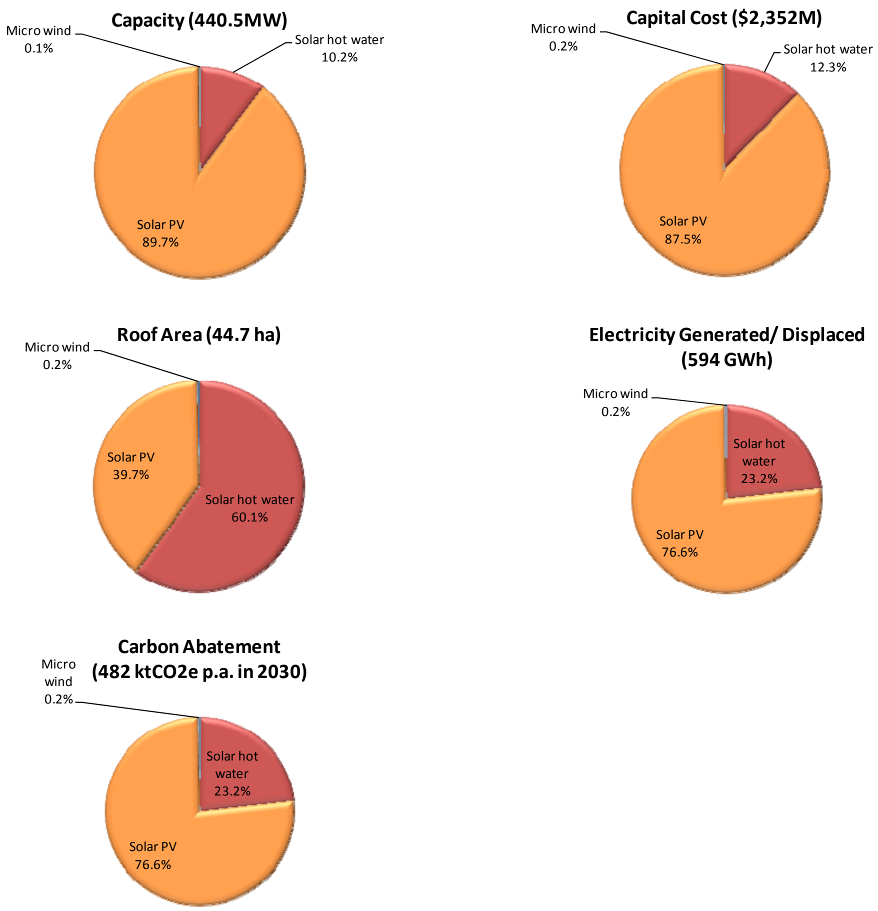

Figure 47 Summary of building integrated renewable technologies results

8.2 Renewable Power Plants Within the City

8.2.1 Concentrating Solar Thermal

CONCENTRATING SOLAR THERMAL

Total installed Capacity: 21MW

Total Land Area Required: 11.3 ha

Total Capital Cost: $87 Million

Cost of Carbon Abatement (no subsidies): -$7 per tCO_2e

Cost of Carbon Abatement (with subsidies): -$27 per tCO_2e

Additional capital subsidy required for cost neutrality: None (better than cost neutral even without subsidies)

Total renewable electricity generated/grid electricity displaced: 47GWh

% of 2030 BaU Electricity: 1.1%

Total carbon abated p.a. in 2030: 38 $ktCO_2e$

% reduction on 2006 carbon emissions: 0.6%

Concentrating solar thermal (CST) may have a significant role in generation within the City where suitable sites can be found. There are a number of locations within the City that theoretically may accommodate solar thermal technology. However, the majority of these are park land which is a valuable community resource, the loss of which would be subject to community debate. There are a number of roofs and industrial sites which may accommodate CST technology. The theoretically appropriate sites are shown in Figure 48 below.

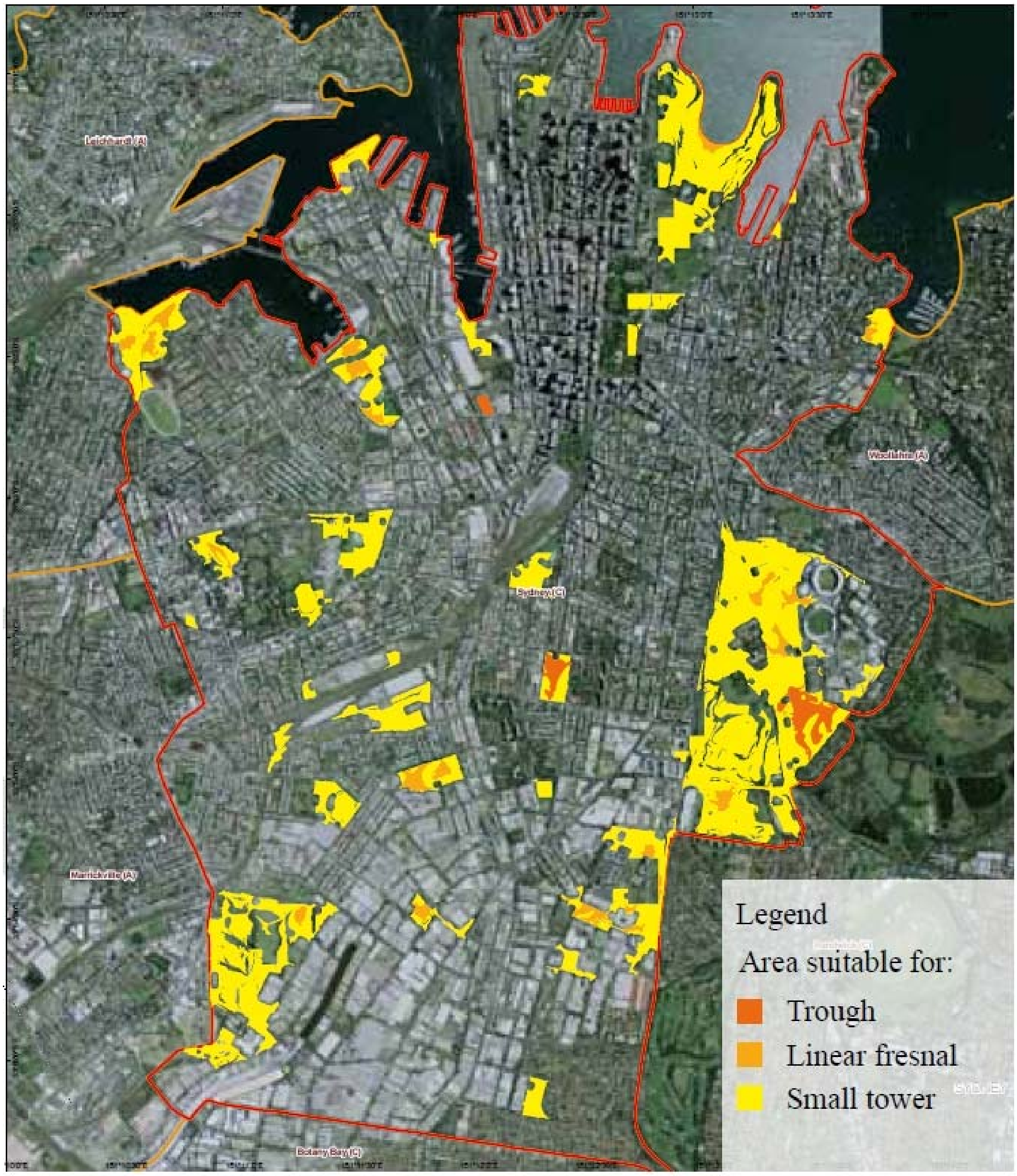

Figure 48 Sites potentially suitable for CST technology

The Master Plan has assumed that 5% of this land area will accommodate CST technology by 2030.

8.2.2 Large Scale Wind Turbines

LARGE SCALE WIND TURBINES

Total installed Capacity: 51MW

Total Land Area Required: 16.9 ha

Total Capital Cost: $186 Million

Cost of Carbon Abatement (no subsidies): $214 per tCO_2e

Cost of Carbon Abatement (with subsidies): $102 per tCO_2e

Additional capital subsidy required for cost neutrality: None (better than cost neutral even without subsidies)

Total renewable electricity generated/grid electricity displaced: 51 GWh

% of 2030 BaU Electricity: 1.2%

Total carbon abated p.a. in 2030: 41 $ktCO_2e$

% reduction on 2006 carbon emissions: 0.6%

Large scale wind turbines in the public domain provide an iconic statement that the City is moving towards a renewable energy future.

Planning costs are the major impediment to small wind farms with only a few turbines; this can be mitigated where the City of Sydney Council is the authority. If this occurs, the City has an opportunity to set an international precedent in urban wind farms. There are clearly some sites within the City which are more appropriate for wind turbines than others which would need to be explored in future stages. The Master Plan has assumed that each site shown below is adopted but that wind is generated at a reduced capacity factor in the more marginal locations to the south west.

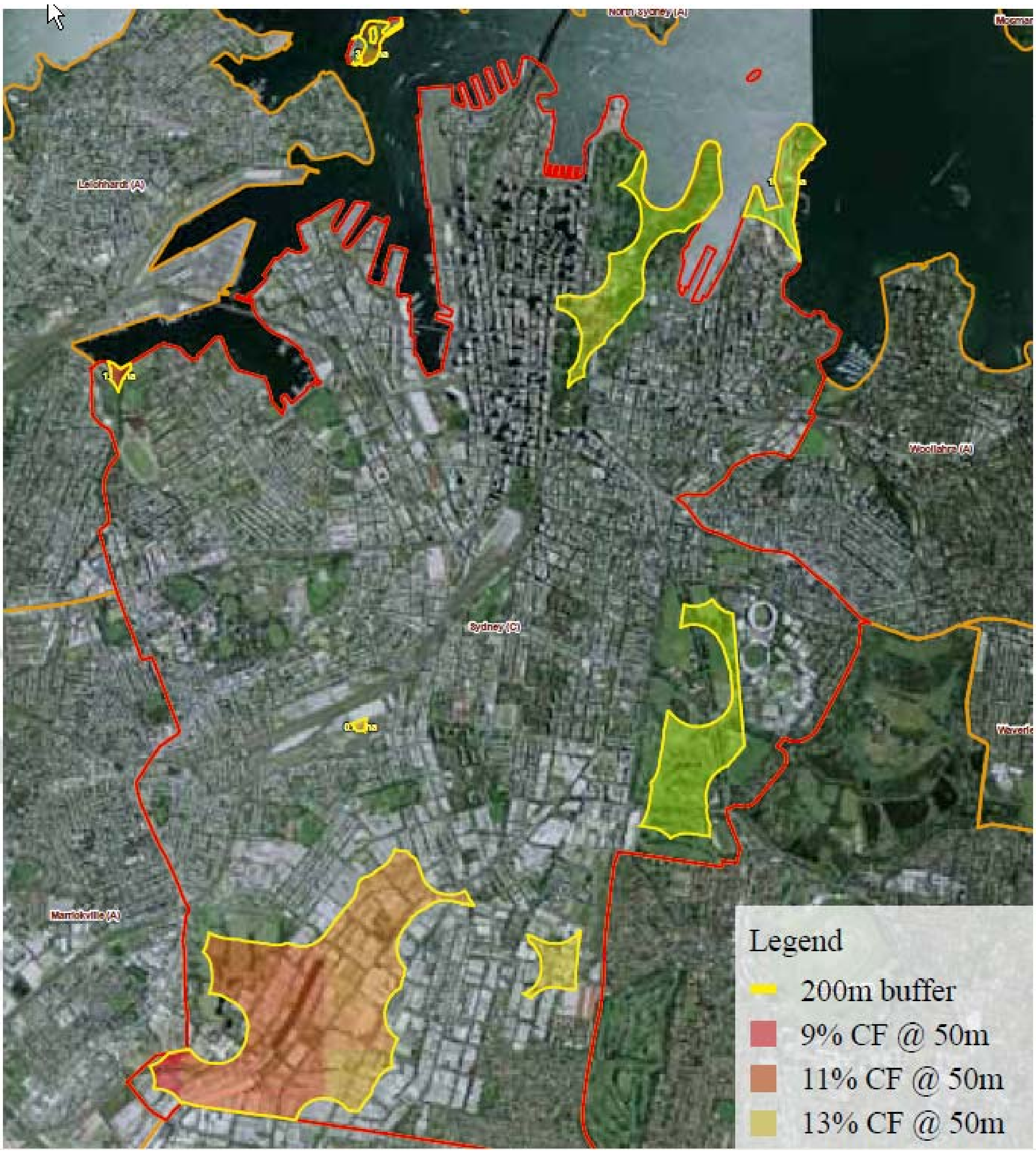

Figure 49 Sites potentially suitable for large wind turbines

8.2.3 Direct Use Geothermal

DIRECT USE GEOTHERMAL

Total installed Capacity: 4.9 MW

Total Land Area Required: 0.1 ha

Total Capital Cost: $17.9 Million

Cost of Carbon Abatement (no subsidies): $168 per tCO_2e

Cost of Carbon Abatement (with subsidies): $168 per tCO_2e (no subsidies currently available for geothermal technologies supplying thermal energy)

Additional capital subsidy required for cost neutrality: $12.9M

Total renewable electricity generated/grid electricity displaced: 10.7 GWh

% of 2030 BaU Electricity: 0.2%

Total carbon abated p.a. in 2030: 9 $ktCO_2e$

% reduction on 2006 carbon emissions: 0.13%

There is significant potential for direct use geothermal technologies to supply thermal energy for heating and cooling applications.

For large scale installations, Circulating Hot Water (CHW) systems may be employed to complement the decentralised energy network. CHW wells would be drilled to a depth of around 2km. At this depth the subsurface temperatures should be high enough to heat water to a temperature suitable for the Trigeneration Master Plan's decentralised energy network (98°C).

CHW is one potential future proofing technology that could replace natural gas fuelled heat in the decentralised energy network. Potential locations for CHW to feed into the low carbon zones distric heating networks are shown in Figure 50 below.

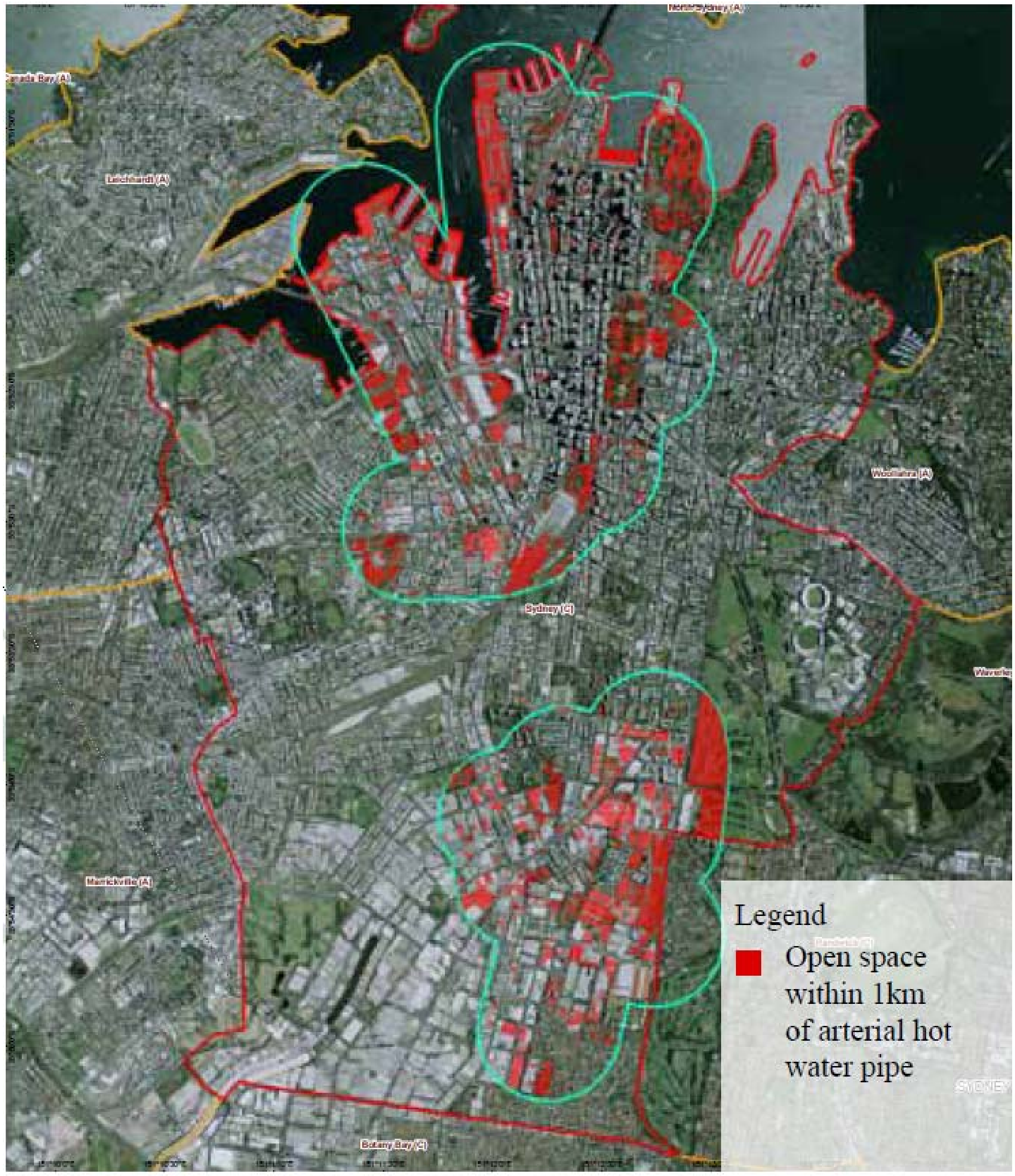

Figure 50 Sites potentially suitable for direct use geothermal

8.2.4 Summary of Renewable Power Plants within the City

A summary of the combined results for renewable power plants within the City is presented in Figure 51 below.

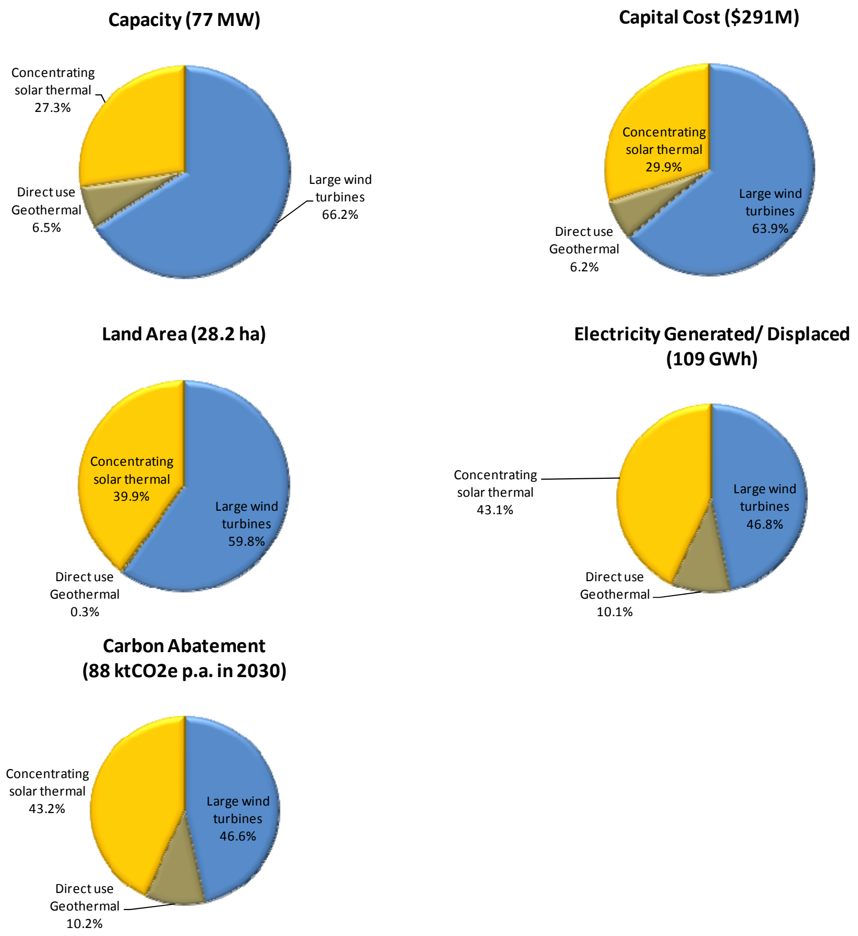

Figure 51 Summary of Renewable Power Plants within the City results

8.3 Renewable Power Plants Beyond the City

There are abundant resources within 250km of the city provide the additional 597 GWh shortfall required to meet the renewable energy target.

Renewable power plants located beyond the City can take advantage of improved resource conditions, reduced land values and land use conflicts to potentially achieve greater commercial returns than investments within the City. A summary of the available resource is presented below. This is based on information relating to:

- Approved plant locations;
- Locations where development application for plans have been lodged;
- Locations known to be currently under investigation by potential proponents; or
- Areas which have been identified as high potential sites based on independent or government funded studies.

Table 21 Summary of beyond the city resources

Parameter	Technology								
	Unit	Geothermal Electric	Wave	Tidal	Onshore Wind	Concentrating Solar Thermal	Hydro	Concentrating PV	Offshore Wind
Capacity required to supply 597 GWh	MW	110	270	120	220	29	110	210	180
Capital investment to supply 597 GWh	$M	$465	$1,702	$19,705	$472	$1,206	$257	$963	$861
Area required to supply 597 GWh	ha	3	6,000	11,576	886	732	1,607	101	2,244
Cost of generation	$ per MWh	$101	$265	$832	$91	$249	$64	$289	$147
Cost of abatement	$ per tCO_2e	$11	$195	$840	$-1	$145	$-17	$213	$63
Fraction current and future resource within 250km required to meet demand	%	18.2%	2.2%	60.9%	0.9%	0.4%	129.6%	0.4%	0.2%

Many of these sites lie within the 250km radius and are incorporated as part of the beyond the City analysis.

However, the 250km radius is set somewhat arbitrarily in an attempt to avoid the potential for requirements for large scale transmission infrastructure upgrades as a result of remotely located renewable power plants.

Notwithstanding, there are likely to be additional sites, located beyond 250km, which may also offer potential opportunities where existing or planned transmission infrastructure exists.

8.4 Renewable Fuel Feedstocks

8.4.1 Agricultural and forestry residues

AGRICULTURAL AND FORESTRY RESIDUES

Total Fuel Availability within City of Sydney LGA: 0TJ

Total Fuel Availability within Sydney Statistical District: 58 TJ

Total Fuel Availability within 250km: 5,125 TJ

% of City of Sydney Requirement within City of Sydney LGA: 0%

% of City of Sydney Requirement within Sydney SD: 0.2%

% of City of Sydney Requirements within 250km: 19.2%

Cost of Carbon Abatement when replacing natural gas in Trigeneration Master Plan (no subsidies): $349 per tCO_2e

Total carbon abated p.a. in 2030: 326 tCO_2e

% reduction on 2006 carbon emissions: 4.8%

There are significant volumes of agricultural and forestry resdiues which may be processed to provide a renewable feedstock for the Trigernation Master Plan sourced from locations as presented in Figure 52 below.

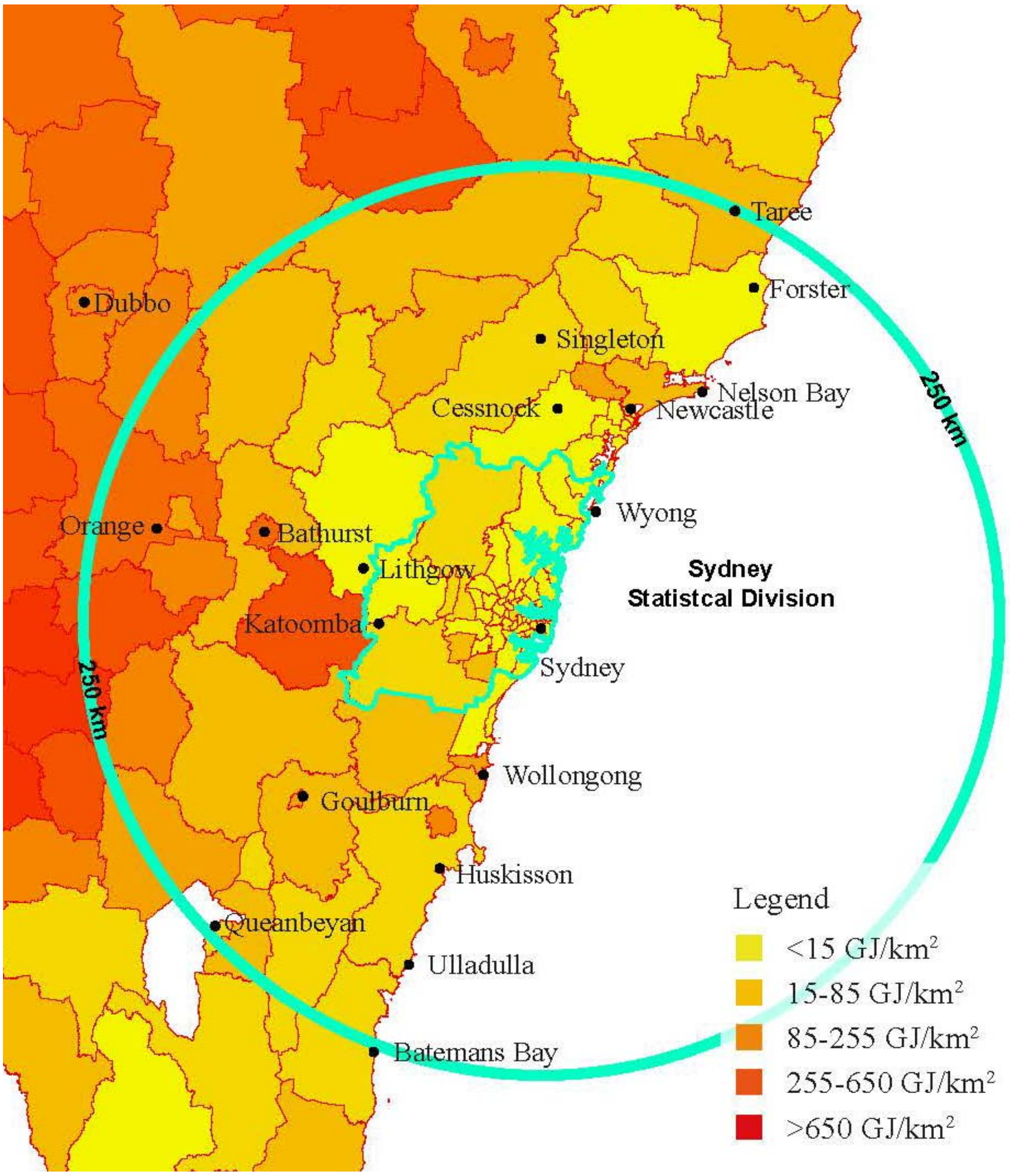

Figure 52 Sources of renewable fuels from agricultural and forestry residues

The agricultural and forestry sector is already collecting much of this waste and achieving economies of scale which should enable fuel conversion to be viable in the future thereby delivering considerable carbon abatement for this sector.

Switching from natural gas to renewable fuels derived from agricultural and forestry residue would be a high cost option in terms of abatement. Under the current and expected future economic circumstances other forms of renewable energy offer more cost effective carbon abatement opportunities for the City.

8.4.2 Existing Biofuels

EXISTING BIOFUELS

Total Fuel Availability within City of Sydney LGA: 0 TJ

Total Fuel Availability within Sydney Statistical District: 1,246 TJ

Total Fuel Availability within 250km: 2,976 TJ

% of City of Sydney Requirement within City of Sydney LGA: 0%

% of City of Sydney Requirement within Sydney SD: 4.66%

% of City of Sydney Requirements within 250km: 11.14%

Cost of Carbon Abatement when replacing natural gas in Trigeneration Master Plan (no subsidies): \$446 per tCO_2e

Total carbon abated p.a. in 2030: 142 $ktCO_2e$

% reduction on 2006 carbon emissions: 2.1%

Existing supplies of biofuels in NSW include ethanol from wheat processing waste, biodiesel from waste vegetable oil, biodiesel from virgin oil from energy crops, and landfill gas.

For the purposes of this study ethanol has been included under agricultural waste to avoid double counting.

Biodiesel from waste vegetable oil is available from a refinery on the central coast of NSW. Biodiesel from virgin oil from energy crops is excluded from the Renewable Energy Master Plan.

There are many existing landfill gas generators in NSW ranging from kW to multi MW scale. These fuels represent a small but important part of the renewable fuel feedstocks available to the City of Sydney. Existing biofuels, including both biodiesel and landfill gas, are already in use and require minimal additional infrastructure for their export to City of Sydney.

The vast majority of NSW's existing biofuels are within a 250km radius of the City of Sydney at single locations as shown in Figure 53 below.

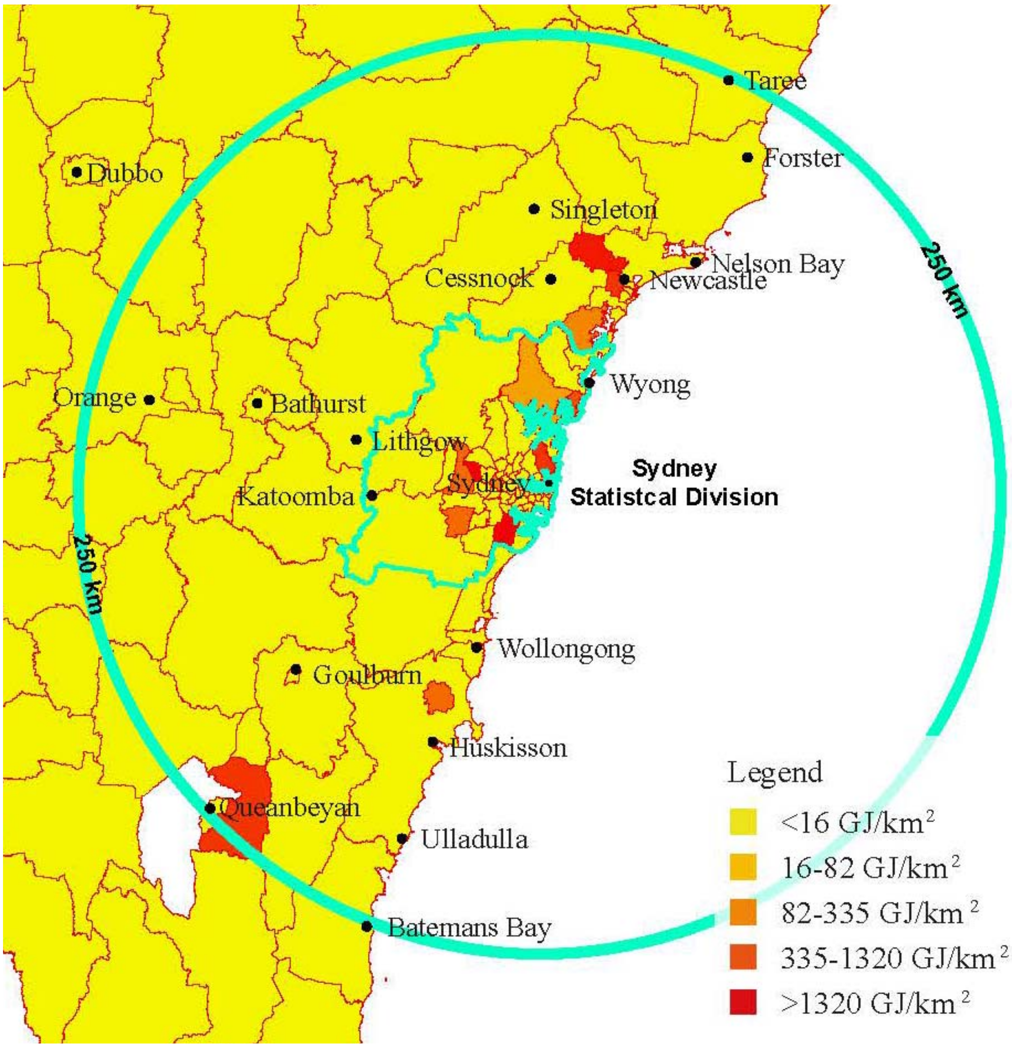

Figure 53 Sources of existing biofuels

The cost of purchasing these feedstocks is more certain than for other resources as both biodiesel and landfill gas follow commodity prices for diesel and wholesale eleectricity respectively. Although these biofuels do not represent as large a resource as other feedstocks, they are available now and would be suitable for the first trials of renewable fuel feedstocks in the Trigeneration systems.

8.4.3 Waste and Sewage

WASTE AND SEWAGE

Total Fuel Availability within City of Sydney LGA: 1,378 TJ

Total Fuel Availability within Sydney Statistical District: 7,960

Total Fuel Availability within 250km: 9,926 TJ

% of City of Sydney Requirement within City of Sydney LGA: 5.0%

% of City of Sydney Requirement within Sydney SD: 29.8%

% of City of Sydney Requirements within 250km: 37.2%

Cost of Carbon Abatement when replacing natural gas in Trigeneration Master Plan (no subsidies): \$476 per tCO_2e

Total carbon abated p.a. in 2030: 408 $ktCO_2e$

% reduction on 2006 carbon emissions: 6.0%

Waste and sewage represent a feedstock source that is already collected and treated. There is a clear trend within the waste and sewage industries towards the generation of energy and biofuels from this waste resource as an additional source of income for the sector as a result of rising costs of landfill. Resource locations are linked to population centres as shown in Figure 54 below.

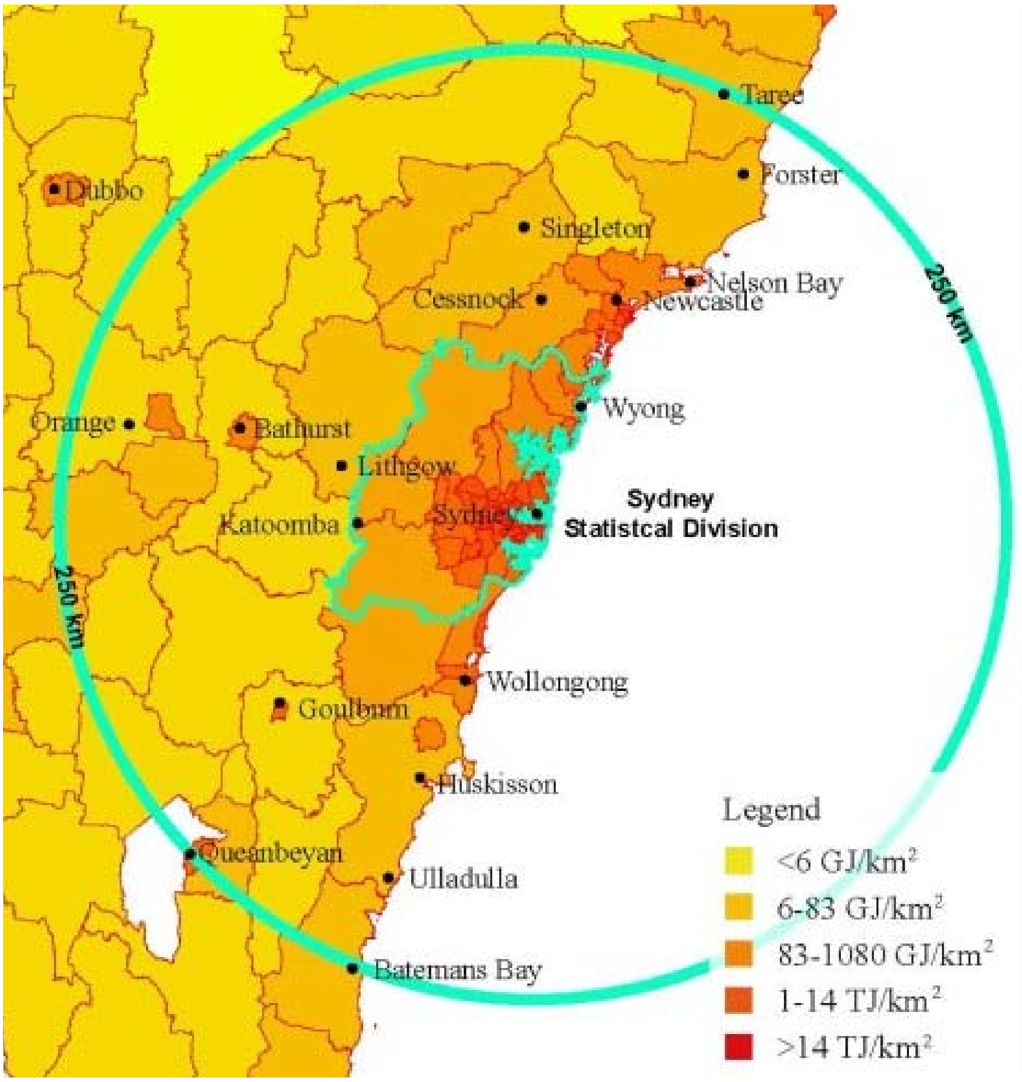

Figure 54 Sources of renewable fuels from waste and sewage

8.4.4 Horticultural waste and livestock manure

HORTICULTURAL WASTE AND LIVESTOCK MANURE

Total Fuel Availability within City of Sydney LGA: 0 TJ

Total Fuel Availability within Sydney Statistical District: 1,973

Total Fuel Availability within 250km: 7,503 TJ

% of City of Sydney Requirement within City of Sydney LGA: 0%

% of City of Sydney Requirement within Sydney SD: 7.4%

% of City of Sydney Requirements within 250km: 28.1 %

Cost of Carbon Abatement when replacing natural gas in Trigeneration Master Plan (no subsidies): $1,253 per tCO_2e

Total carbon abated p.a. in 2030: 217 $ktCO_2e$

% reduction on 2006 carbon emissions: 3.2%

Vegetable processing and manure wastes are generated at farm scale across NSW. Vegetable wastes are generally produced at greenhouses or farms with a large resource base associated with the horticultural industries in proximity to the City.

Livestock manure is already collected at many dairies and feedlots and treated through a number of methods, including anaerobic ponds and lagoons and anaerobic digestion producing a significant biogas resource which is currently not utilised.

Chickens, whether grown for meat or eggs, are farmed by increasingly intensive methods in NSW. The chicken manure produced at these farms is currently collected and disposed of in the way necessary for conversion to energy, but is mostly converted to compost.

The cost of abatement associated with vegetable processing and manure wastes is highest of all the feedstocks due mainly to the small scale and dispersed nature of their sources, compared to other fuels. However, there may be intensive farms closer to the City which could offer improved commercial viability.

Potential locations are shown in Figure 55 below.

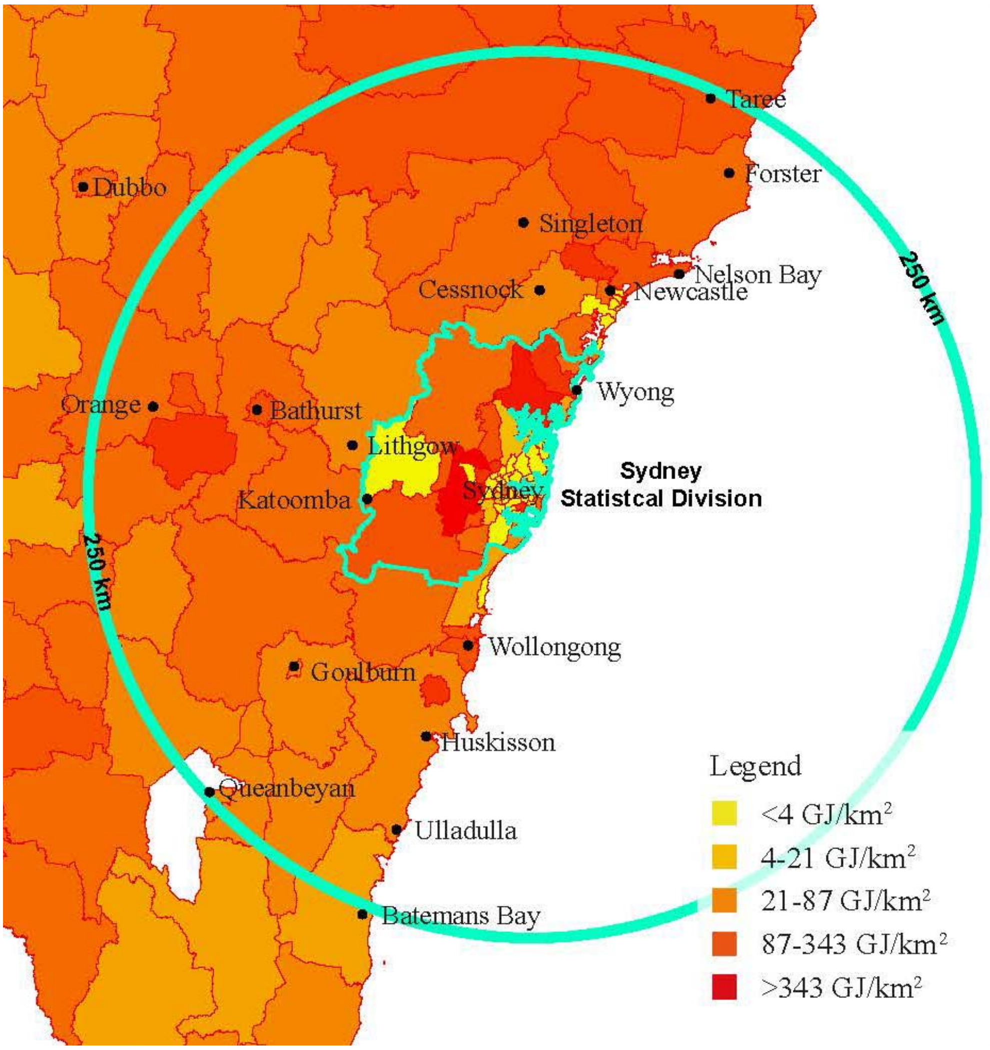

Figure 55 Sources of renewable fuels from vegetable waste and livestock manure

8.4.5 Summary of Renewable Fuel Feedstocks

A summary of the combined results for renewable fuel feedstocks is presented in Figure 57 below.

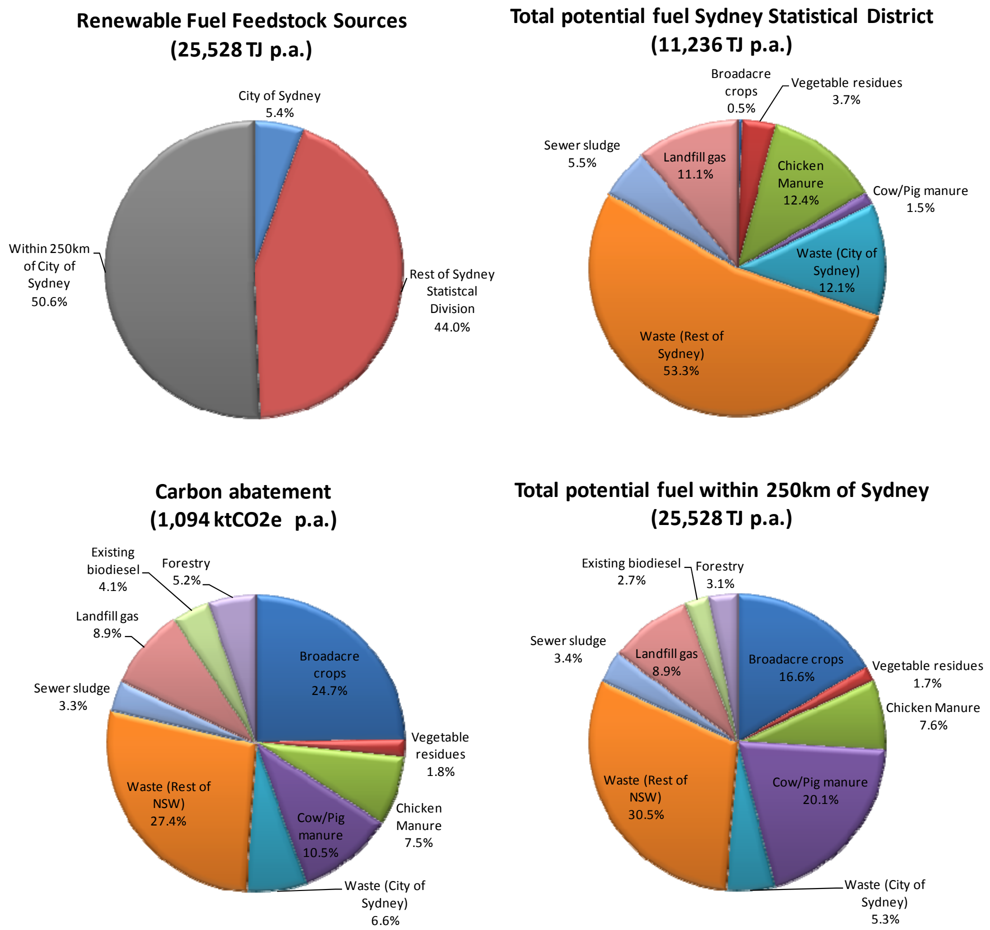

Figure 56 Summary of renewable fuel feedstocks results

8.5 Cost of Abatement Curve

Figure 57 below presents the cost of abatement curve for the City of Sydney Renewable Energy Master Plan. It shows that:

- The lowest cost of abatement comes from solar hot water replacing electric boilers in non residential and residential buildings.
- The largest abatement potential is from renewables beyond the City.
- Despite offering large levels of abatement, replacing natural gas with renewable fuel feedstocks has a larger cost than any of the key renewable energy technologies.

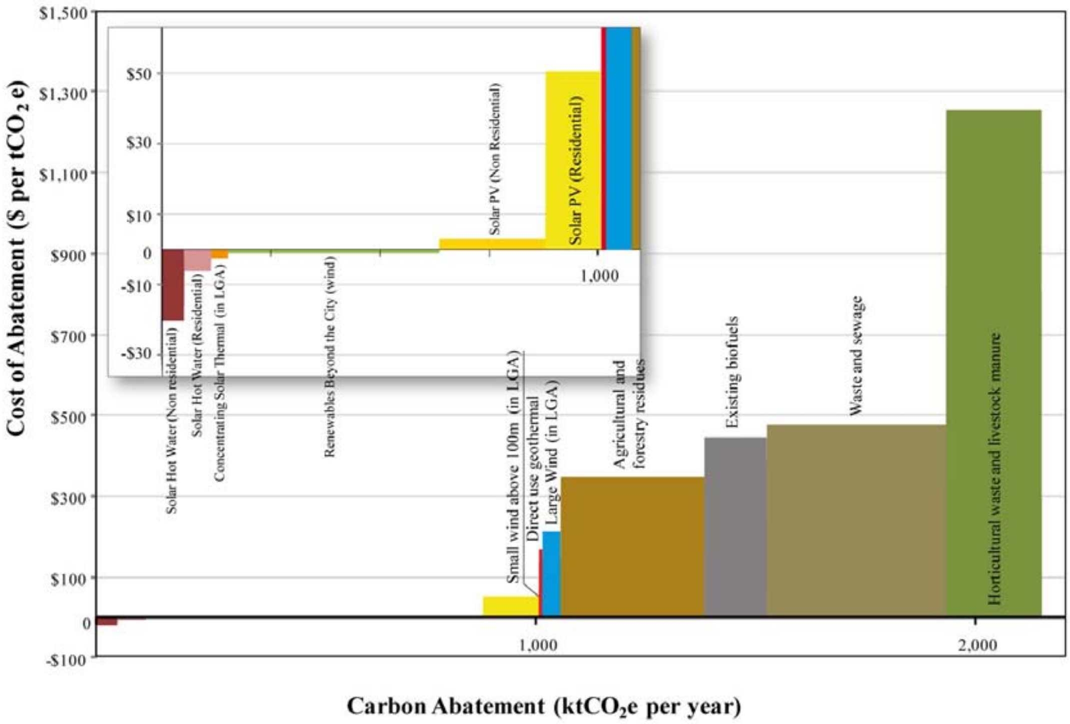

Figure 57 Cost of abatement curve

9 Summary

The Renewable Energy Master Plan shows that renewable energy technologies located within the City of Sydney are potentially able to supply up to 16% of the City's total 2030 electricity demand. This implies that in order to meet the City's 2030 target of 30% of electricity supplied by renewable energy, an additional 14% will need to be supplied by technologies beyond the City.

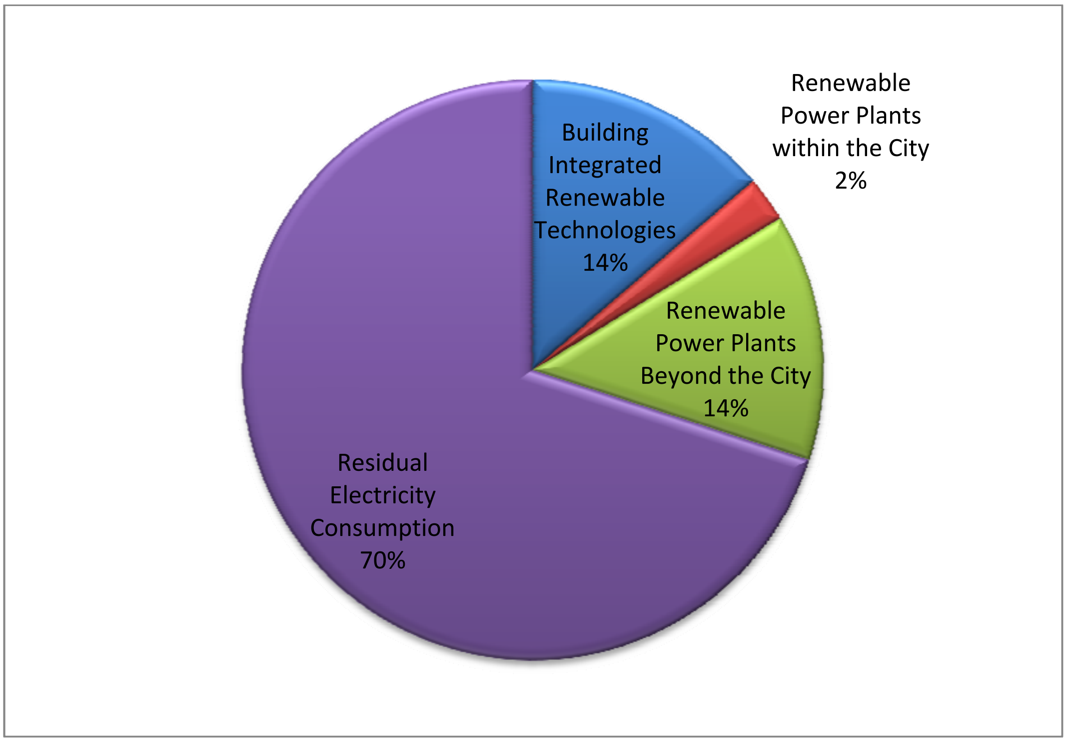

Figure 58 Renewable energy consumption under the Renewable Energy Master Plan

The renewable energy technologies within the City are also potentially able to abate a total of 570 ktCO_2e per year in 2030, representing 8.6% of the City's 2030 BaU carbon emissions. If an additional 598 GWh p.a. is sourced from technologies beyond the City, a further 486 ktCO_2e can be abated, representing a total abatement from renewable energy of 1,065 ktCO_2e p.a. in 2030, or 15.9% of the City's total 2030 BaU carbon emissions. A summary of these results is presented in Table 22 below.

Table 22 Summary of results

Technology		Capacity	Capital Cost	Electricity generated/ displaced	Renewable Fuel	Carbon abated	Reduction on 2006 levels	Cost of abatement
		MW	**\$2010 M**	**GWh p.a.**	**PJ p.a.**	**$ktCO_2e$ p.a. in 2030**	**%**	**\$ per tCO_2e**
Building Integrated Renewable Technologies	Solar hot water	62	\$289	138	NA	112	1.6%	-\$12
	Solar PV	395	\$2,059	455	NA	369	5.4%	\$19
	Micro wind	0.5	\$4	1	NA	1	0.01%	\$62
Renewable power plants (within the City)	Large wind turbines	51	\$186	51	NA	41	0.6%	\$214
	Direct use Geothermal	5	\$18	11	NA	9	0.1%	\$168
	Concentrating solar thermal	21	\$87	47	NA	38	0.6%	-\$7
Total (within the City)		**534**	**2643**	**703**	**NA**	**570**	**8.4%**	**\$28**
Beyond the City renewable power plants*		220	\$472	597	NA	486	7.1%	-\$1
Renewable fuel feedstocks within 250km	Agricultural and forestry residues	NA	NA	NA	5.1	326	4.8%	\$349
	Existing biofuels	NA	NA	NA	3.0	142	2.1%	\$446
	Waste and sewage	NA	NA	NA	9.9	408	6.0%	\$476
	Vegetable waste and livestock manure	NA	NA	NA	7.5	217	3.2%	\$1,253
Total		**754**	**\$3,115**	**1,300**	**25.5**	**2,150**	**31.5%**	**\$307**

* Assumes that all renewable energy beyond the City is sourced from onshore wind farms.

In addition, there is likely to be a renewable feedstock base within a 250km radius of the City to supply 26.7 PJ of renewable fuel. This fuel could be used to supply the proposed 360 MWe trigeneration system, generating an additional carbon abatement in the order of 1,100 $ktCO_2e$ in 2030. The cost of this abatement is greater than for other renewable energy technologies ranging between \$349 per tCO_2e and \$1,253 per tCO_2e abated. Alternatively, renewable energy power plants producing thermal energy within the City, including concentrating solar thermal and direct use geothermal may be able to replace natural gas fired trigeneration as a future proofing strategy towards 2030.

A summary of the contribution of renewable energy to the 2030 carbon abatement target (70% on 2006 levels or 74% on 2030 levels) is presented in below.

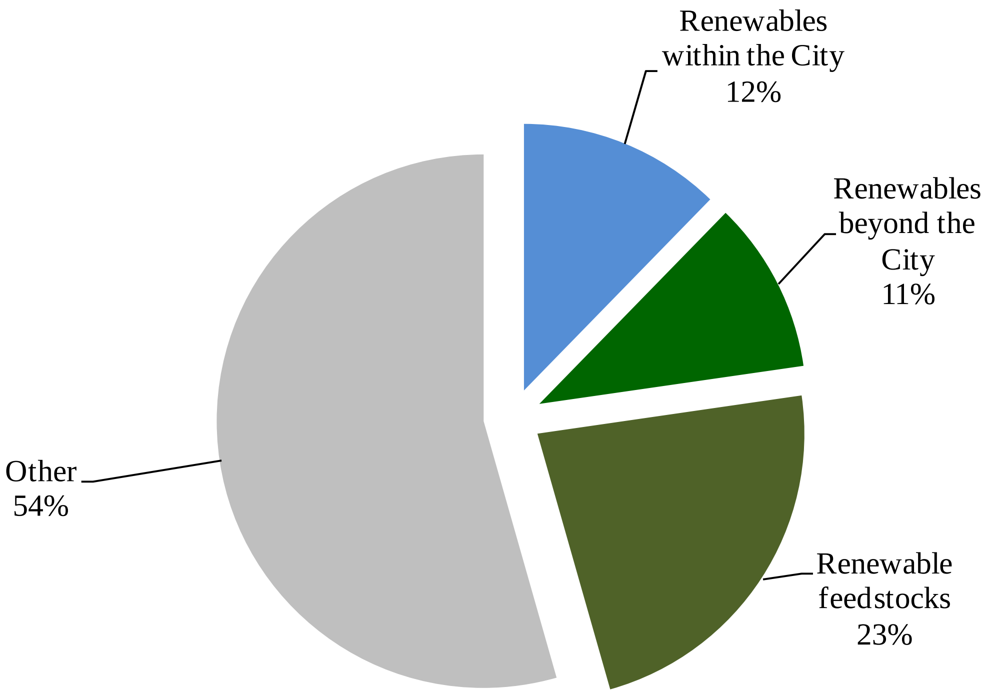

Figure 59 Summary of carbon abatement in 2030

The results highlight the importance of renewable energy technologies, particularly building integrated technologies within the city. While the cost of abatement for building integrated technologies is greater than for other technologies, particularly beyond the City, there are substantial subsidies currently available from both the NSW and Commonwealth Governments.

The subsidies effectively alleviate the City and its residents of a portion of the cost burden, implying that the cost of abatement to the City and its residents is likely to be less than for all other technologies.

Further, renewable energy technologies embedded within the distribution network offer additional benefits including:

- Potential reduction or delay in distribution infrastructure upgrades reducing further escalation in associated network charges passed on to consumers. This is especially true for solar technologies which will be operating at or near capacity during peak times.
- Educational and community awareness value with potential subsequent influence on demand management.
- Relatively few adverse environmental and health impacts as a result of reduced local air emissions and pollutants.

Of further significance is the ability of these technologies to be deployed immediately without the need for infrastructure upgrades or major disruptions to activity within the City.

The greatest abatement over the period to 2030 will occur for technologies which can be installed in the near to immediate future. These technologies will offset grid electricity at current emission intensities currently dominated by fossil fuel technologies which are likely to be phased out by market forces into the future.

Beyond the City, there is abundant resource available to establish cost competitive renewable energy power plants. The wind resource in NSW alone is sufficient to supply 100% of the City's electricity demands at an indicative cost of abatement of -$1 per tCO_2e (without subsidies).

In this respect, the 30% renewable energy target for the City is relatively arbitrary. Studies emerging from around the world, and more recently in Australia, are suggesting that a 100% renewable energy target is feasible for the entire economy by 2020.

To meet its carbon and renewable energy targets the City must identify appropriate mechanisms to enable its community to respond to the Renewable Energy Master Plan as soon as possible. Potential mechanisms may include:

- Planning requirements to ensure that all new development is consistent with the Master Plan in incorporation of building integrated renewable technologies.
- Measures to reduce costs of retrofitting building integrated technologies to existing buildings, including direct subsidies, mass installations or central coordination.
- Consideration of financial mechanisms to encourage renewable power plant proponents into the City which may include:
    - Direct co-investment;
    - Reduced land costs (where sites are owned by the City);
    - Fast tracking of planning approvals where appropriate.
- Setting an example for the community through measures such as the City's $12m renewable energy fund or through the identification of significant building integrated projects.

In addition, there are a number of feasibility studies or further investigations which will need to occur before any one technology or site is selected. In particular, a feasibility study to identify and refine potential sites for large wind turbines and concentrating solar thermal plants within the City should be undertaken to determine the extent to which these technologies may contribute to the target.

A strategy for investment in renewable energy power plants beyond the City will also need to be developed. This strategy should develop criteria against which to evaluate projects and study of potential mechanisms for the City to claim the energy (e.g. power purchase agreement, ESCO, direct investment). This strategy could also include the identification of mechanisms for other businesses and residents within the City to contribute.

The analysis of renewable fuel feedstocks provides an indication of the likely available resource in 2030 within 250km of the City to replace natural gas under the Trigeneration Master Plan.

While biomass has an important role to play in any renewable energy future, the assumption that the City will be able to acquire 100% of these fuels to service the Trigeneration system will need to be reviewed in further stages of the Trigeneration Master Plan, particularly in the context of the competing market for transport fuels from the same resource.

In the first instances this could include:

- Consultation with existing cogeneration plant operators in NSW using biogas (including sewage treatment plants, landfill gas plants and existing biofuel suppliers) to understand the likely commercial barriers of redirecting this resource base to the City.
- Progressing the business case for an alternative waste treatment facility for the City's own waste to provide further experience into the technological and commercial considerations of collection, conversion and transportation of renewable fuel feedstocks
- Feasibility study into the transportation mechanisms for renewable fuels from the conversion plant to the City, especially if syngas transportation is proposed.

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Appendix A

Technology Factsheets

Solar Photovoltaic (PV)

Solar Photovoltaic cells are made of a semi-conductor material, such as crystalline silicon, which is stimulated by photons from sunlight to generate an electrical current.

At a utility scale, plants can be either fixed in orientation, have 1 axis tracking or 2 axis tracking.

Queen Victoria Markets
Location: Melbourne
Date of completion: 2003
Size: 200kW
Annual generation: 252MWh per year
Source: Melbourne City Council

Weinbourg Farm Solar Project
Location: Weinbourg, France
Date of completion: 2009
Size: 4.5MW
Annual generation: 4.5GWh per year.
Source: Suntech Power

Supply chain and maturity

Current level of market penetration:	In 2008 there were 82MW of installed capacity in Australia[1] growing at roughly 10MW per annum. This has accelerated in recent years with feed in tarrifs in most states.
Current Technology suppliers/ developers:	Suntech Power, First Solar, BP Solar, Kyocera and Silex solar all make panels and/or cells. Local installers include Eco-kinetics, Ingenero, Conergy.
Future of market to 2030:	Manufacturers are increasing production quantities and are expecting to do so for the foreseeable future. The Commonwealth Government's Solar Flagship Program plans to have built 400 MW of PV capacity (either PV or CPV) in Australia within in the next 10 years

Economic feasibility

Capital cost ranges ($/W):	$5.5 - $7/W depending on the scale [3]. Panels typically make up 50% of the cost, 20 % for balance of system and 30% for design and installation.
Future cost projections:	Expected to decrease over the short to medium term to as low as $1/W before installation. Conservative estimates are for prices to drop as low as $4/W installed.
Annual operational and maintenance costs:	US$19/kW p.a. for large scale power stations. Primarily for labour and water usage [4]. Inverter technology typically lasts 10 to 15 years so will need to be replaced over the life of the project.
Government subsidies available:	Renewable Energy Certificates. If ownership is broken into 10kW segments PV systems could be eligible for NSW FiT.

Benefits and constraints

Regulatory:	Planning approval would be from NSW Government under Part 3A of the EP&A Act for all large scale generation with capex greater than $30 million or $5 million for State significant sites [5].
Social:	Solar energy is widely accepted and acknowledged by the public as a viabile renewable energy generation technology [6].
Environmental:	Some PV module technologies (i.e. cadmium telluride) contain potentially hazardous materials which raised issues about end of life disposal of panels and any manufacturing waste.
Commercial:	The investment is heavily geared to upfront costs, making projections of future electricity prices very important and increasing overall financial risk.

Technical performance

Resource:	Solar (Global Horizontal Irradiance (GHI))
Energy end use:	Electrical
Electrical Efficiency:	Up to 19.2% for the latest mono crystalline cells (Suntech). 10.8% for CdTe thin film technology (First Solar).
Functional life (years):	30 years (guaranteed for 25)
Capacity factor:	15.3% fixed without cleaning, 16.3% if fixed, 19.6% if one axis tracking, 20.2% if two axis tracking (assuming a 16% derate factor for inverter, wiring, soiling and age etc) [2]
Factors affecting efficiency:	Age of technology (typically 1% reduction per year), shading, soiling, temperature, orientation

Site requirements

Typical suitable sites:	Large sites with little shading. Topography needs to be reasonably flat, however not as much as with CST. North facing slopes are generally preferred.
Resource thresholds:	No thresholds identified, PVs will operate in almost all conditions.
Land use (kWp/ m2):	7.3m2 /kWp (0.137kWp/m²) for the latest mono crystalline modules. Ground cover is up to 90% so the gross land use is 8.13 m2 /kWp (0.123kWp/m²). With tracking systems this can be as low as 25m²/ kWp (0.04kWp/m²) because of the buffer distances required so that panels do not shade each other.
Indicative resource the City of Sydney:	18 Mj/m²/day Global Horizontal Irradiance [7]
Indicative resource in NSW:	22 Mj/m²/day Global Horizontal Irradiance[7]

Summary figures [8]

Parameter	Low	Median	High
Annual generation by land use (kWh/m2):	65.24	160.64	165.24
Long Running Marginal Cost ($/MWh):	$383	$466	$532
Cost of carbon abatement ($/tCO2e):	$312	$404	$477

1. IEA, 2008, Trends in Photovoltaic Applications: Survey Report of Selected IEA countries between 1992 and 2007
2. Capacity factors modelled by PVWATTS v1 available at http://rredc.nrel.gov/solar/codes_algs/PVWATTS/version1/
3. Low based on NREL (footnote 4) and feasibility study of 10MW single axis tracking thin film PV. High cost based on Australian installations to date.
4. Based on average of 6 studies as reviewed by NREL (http://www.nrel.gov/analysis/docs/re_costs_20090806.xls)
5. Includes Sydney Opera House, Redfern Waterloo Authority Sites and Barangaroo site
6. CSIRO, 2009, Perceptions of Low Emission Energy Technologies, Energy Transformed Flagship CSIRO
7. Based on resource mapping published by the South Australian Government available at http://sustainableliving.sa.gov.au/RenewablesSA/solar.htm
8. Figures based on two brands of fixed mono crystalline panels and single axis tracking CdTe thin film panels. One brand of mono crystalline was assumed to be dirty (reduced efficiency) while others were expected to be cleaned (additional operational costs). Figures are based on multi MW installations.

Concentrated PV (CPV)

Heliostats or lens' are used to concentrate solar radiation onto a high efficiency PV module. Concentrated PV tends to cost considerably more than conventional PVs. While PV technology utilizes GHI, concentrating technologies can only convert DNI or direct sunlight in layman terms.

CPV has achieved efficiencies above 30% with new technology developed at UNSW achieving over 40% efficiencies in lab testing.

Hermannsburg, Yiendumu and Lajamanu
Location: 960km South of Darwin
Date of completion: 2006
Size: 720kWp
Capital cost: $7m
Source: Clean Energy Council

Parques Solares De Navarra
Location: Spain
Date of completion: 2008
Size: 7.8MW
Source: Amonix

Supply chain and maturity

Current level of market penetration:	Under 2MWp installed in Australia. However a 150MW plant was planned for Mildura. Internationally the technology is more established.
Current Technology suppliers/ developers:	Amonix, Energy innovations, Solar Systems (now owned by Silex Solar), Green and Gold Energy, SolFocus
Future of market to 2030:	CPV is expected to grow substantially as reflector technology and PV cells reduce in cost. Focus is expected to be on areas with high resource potential. The Commonwealth Government's Solar Flagship Program plans to have built 500 MW of capacity (either PV or CPV) in Australia within in the next 10 years

Economic feasibility

Capital cost ranges ($/W):	$6 (Sol Focus) to $10/W (Solar Systems) for installed systems. $5/W (Green and Gold) claimed by some semi commercialised suppliers. As DNI Resource is lower in Sydney than in example conditions allow for a 30% increase in costs to allow for larger installation.
Future cost projections:	Expected to be 40% of current price by 2016 [1]. Sol Focus targeting $2/W at full production
Annual operational and maintenance costs:	Lens' and mirrors require washing and tracking systems have maintenance requirements. Allow $30/kW p.a.
Government subsidies available:	Renewable Energy Certificates.

Benefits and constraints

Regulatory:	Planning approval would be from NSW Government under Part 3A of the EP&A Act for all large scale generation with capex greater than $30 million or $5 million for State significant sites [3]
Social:	Potential planning constraints with respect to visual impacts of reflected light.
Environmental:	Although the land underneath CPV systems can be used for other purposes, it will need to be fenced off to deter vandalism.
Commercial:	The individual PV cells can be replaced several times over within the life of the structural equipment One of the only Australian suppliers has become insolvent in the past 12 months. International suppliers have limited manufacturing capacity and appear to be concentrating on areas with high feed-in tariffs.

Technical performance

Resource:	Solar (Direct Normal Irradiance (DNI))
Energy end use:	Electrical
Electrical Efficiency:	25% - 29% in proven practice. Up to 45% in lab testing.
Functional life (years):	25 to 40 years (depending on whether the PV cell is replaceable)
Capacity factor:	Up to 26% depending on tracking system.
Factors affecting efficiency:	Shading, cloud cover, tracking effectiveness, temperature, aging of PV cells (0.5% per year).

Site requirements

Typical suitable sites:	Open spaces with little chance of shading. Not necessarily flat however structural requirements make existing roof installations unsuitable.
Resource thresholds:	Standard industry threshold of 21Mj/m²/day DNI will not be met within Sydney
Land use (kWp/ m2):	As low as 6.25 m2 /kWp (0.16 kWp/m2) for the CPV modules themselves. However ground coverage is only 50% or lower so land take can be between 12 and 20 m2 /kWp (0.049 and 0.079 kWp/ m2)
Indicative resource the City of Sydney:	15 Mj/m²/day Direct Normal Irradiance [2].
Indicative resource in NSW:	Up to 27Mj/m²/day Direct Normal Irradiance in north west NSW.

Summary figures [4]

Parameter	Low	Median	High
Annual generation by land use (kWh/m2):	86.55	110.44	159.17
Long Running Marginal Cost ($/MWh):	$411	$423	$724
Cost of carbon abatement ($/tCO2e):	$343	$356	$689

1. http://www.energy.gov/media/SAI_Team_Fact_Sheets.pdf
2. Wyld Consulting et al, 2008, High Temperature Solar Thermal Roadmap, NSW and Victorian Governments
3. Includes Sydney Opera House, Redfern Waterloo Authority Sites and Barangaroo site
4. Cost and capacity factor figures are based on existing installations by Solar Systems and Sol focus as well as MMA, 2009, "Benefits and costs of the Expanded Renewable Energy Target". Figures were inflated by 30% to allow for the reduced DNI resource available in Sydney that would lead to a derating of the CPV system (i.e. assuming 1kW in Broken Hill is only worth 700W in Sydney). Land density is based on the different systems available.

Concentrated Solar Thermal (CST)

There are several major types of CST including Compact Linear Fresnal Reflectors (CLFR), Parabolic dish, Solar Towers and Solar Dish; all use mirrors to focus sunlight.

Temperatures range from 150° C to over 1000° C. Most technologies either drive steam turbines, sterling engine, organic rankine turbines or a combination of the above to generate electricity and heat.

Liddell Power Station
Location: Central Coast NSW
Date of completion: 2008
Size: 9MWth (1.5MWe equivalent)
Annual generation: 4.4GWh
Source: Macquarie Generation

Andasol 1 and 2
Location: Spain
Date of completion:
Size: 50MW each
Annual generation: 180GWh
Source: Solar Millenium

Supply chain and maturity

Current level of market penetration:	Although there are several large projects planned, there is less that 10MWth in Australia. Internationally there are several large scale plants operating in Spain and the United States.
Current Technology suppliers/ developers:	Ausra (Avera), CSIRO, Abengoa, Bright Source, Acciona, Cobra, Stirling Energy Systems are all technology developers and / or operators.
Future of market to 2030:	The Commonwealth Government's Solar Flagship Program plans to have built 500 MW of solar thermal capacity in Australia within in the next 10 years.

Economic feasibility

Capital cost ranges ($/W):	$4 (Kimberlina)-$7.6/W (Andasol 1). Thermal storage currently around 20% premium. As DNI Resource is lower in Sydney than existing plants an allowance for a 30% increase in costs to allow for larger reflector installations.
Future cost projections:	Prices are expected to drop below $3/W by 2015 largely due to mass production of components.
Annual operational and maintenance costs:	According to NREL $54-$65/kW p.a. primarily for labour costs and maintenance to the electricity generation equipment. Other sources assume $10/ MWh.
Government subsidies available:	Renewable energy certificates

Benefits and constraints

Regulatory:	Planning approval would be from NSW Government under Part 3A of the EP&A Act for all large scale generation with capex greater than $30 million or $5 million for State significant sites.[1] Potential planning constraints with respect to visual impacts of reflected light.
Social:	Many technologies require similar components to conventional boilder systems meaning local manufacturing is possible.
Environmental:	Some technologies use hazardous materials as coolant or heating fluid.
Commercial:	Many solar thermal technologies use standard parts that could provide benefits to local manufacturers and employment

Technical performance

Resource:	Direct Normal Irradiance (DNI)
Energy end use:	Electrical and thermal (heating)
Electrical Efficiency:	15% (CLFR) to 25% (Solar Dish) sunlight to electricity over a year based on collector area. 1.1% (Large solar tower) to 4.7% (CLFR) based on solar resource for the total land area of the plant which includes buffer area, generation set, supporting infrastructure etc.
Thermal efficiency:	Useable heat varies on electricity generation technology. If utilising a rankine cycle alone the useful heat would be 61% of energy captured (slightly less if steam turbine).
Functional life (years):	25 to 30 years
Capacity factor:	18% (CLFR) -38% (Solar dish) without storage. Theoretically >75% with storage.
Factors affecting efficiency:	Shading, cloud cover, tracking effectiveness, electricity conversion technology.

Site requirements

Typical suitable sites:	Open, flat areas with little chance of shading. A 1MWe plant would typically require a hectare of space.
Resource thresholds:	Area of at least 740m2 will full solar access. Standard industry threshold of 21Mj/day DNI will not be met within Sydney.
Land use (kWp/ m2):	7.4 m2/kWp (0.135 kWp/m2) (CLFR) to 55 m2/ kWp (0.018 kWp/m2) (Large Solar Tower) for collector area. This is highly dependent on ground coverage. Two axis tracking systems require the larger gaps between reflectors; for solar tower technology the taller the tower the larger the gap between reflectors
Indicative resource the City of Sydney:	15 Mj/m2 /day Direct Normal Irradiance
Indicative resource in NSW:	Up to 27Mj/m2 /day Direct Normal Irradiance in north east NSW

Summary figures [2]

Parameter	Low	Median	High
Annual electrical generation by land use (kWhe/m2):	61.20	101.35	178.30
Long Running Marginal Cost ($/MWh):	$285	$377	$425
Cost of carbon abatement ($/tCO2e):	$34	$68	$82

1. Includes Sydney Opera House, Redfern Waterloo Authority Sites and Barangaroo site
2. Cost, land take and capacity figures based on Kimberlina, Andasol 1 and Nevada Solar 1 as well as a review of several studies by NREL (http://www.nrel.gov/analysis/docs/re_costs_20090806.xls). Capital costs have been inflated by 30% to allow for the larger collector area required for generation due to the lower DNI resource in Sydney.

Onshore wind

Large blades utilise the force from wind to power a generator. A series of mechanisms ensure that the turbines turn to face the wind direction. Although wind speeds are intermittent new battery technology may be able to even out spikes and troughs in power output.

Horizontal Axis Wind Turbines ranging from 100kW up to 5MW are typically placed along ridgelines where wind speeds are greatest.

Hampton Wind Park
Location: 115km west of Sydney
Date of completion: 2001
Size: 1.3MW generating approximately 3 GWh p.a.
Capital cost: $2.5m
Source: Clean Energy Council

McGlynn Elementary School
Location: Massechusetts, U.S
Date of completion: 2009
Size: 100KW
Capital cost: US$644,000 inc installation
Source: Northern Power Systems

Supply chain and maturity

Current level of market penetration:	Over 2750MW of wind in advanced planning in NSW.
Current Technology suppliers/ developers:	Vestas, Suzlon, GE, RE Power are big turbine suppliers. Nothern Power Systems, Windflow and Solwind supply medium scale turbines. Infigen, Pacific Hydro, Acciona, Epuron, and AGL are developers or operators active in Australia
Future of market to 2030:	Expected to grow in Australia over the next decade after which growth will taper off as the grid reaches its capacity to cope with intermittant wind power.

Economic feasibility

Capital cost ranges ($/W):	$1.9-$2.2/W for large wind farms. This can be 1.5 to 2 times more expensive for small installations with only one or two turbines. Assumed to be 1.5 times more expensive for sites within LGA.
Future cost projections:	Steel price fluctuations are expected to put upward pressure on prices, counteracting saving from generator efficiency increases. Local manufacturing may decrease transportation costs in the medium term as large wind farms are built in NSW.
Operational and maintenance costs:	There are several published figures [2] from $35/kW and $2/MWh, $55/kW and $1/MWh, $47/kW and $0/MWh. Industry rule of thumb is 1% of capital cost per year.
Government subsidies:	Renewable Energy Certificates.

Benefits and constraints

Regulatory:	Intermittent power generation means there is a limit to the amount of wind power in any individual region of the grid. Assumptions are that any one region of the electricity grid can cope with up to 40% wind power. Planning approval would be from NSW Government under Part 3A of the EP&A Act for all large scale generation with capex greater than $30 million or $5 million for State significant sites. [4] Under NSW Industrial Noise Policy, large scale wind turbines are unlikely (1MW +) to be allowed within the LGA.
Social:	Sound levels can disturb sensitive receivers. Indicative noise constraints suggest a minimum buffer distance of around 200m is required from residential areas, up to 500m for very large turbines. The flicker effect of the shadows caused by the turbine blades is also a potential issue.
Environmental:	There are some concerns about birds flying into turbines, though these are largely unsupported by experience in Australia.
Commercial:	Currently all medium sized wind turbine manufacturers are overseas. Shipping turbines from international sites would be very expensive.

Technical performance

Resource:	Wind
Energy end use:	Electrical
Functional life (years):	20 to 25 years
Capacity factor:	25%-40% in good sites. Indicative analysis on Sydney 16% to 18% [1]. Sites near the harbour typically have higher wind speeds, with the harbour areas east of the city higher than the west.
Factors affecting efficiency:	Rough ground surface, tall buildings / vegetation that block wind or cause turbulence, distance to demand location that increases transmission losses.

Site requirements

Typical suitable sites:	Sites along ridgelines that are relatively clear of buildings and tall vegetation and at least 200m (100kW) to 500m (1MW) away from sensitive receivers.
Resource thresholds:	Cut-in speed (the speed where turbines begin to generate electricity) is typically around 3.5 to 4 m/s. This results in a general rule of thumb that annual average wind speeds of 8m/s. This would rule out most locations in Sydney if lower wind speeds cannot be compensated by transmission distances.
Land use (kWp/m2):	General spacing is that a turbine mast to mast distance should be greater than 5 x the rotor diameter. Analysis of current commercially available turbines [3] gives a range of between 40 m2 /kWp (0.025 kWp/m2) and 56 m2 /kWp (0.018 kWp/m2) . However it should be noted that the income can still be generated from land use around the turbine.
Indicative resource the City of Sydney:	Annual average wind speeds under 6m/s at 10m above ground surface. This is likely to be higher and lower in specific locations due to surrounding land use and ground roughness.
Indicative resource in NSW:	Annual average wind speeds up to 10 m/s in numerous locations. DECCW has highlighted 6 regions within NSW with good wind resources (this does not include Sydney) [5].

Summary figures [6]

Parameter	Low	Median	High
Annual generation by land use (kWh/m2):	28.38	33.11	37.23
Long Running Marginal Cost ($/MWh):	$305	$331	$340
Cost of carbon abatement ($/tCO2e):	$238	$267	$277

1. Figures based on a wind assessment conducted by Aerogenesis at Jubilee Park , analysis of wind speeds at Fort Dennison and outputs from The Air Pollution Model (TAPM) developed by the CSIRO.
2. From MMA, 2008, Frontier Economics 2009, NREL (http://www.nrel.gov/analysis/docs/re_costs_20090806.xls)
3. Based on a Northern Power 100kW turbine and a Vestas 2MW turbine
4. Includes Sydney Opera House, Redfern Waterloo Authority Sites and Barangaroo site
5. http://www.environment.nsw.gov.au/images/climatechange/WindPrecinctsMap.jpg
6. Onshore figures based on the wind farm at Yambuc, figures in NREL review of several studies (http://www.nrel.gov/analysis/docs/re_costs_20090806.xls) , MMA, 2009 ("Benefits and costs of the Expanded Renewable Energy Target"), and ACIL Tasman, 2008 ("Projected energy prices in selected world regions"). Prices are expected to be 250% of those figures supplied by the different sources to allow for increased cost per MW for small installations of one turbine at a time.

Off shore wind

Offshore wind involves anchoring wind turbines in the ocean. Established anchoring methods involves building seabed foundation. Newer techniques that are yet to be commercialised involve floating the turbine and anchoring several stay cables which hold the turbine mast in place.

As a general rule of thumb the deeper the water the more expensive the project, as the actual installation and foundations for the turbines represent a significant proportion of initial investment.

Scroby Sands
Location: Chatterton, UK
Date of completion: 2004
Size: 60MW generating 171GWh p.a.
Capital cost: £71m
Source: Deutsche WindGuard GMBH et al [1]

Horns Rev
Location: West coast, Denmark
Date of completion: 2004
Size:160MW generating 600GWh p.a.
Capital cost: EUR $278m
Source: Deutsche WindGuard GMBH et al [1]

Supply chain and maturity

Current level of market penetration:	There are no offshore wind farms in Australia
Current Technology suppliers/ developers:	Most of the large onshore turbine manufacturers and developers in Europe also look at offshore projects. Specialist companies like Romboll-wind and Hywind supply offshore foundations for turbines.
Future of market to 2030:	Internationally there are several major offshore projects planned for the next decade (e.g. London array). However it is unlikely that offshore wind will play a large role within Australia given the number of onshore sites available.

Economic feasibility

Capital cost ranges ($/W):	$2.9- $3.7/W for large offshore wind farms. Allow for an increase of 30% for deeper foundations (double foundation cost) [2]
Future cost projections:	Steel price fluctuations are expected to put upward pressure on prices, counteracting any savings from generator efficiency increases. Innovative foundation techniques may reduce costs significantly (Foundations make up 30% of costs)
Annual operational and maintenance costs:	Several ranges publicly available from US$87/kW and $0/MWh, to US$15/kW and US$18/MWh. In all estimates the operational costs are higher than onshore wind.
Government subsidies available:	Renewable Energy Certificates.

Benefits and constraints

Regulatory:	Planning approval would be from NSW Government under Part 3A of the EP&A Act for all large scale generation with capex greater than $30 million or $5 million for State significant sites [3]. An offshore turbine could require approval under the Civil Aviation (Building Control) Regulations if located in close proximity to the Sydney Airport
Social:	Any cost effective offshore wind farm around Sydney would be very visible as waters more than 3 km off the coast are over 60m deep.
Environmental:	Foundation construction could cause disruption to ecology on ocean floor.
Commercial:	Rigs required to mount turbine masts in deep offshore sites are not currently available on the east coast of Australia.

Technical performance

Resource:	Wind
Energy end use:	Electrical
Functional life (years):	20 to 25 years
Capacity factor:	30% to 45% international experience. Indicative analysis for 20km off Sydney indicates a 40% CF
Factors affecting efficiency:	Sea surface roughness and turbulence in ocean breezes, distance to substation.

Site requirements

Typical suitable sites:	Harbour or open sea locations (over 10km offshore) away from waves. If water depth is 35m or less then a concrete gravity base or steel pile foundation can be used significantly reducing costs.
Resource thresholds:	Annual average wind speeds of 8-10 m/s is a general rule of thumb.
Land use (kWp/ m2):	General spacing is that a turbine mast to mast distance should be greater than 6 x the rotor diameter. Analysis of current commercially available turbines [3] gives a density around 125 m2 /kWp (0.008 kWp/m2).
Indicative resource the City of Sydney:	Near shore (within 10km) wind speeds off Sydney up to 7m/s. Average annual wind speeds further away up to 10m/s
Indicative resource in NSW:	Average annual wind speeds relative constant 10km offshore along NSW coast .

Summary figures [4]

Parameter	Low	Median	High
Annual generation by land use (kWh/m2):	20.50	26.10	28.73
Long Running Marginal Cost ($/MWh):	$175	$193	$249
Cost of carbon abatement ($/tCO2e):	$106	$126	$187

1. Deutsche WindGuard GmbH, Deutsche Energie-Agentur GmbH, University of Groningen, 2006, Case Study: European Offshore Wind Farms – A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms, Offshore Wind Association
2. Estimated depth of water is around 60m within 8km offshore. Cost information based on offshore wind farms in northern Europe with water depths between 6 and 20m which allows for different foundation techniques.
Includes Sydney Opera House, Redfern Waterloo Authority Sites and Barangaroo site
3. Based on a Vestas 2MW turbine
4. Cost and land take figures based upon those in an NREL study of several reports (http://www.nrel.gov/analysis/docs/re_costs_20090806.xls) and three different case studies from Europe: Scroby Sands, Horns Rev and Nysted. Assumed a 30% increase in costs to allow for more expensive foundations off Sydney. Capacity factor based on 2MW Vestas Turbine and TAPM predicted wind speeds 20km off the coast.

ARUP

Wave Power

Surface waves and pressure variations below and on the ocean's surface are harnessed to generate intermittent power. Systems vary and the lack of any commercialised technology leaves a wide degree of uncertainty in analysis.

Wave Energy Converters (WECs) typically use floating buoys, platforms, barrage like structures or submerged devices to generate electricity or to generate pressurised water for desalination. WECs can be positioned anywhere from on the water surface or submerged, on the shoreline or up to 100km offshore.

Supply chain and maturity

Current level of market penetration:	No commercial scale installation in operation in Australia however a demonstration scale plant is in commercial operation near Port Kembla
Current Technology suppliers/ developers:	Energetech, Biopower, Carnegie, Pelamis
Future of market to 2030:	There are many promising technologies and companies but none have been proven to be commercial as yet.

Economic feasibility

Capital cost ranges ($/W):	Cost information is very vague. Current demonstration scale $12/W.
Future cost projections:	Future commercial scale (>50MW) predicted to be $4/W to $6/W by MMA [2], $4/W assumed by Arup for a good site [3].
Annual operational and maintenance costs:	Predicted to be around $10/MWh by MMA. Demonstration scale (CETO II, Pelamis) expected to be around $100-$150/kW p.a.
Government subsidies available:	Renewable Energy Certificates.

Benefits and constraints

Regulatory:	Planning approval would be from NSW Government under Part 3A of the EP&A Act for all large scale generation with capex greater than $30 million or $5 million for State significant sites.
Social:	It is uncertain what effects if any a subsurface WEC would have on the waves at a nearby beach.
Environmental:	Subsurface WECs can potentially have impact on sea floor ecosystems, although Carnegie Corp claims that their system may actually improve habitat.
Commercial:	Near shore and on shore technologies may be in conflict with other land uses.

Energetech – Port Kembla Demonstration
Location: Port Kembla (South of Sydney)
Date of completion: TBA
Size: 500kW generating approximately 1GWh p.a.
Capital cost: $6m
Source: Clean Energy Council

Pelamis / Scottish Power -
Location: UK
Date of completion: 2007
Size: 3 MW
Capital cost: £10m
Source: Pelamis

Technical performance

Resource:	Waves
Energy end use:	Electrical
Electrical Efficiency:	Wave to wire efficiency modelled to be 24.8% by Arup.
Functional life (years):	Uncertain but several studies give life between 20 and 30 years[1,2,3,4]
Capacity factor:	Between 15% and 40% if at a good site.[1]
Factors affecting efficiency:	Wave front, turbulence, tidal range and current (sub surface)

Site requirements

Typical suitable sites:	25m is optimum depth for some underwater systems (CETO).
Resource thresholds:	30kW/m of wave front
Land use (kWp/ m2):	Around 220 m^2/kWp (0.0045 kWp/m2) [4]
Indicative resource the City of Sydney:	Sydney modelled at 11kW/m by Carnegie Corp. However wave power is very site specific; areas surrounding Sydney (Nelson Bay and Port Kembla) have both been shown to have resources in excess of 30kW/m.
Indicative resource in NSW:	NSW coast predicted to have a 13.61kW/m less than 50m or 16.19 kW/m for deep water [5].

Summary figures [6]

Parameter	Low	Median	High
Annual generation by land use (kWh/m2):	9.00	10.41	11.83
Long Running Marginal Cost ($/MWh):	$341	$380	$917
Cost of carbon abatement ($/tCO2e):	$289	$332	$922

1. PB Power, 2007, Technical Appraisal of the "CETO" Wave Power Generating Devices, Renewable Energy Holdings PLC
2. MMA, 2009, "Benefits and costs of the Expanded Renewable Energy Target", Treasury
3. Arup, Marine Energy Challenge: Oscillating Water Column Wave Energy Converter Evaluation Report, Carbon Trust
4. Global Energy Patrtners LLC et al, 2006, System Level Design, Performance and Costs for San Francisco California Pelamis Offshore Wave Power Plant
5. Hughes M.G., Heap A.D., 2009, National-Scale Wave Energy Resource Assessment for Australia, Renewable Energy 1-9
6. Scenarios based upon demonstration scale Pelamis and Oceanlinx technology as well as predicted figures for future (around 2020) Pelamis, Oceanlinx and CETO II installations. WECs expected to be placed in localised conditions with at least 30kW/m of wave front. Land use based on Pelamis.

Tidal power

There are two main forms of tidal energy technologies: tidal barrage (including tidal pond /lagoons) and tidal stream. Tidal barrage and tidal pond systems generate electricity by forcing water through a sluice gate and turbine. The technology is similar to hydro electricity except that it relies on the tides to move water from one side of a barrier to another, rather than a consistent flow from one side.

Tidal stream or current energy works in a similar way to wind power, where the flow of water forces blades to turn or oscillate and generate electricity.

La Rance Tidal Power Station
Location: La Rance, France
Date of completion: 1966
Size: 240 MW
Annual generation: 540 GWh
Source: Sea Generation

Annapolis Royal tidal plant
Location: Bay of Fundy, Canada
Date of completion: 1984
Size:18 MW
Annual generation: 50 GWh
Source: Nova Scotia Power

Supply chain and maturity

Current level of market penetration:	No commercial scale installation in operation in Australia
Current Technology suppliers/ developers:	Biopower, Seagen, Neptune, DeltaStream, Open Centre and many more are developing tidal stream technology. Barrages use conventional turbines from companies like Siemens and GE.
Future of market to 2030:	Although there are large installations proposed around the world it is uncertain if any of them will ever be built.

Economic feasibility

Capital cost ranges ($/W):	Tidal stream technologies are still in prototyping phase and can cost up to $15/W. According to recent tidal pool feasibility studies[1] capital costs are likely to be $1-$1.5/W for the generation set and $20m per km of embankment / barrage.
Future cost projections:	Large scale tidal pool projects (>50 MW) could be as low as $1.5-$1.8/W according to some sources [3].
Operational and maintenance costs:	Using hydro electricity as a proxy for a barrage costs are in the order of US$14/kW p.a. and US$4/MWh
Government subsidies available:	Renewable energy certificates

Benefits and constraints

Regulatory:	The shipping industry is likely to be hostile to any barrage. If locks were provided this would add substantial cost to the infrastructure.
Social:	Any obstructions to shipping movements in and out of the Harbour would need to be addressed especially those that affected the commercial viability. Sydney Harbour is also world class sailing venue. Any tidal pool or barrage would be in direct conflict with the sailing community
Environmental:	There are major environmental issues with constructing and operating a tidal barrage. Altering the hydrology and salinity of an estuary can have significant impacts on tide dependent ecosystems [5].
Commercial:	To be commercially viable tidal barrages and pools need to be multi MW installations. With such a low tidal range special turbines may need to be used, increasing the cost.

Technical performance

Resource:	Ocean tides or currents
Energy end use:	Electrical
Electrical Efficiency:	Turbine efficiency is around 30%.
Functional life (years):	Turbines typically last for 40 years but barrage itself would last for much longer (up to 120 years) [1].
Capacity factor:	23%-27% for existing tidal barrages in good locations. This is expected to be as low as 12% in areas with small tidal range[2] like Sydney because of the minimum hydrostatic head (height difference) required for the hydro turbine to operate.
Factors affecting efficiency:	Tidal range / tidal velocity.

Site requirements

Typical suitable sites:	Areas with high tidal ranges (not Sydney)
Resource thresholds:	Mean spring tidal velocity of 2.5m/s for tidal stream.
Land use (kWp/ m2):	International developments focus on areas with a tidal range over 4m[4] According to Arup calcs, a 1km2 tidal pool located around Sydney would be around 1.2MW capacity. This gives around 833 m2 / k Wp (0.0012 kWp/ m2).
Indicative resource the City of Sydney:	Mean spring tidal range in Sydney is around 1.9m . Based on a hydro turbine with 30% efficiency and a minimum head height of 300mm , a barrage at the mouth of Sydney Harbour would generate 20GWh per year.
Indicative resource in NSW:	Tidal ranges do not vary significantly along the NSW coast.

Summary figures [6]

Parameter	Low	Median	High
Annual generation by land use (kWh/m2):	1.24	2.06	39.42
Long Running Marginal Cost ($/MWh):	$498	$1,258	$5,635
Cost of carbon abatement ($/tCO2e):	$462	$1,305	$6,157

1. Department of Trade and Industry and the Welsh Development Agency, 2006, Tidal Lagoon Power Generation Scheme in Swansea Bay
2. O'Rourke F et al, 2010, Tidal Energy Update 2009, Applied Energy Issue 87 pp 398-409
3. Sustainable Development Commision UK, 2007, Turning the Tide: Tidal Power in the UK
http://www.environment.gov.au/coasts/publications/nswmanual/appendixb4.html
4. Pelc, Robin and Fujita, Rob. 2002, Renewable Energy from the Ocean, Marine Polilcy Volume 26, Issue 6
5. Retiere, C. Tidal power and aquatic environment of La Rance. Biological Journal of the Linean Society
6. Cost figures for tidal pool and barrage based on Department of Trade and Industry and the Welsh Development Agency, 2006 (see footnote 17); cost figures for Tidal stream based on SeaGen installation in UK. Costs were calculated based upon several different sized tidal pools ($5km^2$, $10km^2$, $100km^2$), a tidal current turbine, and a tidal barrage at the mouth of the Sydney Harbour. Annual generation was based on a two way generating system and a 1 hour hold per tide (based on a very low 300mm minimum hydrostatic head).
The low cost values indicate the barrage option. It should be noted that tis option would be extremely damaging to the ecosystems within the Sydney Harbour and would not receive planning approval under current environmental standards.

Direct Use Geothermal

Direct Use Geothermal uses the temperature difference between the ground and air to provide low energy intensive heating and cooling. Circulating Hot Water (CHW) and Ground Source Heat Pumps (GSHP) are the two major direct use applications.

In CHW bore holes or wells are drilled in depths of up to 1000m where there is a hot aquifer; no such hot aquifer is present in Sydney. However an abandoned mine under Goat Island is reported to have a large body of heated water.

Portland District Heating System
Location: Victoria
Date of completion: 1985
Size: 3.6MWth
Source: Sustainability Victoria

Southampton District Heating Scheme
Location: United Kingdom
Date of completion: 1987
Size: Part of a 5.7MW CHP generating 30GWhth p.a.
Capital cost: $14m
Source: Southampton City

Supply chain and maturity

Current level of market penetration:	In 2008, there was 110MWth installed capacity of ground source heating in Australia . These were, for the most part, building scale systems set up for space cooling.
Current Technology suppliers/ developers:	Geoexchange, Energycore, Earth-to-air are all technology suppliers and installers.
Future of market to 2030:	Industry is expanding overseas and is expected to grow in Australia.

Economic feasibility

Capital cost ranges ($/W):	$0.25-0.3/Wth for loops and heat exchanger alone. $2.5-$3/Wth for heating and cooling system (not linked to district heating). Around $400 - $700/m depth for drilling deep wells.
Future cost projections:	The price of well drilling is expected to increase in the short to medium term because of resource prices.
Annual operational and maintenance costs:	European systems are cheaper than those available in Australia ($1 - $2/W), if GSHP become more popular prices would be expected to drop to European costs. $62/kWth for labour. Electricity costs additional
Government subsidies available:	None available as yet. Although the Australian Geothermal Energy Association is lobbying for GSHP to receive the same treatment as solar hot water.

Benefits and constraints

Regulatory:	To drill a well deep enough to provide temperatures above those at the surface all year round may require special approvals from the NSW Department of Natural Resources.
Social:	Investment in direct heating technology and well drilling technology could help the industry grow in NSW, increasing skilled employment.
Environmental:	Ground source heating still relies on electricity generated elsewhere. If this electricity comes from the grid or the CHP system then there will be emissions associated
Commercial:	The well drilling equipment is the same as for Coal Seam Gas which increases the availability of the technology within Sydney.

Technical performance

Resource:	Ground temperatures
Energy end use:	Thermal (heating), thermal (cooling)
Thermal efficiency:	Coefficient Of Performance (C.O.P) between 3.5 and 5 for cooling. For CHW the electricity usage can be as low as 1kWe /50kWth depending on the ground temperatures.
Functional life (years):	20 years before major refurbishment required
Capacity factor:	Dependent on load
Factors affecting efficiency:	Ambient temperatures, ground temperatures, well depths, initial temperature of water

Site requirements

Typical suitable sites:	An open space or site in proximity to the district heating or district cooling network.
Resource thresholds:	80°C required for space heating and cooling for CHW. Lower temperatures can be upgraded if using a GSHP, however this uses more electricity. Commerically available organic rankine turbines require at least 150 degrees although temperatures below this are technically possible.
Land use (kWp/m2):	For wells, heat exchanger and heat pumps 0.2 m² / kWp (5kWp/m2)
Indicative resource the City of Sydney:	Indicative information from various sources points to a 40 degrees temperature at achievable depths (500-1000m). Ground temps near surface around 17 degrees are suitable for cooling only.
Indicative resource in NSW:	There are several areas of interest for geothermal within NSW, specifically around the Hunter region where sub surface temperatures are in excess of 200 degrees around 5000m underground.

Summary figures

Parameter	Low	Median	High
Annual generation by land use (kWhth/m2):	36500	42583	73000
Long Running Marginal Cost ($/MWhth):	$36	$53	$77
Cost of carbon abatement ($/tCO2e):	$109	$160	$232

1. Payne W.J.B et al, 2008, Position Paper: Direct Use of Geothermal Applications, Australian Geothermal Energy Association
2. Based on a cost analysis in SKM, 2005, The Geothermal Resources in Victoria, The Sustainable Energy Authority
3. Pers Comms, 2009, Apollo Gas
4. Jaworska J., 2009, Sydney Basin GIS-based geothermal studies, Department of Primary Industries, available at www.pir.sa.gov.au/__data/assets/pdf_file/0004/123664/jola_sydneybasin.pdf+Sydney+basin+geothermal&cd=3&hl=en&ct=clnk
5. Cost, capacity factor and land take figures based on those modelled in SKM, 2005 (see footnote 22). Scenarios differed by the depth of wells required to reach desired temperature (95°C at 70L/s) and the costs of drilling the wells. Best case temperatures for Sydney were assumed to be 17°C at 10m, 40°C at 500m and 150°C at 5000m. Worst case temperatures for Sydney were assumed to be 17°C at 10m, 30°C at 500m and 120°C at 5000m. Land use changed depending on whether wells were directly accessible or not.

Solar Photovoltaic (PV)

Solar Photovoltaic cells are made of a semi-conductor material, such as crystalline silicon, which is stimulated by photons from sunlight to generate an electrical current.

Most building integrated PV modules are fixed orientation ona flat or north facing roof surface. In the commercial office applications PV is also available as PV integrated external sunshades affixed to the sides of buildings.

K2 Apartments, Melbourne
Location: Melbourne, Vic
Date of completion: 2008
Size: 21.4kWe
Source: Arup project database

Jingya Greenpix
Location: Beijing, China
Date of completion: June 2008
Size: 79kW (2,200m2) generating over 50MWh p.a.
Capital cost: Integrated into façade costs. N/A
Source: Arup project case studies

Supply chain and maturity

Current level of market penetration:	In 2008 there were 82MW of installed capacity in Australia[1] growing at roughly 10MW per annum. This has accelerated in recent years with feed in tarrifs in most states.
Current Technology suppliers/ developers:	Suntech Power, First Solar, BP Solar, Kyocera and Silex solar all make panels and/or cells but there are many more. Local installers include Eco-kinetics, Ingenero, Conergy.
Future of market to 2030:	Manufacturers are increasing production quantities and are expecting to do so for the foreseeable future.

Economic feasibility

Capital cost ranges ($/W):	$6.5 - $8/W depending on the scale [2]. Panels typically make up 45% of the cost, 15 % for balance of system and 40% for design and installation.
Future cost projections:	Expected to decrease over the short to medium term to as low as $1/W before installation. Conservative estimates are for prices to drop as low as $5/W installed.
Annual operational and maintenance costs:	Operating costs are minimal. Wiring and inverter should have an annual check. Inverter would need replacing after 15 years.
Government subsidies available:	Federal government solar homes and communities scheme. Solar credits (a multiplier of Renewable Energy Certificates) from the Commonwealth Government. If system is under 10kW segments PV systems could be eligible for NSW FiT.

Benefits and constraints

Regulatory:	DA approval is required in some locailties. Energy Australia require notification in order to connect the gross metering system.
Social:	Solar energy is widely supported by the public and is one of the most known and accessible renewable energy technologies.
Environmental:	Some PV module technologies (i.e. cadmium telluride) contain potentially hazardous materials.
Commercial:	Historically PV technology has relied on government subsidy to be commercially viable. Costs will need to continue the downward trend to be competitive without the assistance of subsidies.

Technical performance

Resource:	Solar (Global Horizontal Irradiance (GHI))
Energy end use:	Electrical
Electrical Efficiency:	Up to 19.2% for the latest mono crystalline cells (Suntech). 10.8% for CdTe thin film technology (First Solar).
Functional life (years):	30 years (guaranteed for 25)
Capacity factor:	15.3% fixed without cleaning (assuming a 16% derate factor for inverter, wiring, soiling and age etc)
Factors affecting efficiency:	Age of technology (typically 1% reduction per year), shading, soiling, temperature, orientation. Cell temperature. Temperature coefficient approximately 0.38%/°C higher than rated temperature of 20°C.

Site requirements

Typical suitable sites:	Residential, Commercial, Industrial. Any building with electrical demand and solar access.
Resource thresholds:	0.137kWp/m2 for the latest mono crystalline modules. Ground cover is up to 90% so the gross land use is 0.123kWp/m2. For tracking systems this can be as low as 0.04kWp/m2
Roof / facade use (kWp/m2):	If buildings cover 30% of the LGA and 50% of the total roof area is covered there would be 427MWp generating 599GWh p.a
Indicative resource the City of Sydney:	4.53kWh/m2/yr (solar resource per unit ground area). 5.04kWh/m2/yr (solar resource per unit PV collector area for north facing unit at 33.95° tilt angle). [3]

Summary figures

Parameter	Low	Median	High
Annual generation by land use (kWh/m2):	65.24	162.94	180.94
Cost of carbon abatement ($/tCO2e):	$224	$307	$320

1. IEA, 2008, Trends in Photovoltaic Applications: Survey Report of Selected IEA countries between 1992 and 2007
2. Based on quotes from building scale solar PV suppliers and infmroal conversations with large installers.
3. IWEC Sydney weather file using NREL PV Watts tool

ARUP

Organic PV (OPV)

Organic photovoltaics use specially developed organic compounds - instead of silicon semi conductors - to generate electrical current when exposed to solar radiation.

These compounds are generally applied in the form of OPV dye, printed onto surfaces such as glass or steel building fabrics. This makes them highly amenable to more complex architectural surfaces and shapes.

K2 Apartments, Melbourne
Location: Melbourne, Vic
Date of completion: 2008
Size: 21.4kWe
Source: Arup project database

Jingya Greenpix
Location: Beijing, China
Date of completion: June 2008
Size: 79kW (2,200m2) generating over 50MWh p.a.
Capital cost: Integrated into façade costs. N/A
Source: Arup project case studies

Supply chain and maturity

Current level of market penetration:	There are currently a number of OPV technology developers breaking into the global market. There are currently very few large scale applications. Many OPV technology companies currently market equipment and technology to make OPV cells. Some are involved in providing OPV on small user goods, such as bags, etc. Other are providing tailor made building integrated solutions.
Current Technology suppliers/ developers:	Konarka, Skyshades, Plextronics, heliatec, Flexcell, Dyesol Industries, CSIRO, IDTechEx, Solarmer
Future of market to 2030:	OPV is currently a rapidly maturing technology. It is foreseeable that OPV will be extremely cost competitive with required durability in the timeline of this masterplan.

Economic feasibility

Capital cost ranges ($/W):	OPV cost data is currently highly unreliable due to the maturity of manufacture at present. Current estimates place cost in the order of $1.0/Wp - $2.30/Wp before installation.
Future cost projections:	Due to the inexpensive nature of material input, as manufacture capacity and market penetration increase, OPV has potential in the medium term to cost well below $1/W before installation.
Annual operational and maintenance costs:	As durability and life span are improved the life cycle economics for OPV become more attractive. As with other solar PV technologies wiring and inverter require annual checkup and inverter requires replacement after 15 years.
Government subsidies available:	Federal government solar homes and communities scheme. Federal government Renewable Energy Credits scheme (RECS). NSW state government gross feed in tariff (FIT).

Benefits and constraints

Regulatory:	DA approval is required in some locailties. Energy Australia require notification in order to connect the gross metering system.
Social:	Solar energy is widely supported by the public and is one of the most known and accessible renewable energy technologies.
Environmental:	OPV uses less precious, more abundant materials as a semi-conductor than other PV technologies.
Commercial:	OPV has the potential to significantly undercut the cost of other PV technologies on a $/W basis.

Technical performance

Resource:	Solar (Global Horizontal Irradiance (GHI))
Energy end use:	Electrical
Electrical Efficiency:	OPV Technology currently has efficiencies of up to 6.8%. Industry is targeting approximately 10%-15%[1] efficiency before 2020.
Functional life (years):	5-20 years. Current durability issues limiting life span. Technology developing to solve these issues. Expected improvements to 2020 to result in 15-20 year lifespan for OPV technology.
Capacity factor:	19.6% fixed without cleaning, (assuming a 16% derate factor for inverter, wiring, soiling and age etc)
Factors affecting efficiency:	Current lifespan/durability issues are being tested out in OPV technology.

Site requirements

Typical suitable sites:	Residential, Commercial, Industrial. Any building with electrical demand and solar access.
Roof / facade use (kWp/m2):	0.068kWp/m2 for the latest printed organic photovoltaic modules. Allowing for 90% rooftop so the gross land use is 0.123kWp/m2. For tracking systems this can be as low as 0.04kWp/m2
Indicative resource the City of Sydney:	4.53kWh/m2/yr (solar resource per unit ground area). 5.04kWh/m2/yr (solar resource per unit PV collector area for north facing unit at 33.95° tilt angle) If buildings cover 30% of the LGA and 50% of the total roof area is covered there would be 148MWp generating 228GWh p.a

Summary figures

Parameter	Low	Median	High
Annual generation by land use (kWh/m2):	77.26	117.44	231.79
Cost of carbon abatement ($/tCO2e):	-$6	$75	$128

1. Kalowekamo, 2009, University of Massachusetts, “Estimating manufacture cost of purely organic photovoltaic cells
2. IWEC Sydney weather file using NREL PV Watts tool

Concentrated PV (CPV)

Heliostats or parabolic lens or Fresnel lens' are used to concentrate solar radiation onto a high efficiency PV module which tend to cost considerably more than conventional PVs.

Existing installed systems in Australia have efficiencies above 30%; new technology developed at UNSW has seen +40% efficiencies in lab testing.

Although most of the suppliers of this technology are focussing on the utility scale applications there are several developing smaller, building scale versions.

Green and Gold SunCube (Australia)
Location: Adelaide, South Australia
Date of completion:
Size: 30kW
Capital cost: Approximately $150k
Source: Green and Gold

Menova Technologies, Canada
Location: Ontario, Canada
Date of completion: June 2008
Size: 28kW
Source: Menova

Supply chain and maturity

Current level of market penetration:	There are a number of commercial scale systems in operation in Australia. The building integrated market for CPV yet to experience uptake in Australia. Green and Gold Energy in South Australia are expanding manufacturing capacity of their Sun Cube product with partners in India.
Current Technology suppliers/ developers:	Amonix, Energy innovations, Solar Systems, Green and Gold Energy, SolFocus, Concentrix Solar, Menova, Pyron Solar,EQSolaris
Future of market to 2030:	As with other PV technologies, the CPV market is expected to grow dramatically in the future

Economic feasibility

Capital cost ranges ($/W):	$6 (Sol Focus) to $10/W (Solar Systems) for installed systems. $5/W (Green and Gold) claimed by some semi commercialised suppliers.
Future cost projections:	Expected to be 40% of current price by 2016 [1]. Sol Focus targeting $2/W at full production
Annual operational and maintenance costs:	Lens' and mirrors require washing and tracking systems have maintenance requirements. Arup have assumed $30/kW p.a. including allowance for inverter replacement.
Government subsidies available:	Federal government solar homes and communities scheme. Solar credits (a multiplier of Renewable Energy Certificates) from the Commonwealth Government. If system is under 10kW segments PV systems could be eligible for NSW FiT.

Benefits and constraints

Regulatory:	DA approval is required in some locailties. Energy Australia require notification in order to connect the gross metering system.
Social:	Solar energy is widely supported by the public and is one of the most known and accessible renewable energy technologies.
Environmental:	Some PV module technologies (i.e. cadmium telluride) contain potentially hazardous materials.
Commercial:	Historically PV technology has relied on government subsidy to be commercially viable. Costs will need to continue the downward trend to be competitive without the assistance of subsidies.

Technical performance

Resource:	Direct Normal Irradiance (DNI)
Energy end use:	Electrical
Electrical Efficiency:	25% - 34% in proven practice. Up to 40% in lab testing.
Functional life (years):	25 to 40 years (depending on whether the PV cell is replaceable)
Capacity factor:	Up to 26% depending on tracking system.
Factors affecting efficiency:	Shading, cloud cover, tracking effectiveness, temperature, aging of PV cells (0.5% per year).

Site requirements

Typical suitable sites:	Residential, Commercial, Industrial. Any building with electrical demand and solar access.
Roof / facade use (kWp/m2):	Up to 0.16 kWp/m2 for the CPV modules themselves. However ground coverage is only 50% or lower so land take can be between 0.049 and 0.079
Indicative resource the City of Sydney:	6.0kWh/m2/yr (solar resource per unit collector area for a single axis tracking system in Sydney). 6.25kWh/m2/yr (solar resource per unit collector area for a 2 axis tracking system in Sydney) [2] If buildings cover 30% of the LGA and 50% of the total roof area is covered there would be 191MWp generating 435GWh p.a.

Summary figures

Parameter	Low	Median	High
Annual generation by land use (kWh/m2):	86.5	98.5	159.2
Cost of carbon abatement ($/tCO2e):	$452	$596	$625

1. http://www.energy.gov/media/SAI_Team_Fact_Sheets.pdf
2. IWEC Sydney weather file using NREL PV Watts tool Low based on NREL (footnote 4) and feasibility study of 10MW single axis tracking thin film PV. High cost based on Australian installations to date.

Building Integrated Wind

Building integrated wind turbine often known as micro wind turbines (MWT), are smaller than their utility scale cousins. Generally ranging from 400W to 15kW. They are limited in size due to the structural loads they put on a building.

The are two main streams of MWT, horizontal axis and vertical axis. In recent years there has been significant growth in the vertical axis turbine market, for their reduced directional sensitivity, operational noise and stylish architectural aspects.

ANZ Centre, Docklands
Location: Melbourne
Date of completion: 2009
Size: 6 * 6kW turbines
Image Source: Arup

Pacific Garden Mission, Housing Apartments
Location: Chicago, USA
Date of completion: 2007
Size: 8 * 1.5kW turbines
Annual generation: over 16MWh
Source: Aeroturbines & New York Times

Supply chain and maturity

Current level of market penetration:	Building integrated wind not yet as prevalent as utility scale wind. Cost case is currently compelling; however variability of wind in urban areas creates uncertainty in the market.
Current Technology suppliers/ developers:	Aerotechture, Airovironment, Ampair, Soma, Home Energy, Conergy, Westwind, Gazelle (MKW Group), Quiet Revolution, Enercon, Acconia, Goldwind, Soma Renewable Energy Solutions, Vestas, Nordex, Proven Energy, Philippe Starck / Pramac, Turby, Vertical Wind Energy, Windside, Windspire, Humdinger Wind Energy
Future of market to 2030:	Innovative manufacture techniques and improved aesthetic appeal provide growth opportunity for MWT. An example of new technology innovations in MWT is the Humdinger Windbelt. An entirely new MWT technology stream claiming manufacture costs of approximately $1/W[2]. Noise created by turbines is an issue that will restrict growth in densely populated residential areas.

Economic feasibility

Capital cost ranges ($/W):	$3/W[3] (Before installation) and $5/W[4] - $11/W[5] (Grid integrated system installed), Average of $7/W[6] for building integrated applications over approximately 2kW capacity. Smaller MWT 400W-2kW price ranges from $10/W - $14/W[7]. Building integrated costs vary greatly depending on additional structural works requirements.
Future cost projections:	Newer models which are injection moulded (a mass manufacturing technique) have the potential to dramatically decrease prices in the next 5 years. Economies of scale will improve cost as uptake of MWT increase making RD costs for MWT a lower proportion of overall turnover.
Annual operational and maintenance costs:	MWT are designed for high reliability and near $0/MWh maintenance budgets. However a rule of thumb is 1% of capital cost per annum. and as with PV technologies the inverter will require replacement.
Government subsidies available:	Solar credits (a multiplier of Renewable Energy Certificates) from the Commonwealth Government. If system is under 10kW segments PV systems could be eligible for NSW FiT.

Benefits and constraints

Regulatory:	Variable frequencies in the power harmonics generated by wind power means there is a limit to the amount of wind generation in any individual region of the grid.
Social:	Sound levels can disturb sensitive receivers.
Environmental:	There are some concerns about birds flying into turbines, though these are largely unsupported by experience in Australia.
Commercial:	Competing technologies such as solar PV are becoming price competitive and present more reliable payback case.

Technical performance

Resource:	Wind
Energy end use:	Electrical
Functional life (years):	20 to 25 years
Capacity factor:	25%-40% in good sites. Indicative analysis[1] on Sydney 17% to 18%.
Factors affecting efficiency:	Rough ground surface, tall buidings / vegetation, distance to demand location. Urban settings require detailed analysis to determine local wind resource and optimal turbine placement.

Site requirements

Typical suitable sites:	Favourable wind energy characteristics are likely to be strongly associated with open terrain and/ or substantial elevation above the aerodynamically rough layer of the urban landscape. MWTs installed in typical built-up urban terrain are likely to operate at low capacity factors, suffer protracted periods of nonoperation and have long payback periods
Roof / facade use (kWp/m2):	General spacing is that a turbine mast to mast distance should be greater than 5 x the rotor diameter. Analysis of current commercially available turbines[7] gives a range of between 0.018 kWp/m2 and 0.025 kWp/ m2 as a maximum. Additional factors include availability of roof space which is traditionally populated by plant rooms, structural limitations. Some building types i.e. industrial sheds are ill equiped to take additional structural loads created by MWTs.
Indicative resource the City of Sydney:	If buildings cover 30% of the LGA and 50% of the total roof area is covered there would be 44.4MWp generating 97.2GWh p.a. based on indicative wind speed analysis.

Summary figures

Parameter	Low	Median	High
Annual generation by land use (kWh/m2):	17.26	25.22	50.19
Cost of carbon abatement ($/tCO2e):	$385	$419	$503

1. Based on wind assessment conducted by Aerogenesis at Jubilee Park and Arup analysis of Fort Dennison wind speeds.
2. Humdinger Wind Energy, http://www.humdingerwind.com
3. Turby, http://www.turby.nl/
4. Proven Energy http://www.provenenergy.co.uk/
5. Aerovironment, http://www.avinc.com/engineering/architecturalwind1/
6. Pramac, http://www.revolutionair-pramac.com/
7. Rainbow Power Company Price listings
8. Based on a series of turbines from various manufacturers

Ground Source Heat Pump (GSHP)

Ground source heat pumps use a refrigeration cycle rejecting or accepting heat from a water loop in the ground. GSHP have the ability to provide both heating and cooling to buildings using reversible chiller cycle technology.

They involve digging bore holes deep into the ground to access stable ground temperatures and provide heat transfer capability.

Geosciences Australia Building, Canberra
Location: Canberra
Date of completion: 1997
Size: 30,700m2 office. 1.5MW heating capacity 500kW
Capital cost: $700k
Source: Geosciences Australia

Hotel Grand Chancellor
Location: Tasmania
Size: 710kWc / 780kWh
Capital cost: $2.95M
Source: Geoexchange

Supply chain and maturity

Current level of market penetration:	Ground source heat pumps are prevalent in Europe and the UK, especially in the domestic market. There are established markets, regulations and design standards. The Australian market has yet to develop to this level. There are a small number of companies with capability in this area.
Current Technology suppliers/ developers:	Geoexchange, Earth to Air Systems, Nicholls Boreholes, PAV Plumbing Sydney, Environplumbers, Phnix, Gleo Climate Systems
Future of market to 2030:	Both ground and air source heat pumps are an attractive option in decarbonising heating applications. Cost of bore holes are the most prohibitive element. These costs currently hinder uptake.

Economic feasibility

Capital cost ranges ($/W):	$1.8/Wth - $4.2/Wth for installations of above 100kW thermal capacity. Costs higher for smaller applications. (Note: that in the case of new build these costs are offsetting some conventional base building system costs)
Future cost projections:	Boreholes are the most prohibitive element. There are currently no indications that these costs will significantly reduce. In operation these units are currently quite cost effective. However the increase electricity prices compared to natural gas may reduce this operational advantage.
Annual operational and maintenance costs:	GSHP operate on electricity. Thus the operating cost of electricity needs to be considered. With an average COP of 5 GSHP would use 1kWh electricity for every 5kWh of heating or cooling. Maintenance costs equate to 2.4%-3.3% installed base per year ($33/kWth per annum - $59/Wth per annum) [1]
Government subsidies available:	Victorian Government Four Seasons Program (Not applicable to Sydney)

Benefits and constraints

Regulatory:	Water access licences may be required for drilling of boreholes where groundwater is intercepted
Social:	None identified
Environmental:	Excessive heat rejection into soil on a large scale can have detrimental impacts. To achieve carbon abatement over standard gas heating systems GSHP needs to run off a green electricity source. If electricity is purchased from a brown source, there would be little to no carbon abatements.
Commercial:	Retrofit of ground source heat pumps is often not practical in urban settings where subsurface works are required and are generally only cost effective on cleared sites.

Technical performance

Resource:	Electricity from grid or other source. Thermal energy from ground source.
Energy end use:	Electrical, thermal (heating), thermal (cooling)
Thermal Efficiency:	Coefficient of Performance (COP) of 3.5-6
Functional life (years):	20-30 years with servicing
Capacity factor:	Dependent on building operation. Estimated at approximately 20-30%
Factors affecting efficiency:	Ground source temperatures, operating part load in real time (e.g. 50% of thermal capacity). Ground quality effects performance of heat rejection units. Good ground types include massive limestone, granite, and sandstone. Suitable but less effective are clay and basalt. Dry gravel or sand are very poor.

Site requirements

Typical suitable sites:	Commercial office and residential buildings. Must be built on land where bore hole drilling of up to 100m depth or more for large applications. Can use 1.5-3m deep horizontal heat rejection for small residential applications.
Roof / facade use (kWp/m2):	10W/m² for horizontal heat rejection. 97-230W/m² for 100m deep bore holes depending on ground qualities (e.g. moist clay, granite, etc.)
Indicative resource the City of Sydney:	Retrofit of GSHP is extremely cost prohibitive and often not practical in an urban environment. Consider for new build office and residential only.

Summary figures

Parameter	Low	Median	High
Annual generation by land use (kWhth/m2):	2628	2628	2628
Cost of carbon abatement ($/tCO2e):	$5,581	$6,529	$6,628

1. Geosciences Australia, GSHP installation 10year review

Solar Thermal - Hot Water

Solar thermal hot water can be broken into two main categories based on solar collector technology, flat plate or evacuated tube.

Solar collectors are linked to a thermally insulated storage unit which generally also has a gas electric or electric heat pump booster which supplements the solar heating.

Redfern Community Centre
Location: Redfern, NSW
Date of completion: October 2009
Size:90 Tubes, 3 x 315L tanks
Annual generation: 10.9MWh (Based on AS4234:2008)
Source: Endless Solar

Proximity Hotel
Location: Greensboro, Nth Carolina, USA
Date of completion: 2007
Size: 100 Panels (372m2), over 210kWth generating approximately 60% of Hotel's hot water demand
Source: USGBC

Supply chain and maturity

Current level of market penetration:	Solar hot water systems are well established within Australia. Government RECs data shows hundreds of thousands of installations in Australia [1]. This market is currently dominated by the residential sector.
Current Technology suppliers/ developers:	AAE Solar, Apricus Australia, AquaMax, Atlas Trading, Australian Solar Company, Bosch, Chromagen, Conergy, Dinnai Demand Duo Solar, Douglas Solar, Dux, Ecosmart, Edwards, Endless Solar, ETCO, Greenland Systems, Latento, Megasun, Ochsner, Quantum, Rinnai, Rheem, Saxon, Sidec Solar, Solahart, Solar First, Solar Lord, Solarpower, Solco, Stratco, Stieben Eltron, Sunplus Solar, Suntrap, Velux, Vulcan,
Future of market to 2030:	Solar hot water is a cost effective readily available and accessible renewable energy form. Greater market penetration into the commercial market shows additional promise, combined with massive uptake in the residential sector.

Economic feasibility

Capital cost ranges ($/W):	$1/W to $2.8/W for complete system including storage tanks and booster systems [2,3].
Future cost projections:	This is a mature and sizable manufacturing industry as such huge cost savings in design are unlikely through economies of scale.
Annual operational and maintenance costs:	Material costs of stainless steel, copper, aluminium and glass will affect production costs. Packaged solar hot water systems are designed for high reliability and near $0/MWh maintenance budgets. The target market with these systems is residential where ongoing maintenance and costs are not desirable.
Government subsidies available:	Solar credits (a multiplier of Renewable Energy Certificates) from the Commonwealth Government.

Benefits and constraints

Regulatory:	
Social:	Solar energy, including solar hot water is widely supported by the public and is one of the most known and accessible renewable energy technologies.
Environmental:	If electric boosted by a conventional resistance electric tank, solar hot water can use as much electricity as a air source heat pump hot water system.
Commercial:	Historically solar thermal technology has relied on government subsidy to be commercially viable when compared to gas fired hot water. Costs will need to continue the downward trend to be competitive without the assistance of subsidies.

Technical performance

Resource:	Solar Global Horizontal Irradiance
Energy end use:	Thermal (heating),
Electrical Efficiency:	50-60% solar to heat peak efficiency
Functional life (years):	10-20 years depending on system and servicing. 5-10year warranty available from most manufacturers
Capacity factor:	10-19% depending on hot water demand (Solar is typically able to provide 60% of annual hot water requirements in standard residential applications) and system type (evacuated tube collectors have higher year round yield than flat plate collectors, resulting in a higher capacity factor)
Factors affecting efficiency:	Solar irradiance levels, hot water output temperature, outside air temperature.

Site requirements

Typical suitable sites:	Residential, Commercial, Heated Pools, Industrial.
Roof / facade use (kWp/m2):	Approximately 0.5-0.6kWp/m2. If ground cover is up to 90% the gross land use is 0.45-0.54kWp/m2.
Indicative resource the City of Sydney:	4.53kWh/m2/yr (solar resource per unit ground area). 5.04kWh/m2/yr (solar resource per unit solar collector area for north facing unit at 33.95° tilt angle) [4] If buildings cover 30% of the LGA and 50% of the total roof area is covered there would be 1600MWth generating 2150GWhth p.a

Summary figures

Parameter	Low	Median	High
Annual generation by land use (kWhth/m2):	1314.0	1576.8	1664.4
Cost of carbon abatement ($/tCO2e):	$312	$432	$514

1. http://www.orer.gov.au/swh/register.html
2. Dux, Rinnai and Endless Solar
3. http://www.energymatters.com.au
4. IWEC Sydney weather file using NREL PV Watts tool

Solar Thermal - Cooling

Solar thermal cooling utilises higher temperature hot water to drive an absorption (thermally driven) chiller which provides cooling. Typically parabolic trough or linear Fresnel solar collectors are used to achieve the temperatures required (90°C to 200°C); evacuated tube collectors can be used at the lower end of this temperature range.

Installations are only viable on a larger scale 100kW+ in commercial, public, shopping centre or industrial buildings with centralised cooling plant. Utilisation of this technology benefits from the coincidence of cooling load and solar irradiance.

Supply chain and maturity

Current level of market penetration:	Australia currently has very few solar cooling installations. There are some academic and larger scale technology demonstration projects giving industry further feedback on effectiveness and refinements for the technology.
Current Technology suppliers/ developers:	There are local manufacturers and suppliers with specific capability in this technology. NEP Solar, Endless Solar, Solid Solar Installation & Design, Energy Concepts, Climate Well, Heliodynamics, Sopogy
Future of market to 2030:	The market is becoming more aware and comfortable with this technology as it matures. Solar cooling technology is included in some large scale private sector building projects currently at planning stage. For example - GPT Group owned - Charlestown Sqaure shopping centre expansion project [1].

Economic feasibility

Capital cost ranges ($/W):	Capital cost depends on building HVAC system design, plant room locations, and roof structure. System costs including installation are expected to range from $1.9/W - $2.8/W of cooling capacity (for systems ranging in size from 100kWc – 250kWc)
Future cost projections:	Reduction in cost of "low concentration" parabolic trough technology and market penetration of linear Fresnel technology is expected to reduce overall system cost significantly. Installation costs are expected to reduce as local market matures.
Annual operational and maintenance costs:	$30/W-$70/W installed per annum additional to existing HVAC maintenance costs
Government subsidies available:	It is unclear if the current solar credit scheme provides subsidies for solar cooling. There is potential to claim the hot water component of the system under solar credits.

Benefits and constraints

Regulatory:	While solar energy may be popular with the wider public the scale of the plant required to make the system work may mean that it will require development approval.
Social:	Concentrated systems have the potential to reflect light onto neighbouring properties.
Environmental:	Solar cooling technology is still reliant on refrigerants which can be harmful to the environment including the ozone
Commercial:	Systems are only viable on buildings with centralised HVAC plant. Additionally the availability of small absorption chillers limits the size of these systems to a minimum of approximately 150kWth.

K2 Apartments, Melbourne
Location: Melbourne, Vic
Date of completion: 2008
Size: 21.4kWe
Source: Arup project database

Jingya Greenpix
Location: Beijing, China
Date of completion: June 2008
Size: 79kW (2,200m2) generating over 50MWh p.a.
Capital cost: Integrated into façade costs. N/A
Source: Arup project case studies

Technical performance

Resource:	Solar Global Horizontal Irradiance (for Evacuated tube solar collectors) Direct Normal Irradiance (for concentrated solar technologies)
Energy end use:	Thermal (cooling)
Electrical Efficiency:	40-60% Peak thermal efficiency for evacuated tubes is lower at temperatures required. Concentrating technologies have thermal efficiencies nearing 60%[2].
Functional life (years):	10-20 years depending on system and servicing.
Capacity factor:	15-25% for Sydney area[3,4]
Factors affecting efficiency:	Solar irradiance levels, absorption chiller hot water input temperature, outside air temperature.

Site requirements

Typical suitable sites:	Commercial, Industrial. Medium to large building with centralised cooling plant and good solar access.
Roof / facade use (kWp/m2):	Up to 0.5 – 0.6kWp/m2 for the concentrated modules themselves. However ground coverage is only 30% - 50%, so land take can be 0.15 – 0.3kWp/m2
Indicative resource the City of Sydney:	4.53kWh/m2/yr (solar resource per unit ground area). 5.04kWh/m2/yr (solar resource per unit solar collector area for north facing unit at 33.95° tilt angle).[5] 6.0kWh/m2/yr (solar resource per unit collector area for a single axis tracking system in Sydney). 6.25kWh/m2/yr (solar resource per unit collector area for a 2 axis tracking system in Sydney).[5] If buildings cover 30% of the LGA and 50% of the total roof area is covered there would be 603MWth generating 549GWhth p.a.

Summary figures

Parameter	Low	Median	High
Annual generation by land use (kWh/m2):	204.98	256.23	273.31
Cost of carbon abatement ($/tCO2e):	$295	$586	$983

1. GPT Group http://www.gpt.com.au/
2. Sopogy http://sopogy.com/
3. NEP Solar http://www.nep-solar.com/
4. Australian Solar Cooling interest group http://ausscig.com.au
5. IWEC Sydney weather file using NREL PV Watts tool

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Municipal solid waste

Municipal solid waste (MSW), also called urban solid waste, is a waste type that includes predominantly household waste (domestic waste) with sometimes the addition of commercial wastes collected by a municipality within a given area. The waste is in either solid or semisolid form and generally exclude industrial hazardous wastes.

Eastern Creek UR3R
Location: Sydney
Date of completion: 2007
Size: 2MW
Suorce: WSN

Supply chain and maturity

Availability of feedstock:	Collection supply chain already in place as waste is collected from households and businesses.
Current use of feedstock:	Most MSW is currently sent to landfill, although there are already Mechanical Biological Treatment (MBT) type Alternative Waste Treatment (AWT) which harvests biogas from the waste.
Future supply:	Guaranteed supply of MSW into the future. Even if aggressive education and other waste minimisation campaigns are effective it is unlikely to outweigh continued population growth in Sydney.

Technical performance

Calorific value (Gj/t dry basis):	~12Gj/dbt
Moisture content as received (%):	38.5%
Specific gravity (t/m3):	0.72
Availability / seasonality:	Available all year round

Sewer gas / sludge

Sewer gas is mainly made up of methane, but in addition contains a complex mixture of toxic and non-toxic gases that vary depending on the type of sewage digested.

The gas is produced and collected at waste water treatment plants that use anaerobic digestion to break down household and industrial sewage into both gas and solid by products that can be used to make compost or liquid fertiliser.

Bondi waste water treatment facility
Location: Sydney
Date of completion: 2009
Size: 2MW
Source: Sydney Water

Supply chain and maturity

Availability of feedstock:	Collection supply chain already in place with Sydney Water collecting almost all of the available resource within 50km.
Current use of feedstock:	Most sewage from City of Sydney is currently sent to Malabar or Bondi waste water treatment facilities. Both of these sites have anaerobic digestors and on site CHP systems
Future supply:	Guaranteed supply of sewage sludge as long as there is a centralised waste water system.

Technical performance

Calorific value (Gj/t dry basis):	~12.4Gj/dbt for sludge
Moisture content as received (%):	73%12 for sludge
Specific gravity (t/m3):	0.72 for sludge
Availability / seasonality:	Available all year round, however there is a demand for heat during winter which could limit the export of gas to warmer months.

Landfill gas

Landfill gas is the gas derived from the fermentation of biomass and solid waste in landfills. Landfils essentially capture the high methane content gas that is emitted by biodegration of organic materials.

Although waste in the future may be treated by AWT and not disposed of to landfill, the landfills that exist today will be generating methane for several decades even without any additional waste.

Summer Hill Waste Management Faclity
Location: NSW
Date of completion: 2009
Size: 2MW
Source: LMS Generation

Supply chain and maturity

Availability of feedstock:	Collection supply chain already in place.
Current use of feedstock:	There are several landfills that capture landfill gas to generate electricity in and around Sydney.
Future supply:	As more waste is treated by methods other than landfill there is likely to be a tapering off of landfill gas available. However this is not likely in the short to medium term.

Technical performance

Calorific value (Mj/Nm3):	~19Mj/Nm3
Availability / seasonality:	Available all year round, however there is a demand for heat during winter which could limit the export of gas to warmer months.

Forestry residue (pine)

When harvesting timber from plantations and processing large amounts of waste (i.e. small branches, bark, off cuts etc) is generated. Processing the harvested timber at saw mills creates even more waste.

Similar waste created by the harvesting of old growth timber is not considered renewable.

Big River
Location: NSW
Date of completion: 2007
Size: 450kW
Source: Big River Timbers

Supply chain and maturity

Availability of feedstock:	Forests NSW have begun investigations into their own plantation waste fuelled CHP systems for the Oberon Sawmill which is the closest region with large pine plantations.
Current use of feedstock:	Significant amounts of wood waste left in plantations to biodegrade. Waste from saw mills is typically used by panel board manufacturers, however bark and thinning waste is typically used in landscaping industry
Future supply:	Forest NSW plantations around Sydney are expected to grow annual output significantly in the medium term.

Technical performance

Calorific value (Gj/t dry basis):	~20.6Gj/dbt
Moisture content as received (%):	41.2%
Specific gravity (t/m3):	0.35 as wood chips, 0.62 as pellets
Availability / seasonality:	Availability is dependent on plantation harvesting schedules, however biomass can be stored to maintain consistent supply.

Broad acre crop stubble

Broad acre crop waste refers to the waste created when harvesting crops such as wheat, barley, oats, canola and lupin as well as rice, hay and sugar cane.

The stalks that are left after harvesting grain and the husks left after processing the grain can be used as biomass feedstocks. They are sometimes referred to as infield residues (crop stubble) and trash (processing waste).

Broadwater Sugar Mill
Location: Broad water, NSW
Date of completion: 2008
Size: 35MWe
Source: Sunshine electricity

Supply chain and maturity

Availability of feedstock:	Large areas of NSW west of the Great Dividing range are used to grow grain crops however the availability of the feedstock within 100km of the City of Sydney is comparatively small.
Current use of feedstock:	Grain crop stubble is typically bailed as straw or left to decompose on farmland. Some grain husks (wheat) are used to make ethanol or other valuable by-products.
Future supply:	Although extended drought poses a level of risk to the supply of grain in NSW, the closest areas to Sydney have not experienced the same level of drought as the rest of NSW.

Technical performance

Calorific value (Gj/t dry basis):	~17.9Gj/dbt
Moisture content as received (%):	60%
Specific gravity (t/m3):	0.036 loose, 0.28 bailed
Availability / seasonality:	Availability is dependent on plantation harvesting schedule. However biomass can be stored for a short time to maintain consistent supply.

Vegetable crop waste

When harvesting vegetables from greenhouses and farms there is inevitably an amount of waste generated. This waste is typically generated at the processing end.

Earth Power technologies
Location: Sydney
Date of completion: 2003
Size: 3.5MWe
Feedstock: Green waste and vegetable waste
Source: Earth Power technologies

Supply chain and maturity

Availability of feedstock:	There is a relatively large horticultural industry close to Sydney in comparison to broad acre farming.
Current use of feedstock:	The organic waste generated is typically disposed of as green waste or composted for use onsite.
Future supply:	The use of greenhouses and other more intensive farming practices is likely to increase in the future as more water efficient practices are sought. This could increase the potential waste available to the City of Sydney as more intensive operations make collection easier

Technical performance

Calorific value (Gj/t dry basis):	~14.5Gj/dbt
Moisture content as received (%):	19.3%
Specific gravity (t/m3):	0.47
Availability / seasonality:	All year round although some crops a seasonal.

Chicken manure

Chickens, whether grown for meat or eggs, are farmed by increasingly intensive methods in NSW. This means that the manure the chickens produce is already collected and disposed of in the way necessary for conversion to energy.

Chicken manure is an energy dense, low moisture content feedstock that can be anaerobically digested or gasified depending on the conversion technology available.

Gut Mennewitz
Location: Germany
Date of completion: 2008
Size: 2.1MW
Source: resourceinvestor.com

Supply chain and maturity

Availability of feedstock:	There are a large number of chicken farms (for both meat and eggs) on the western edge of Greater Sydney.
Current use of feedstock:	Chicken manure is used as a natural fertilizer.
Future supply:	Unless there is a large scale decline in the consumption of chicken meat or eggs, or the farming of chickens moves further away from Sydney, the supply of chicken manure is secure.

Technical performance

Manure production (t/animal p.a.)	0.04
Volatile solids	24%
Gas Yield (m3/t VS)	350
Calorific value of gas (GJ/Nm3)	22.6
Availability / seasonality:	Availability is constant.

Pig manure

Livestock manure is comprised of approximately 10% solids and 90% liquids which produces methane as it decays. Pig manure is already collected at many piggery feedlots and treated through a number of methods including anaerobic ponds and lagoons and anaerobic digestion as a relatively new technology. Methane from these technologies represents a significant biogas resource.

The high liquid content means that transportation of the manure to a centralised treatment facility is not likely to be viable

Berrybank Farm
Location: Vic
Date of completion: 1991
Size: 225kWe
Source: Ballarat University

Supply chain and maturity

Availability of feedstock:	Pigs produce manure in piggery feedlots that is collected for disposal. Estimated availability manure from 65% of Pigs
Current use of feedstock:	Manure is disposed of via a range of methods including direct land application, anaerobic ponds and lagoons, and anaerobic digestion. Often solids are removed prior to disposal via screening systems or centrifuges and composted for sale as fertiliser. Significant methane produce can occur in these systems. Some collection of methane for combustion currently occurs. Manure deposited on fields and pastures, or otherwise handled in a dry form, produces insignificant amounts of methane.
Future supply:	Retrofitting of existing ponds for methane capture Installation of anaerobic digestion technology

Technical performance

Manure production (t/animal p.a.)	1.22
Volatile solids	6%
Gas Yield (m3/t VS)	250
Calorific value of gas (GJ/Nm3)	26.4
Availability / seasonality:	Availability is constant.

Cow manure

Livestock manure is comprised of approximately 10% solids and 90% liquids which produces methane as it decays. Cow manure is already collected at many dairies and feedlots and treated through a number of methods including anaerobic ponds and lagoons and anaerobic digestion as a relatively new technology. Methane from these technologies represents a significant biogas resource.

The high liquid content means that transportation of the manure to a centralised treatment facility is not likely to be viable

Dos Pinos Dairy Farmers Cooperative
Location: Costa Rica
Date of completion: 2008
Capital cost: $20k
Size: 16kWe
Source: Adelaide University

Supply chain and maturity

Availability of feedstock:	Livestock raised or temporarily yarded in concentrated areas, including dairy cows and feedlot cattle, produce manure that is collected and disposed of. Estimated available manure of 5% from Meat cattle, and 50% from dairy cattle
Current use of feedstock:	Manure is disposed of via a range of methods including direct land application, anaerobic ponds and lagoons, and anaerobic digestion. Often solids are removed prior to disposal via screening systems or centrifuges and composted for sale as fertiliser. Significant methane produce can occur in these systems. Some collection of methane for combustion currently occurs. Manure deposited on fields and pastures, or otherwise handled in a dry form, produces insignificant amounts of methane.
Future supply:	Retrofitting of existing ponds for methane capture. Installation of anaerobic digestion technology

Technical performance

Manure production (t/animal p.a.)	9.13
Volatile solids	10%
Gas Yield (Nm3/t VS)	200
Calorific value of gas (GJ/Nm3)	20.7
Availability / seasonality:	Availability is constant.

Existing Biodiesel

When harvesting vegetables from greenhouses and farms there is inevitably an amount of waste generated. This waste is typically generated at the processing end.

BIA Biodiesel
Location: Maitland, NSW
Feedstock: waste vegetable oil
Annual production: 2.5ML p.a.
Source: BIA Biodiesel

Supply chain and maturity

Availability of feedstock:	There are several biodiesel refineries in NSW, however only one produces biodiesel from waste products.
Current use of feedstock:	Biodiesel is predominantly used in vehicles as a replacement for conventional diesel fuel.
Future supply:	While there is a certain level of scepticism about using energy crops to produce biodiesel, there will almost certainly be a continuous supply of waste vegetable oil for which there are limited other uses.

Technical performance

Calorific value (Gj/kL):	~34.6Gj/kL
Availability / seasonality:	All year round.

Existing ethanol

Ethanol is produced by fermenting sugars found in biomass with yeast or other micro-organisms. Ethanol is essentially alcohol with the chemical processes at an industrial scale ethanol plant being quite similar to a home brew beer kit where yeast is added to break down sugars.

Manildra Flour Mill
Location: Nowra, NSW
Feedstock: Wheat husk and stalk residue
Annual production: 126ML p.a.
Source: Manildra

Supply chain and maturity

Availability of feedstock:	There are several ethanol plants in NSW, however only one produces ethanol from waste. In this instance the ethanol is from wheat mill waste.
Current use of feedstock:	Ethanol is used in many industrial processes however is most commonly known as a petroleum replacement in vehicle fuel
Future supply:	The use of broad acre crops to produce ethanol is likely to increase into the future as there is an established market with Commonwealth and State Government support.

Technical performance

Calorific value (Gj/kL):	23.4
Specific gravity (t/m³):	0.789
Availability / seasonality:	Ethanol can be stored easily

Coal seam methane (CSM)

Coal seam methane or CSM is produced during the creation of coal from peat. The methane in CSM is adsorbed onto the surface of micropores in the coal. The amount of methane adsorbed increases with pressure. CSM is expelled fro the seam over geologic time because coal has the capacity to hold only about a tenth of the methane it produces. Coal seam methane refers to the source of the methane, but the gas is indistinguishable from conventional natural gas.

It should be noted that CSM is not renewable and has virtually the same greenhouse gas impacts as natural gas.

Camden Coal Seam Gas
Location: Sydney
Date of completion: 2007
Annual production: 5.4PJ
Source: AGL

Supply chain and maturity

Availability of feedstock:	Currently there is no direct supply of coal seam methane to City of Sydney. There are some small scale CSM projects in and around Sydney that feed into the gas network.
Current use of feedstock:	Coal seam methane is still a largely untapped resource, with large quantities of supply in and around Sydney
Future supply:	Companies like AGL and Apollo Gas plan to extract CSM in significant quantities from within Sydney in the near future.

Technical performance

Calorific value (Gj/Nm³):	~37.7 depending on the CO2 content
Availability / seasonality:	CSM is not seasonal dependant.

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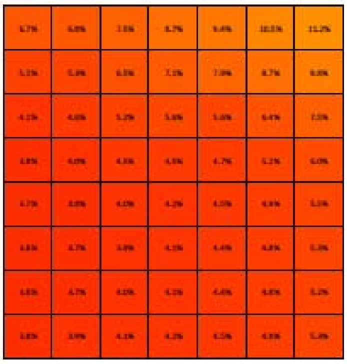
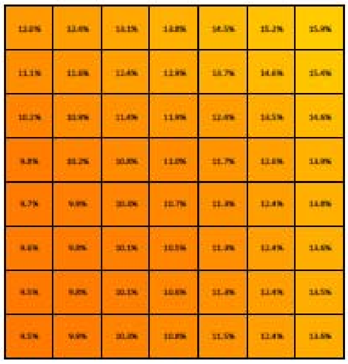
Appendix B

Wind Analysis

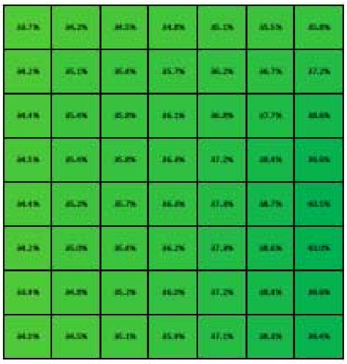
25m



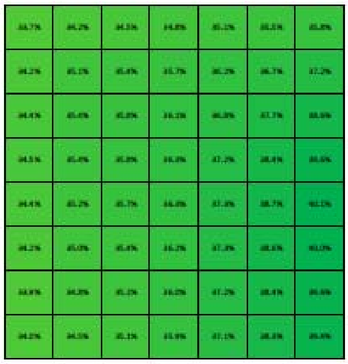
50m



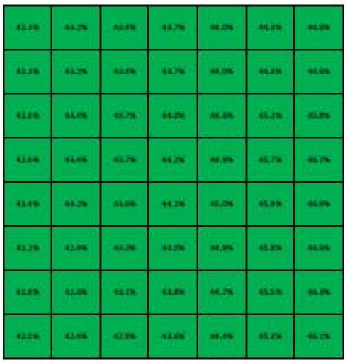
150m



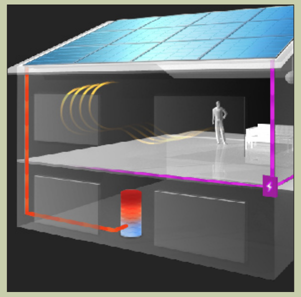
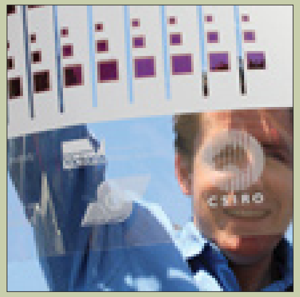
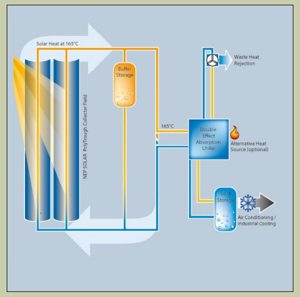
150m



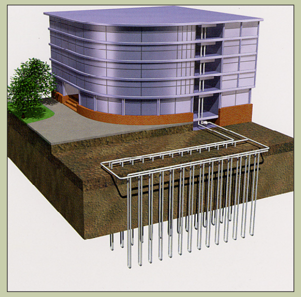
200m



Longlist of building scale technologies

								
Technology	Solar PV (Mono and poly crystalline silicone)	Thin film PV (cadmium telluride, amorphous silicone)	Concentrated PV	Solar PV thermal	Organic PV	Solar thermal	Solar thermal cooling	Solar CHP
Description	PV cells are made of a semi-conductor material, generally mono or poly-crystalline silicon, that is stimulated by photons of sunlight to generate an electrical current. Building integrated PV cells now applied in a number of different sizes and forms.	Different from standard PV cells in that this technology is a laminate applied as an intermediate layer in glazing, or as an external laminate to roofing and steel or glass work.	Traditionally uses dish or trough collector technology to focus solar energy onto smaller, ultra high efficiency PV cells. New lens technology has led to the development of a large number of flat CPV panels.	PVT combines solar PV and solar thermal technology. A water loop relieves heat from the back of a PV collector or collector array. This can be combined with standard PV arrays for low grade heat recovery for domestic use, or with concentrated solar PV for high grade heat and CHP applications.	Organic PVs use specially developed organic compounds - instead of silicon semi conductors - to generate electrical current when exposed to solar radiation. These compounds are generally applied in the form of OPV dye or polymer, printed onto surfaces such as glass or steel building fabrics. This makes them highly amenable to more complex surfaces and shapes.	Sunlight is used to heat water, either directly or indirectly, to between 70 and 200°C depending on the system. This water can then be used for hot water or, when combined with a heat pump, upgraded to high grade heat.	Solar thermal cooling uses solar thermal collectors - either evacuated tube, or concentrated trough collector - technology to create medium to high grade heat (90 - 200°C) which then runs an absorption chiller to produce cooling.	Typically a micro concentrated solar thermal (CST) collector trough or dish producing steam to drive Organic Rankine Cycle turbine, or directly driving a Stirling engine. Waste heat is captured for use in water and space heating and or cooling applications
Existing examples	Since the introduction of the Solar rebate Scheme (ending June 09) approximately 60,000 applications relating to separate installations had been lodged. 5616 School have registered for the Federal Government Solar Schools Program	Thin film makes up a small proportion of the Australian PV market, although the technology is readily available and commercially mature.	Currently there are very few building integrated CPV installations in Australia. Several utility scale plants in operation in Australia	Owens Corning Manufacture Facility Canada 1,030 SolarWall installation Beijing Olympic Village 10kW PV, 20kW thermal capacity Chewonki Centre for Environmental Sustainability 3.5kW PV, 20kW thermal capacity	Skyshades Australia currently commercialising OPV shading. Konarka Power Plastics USA have completed a OPV curtain wall for Arch Aluminium and Glass. Solarmer Energy Inc prototyping building integrated products, anticipated release in 2011. CSIRO are currently investigating commercialisation of newly developed OPV technology	Conventional flat panel hot water heaters (Solahart, Rheem etc) Evacuated tube hot water systems Evacuated tube and parabolic trough systems (Solitem, NEP Solar). Large custom evacuated tube widely used in domestic and commercial buildings in Australia.	Solitem cooling, REDI Solar Cooling Demonstration Project, Newcastle. System developed by NEP solar	Southern California Gas Co. Solar Cooling and Power Sopogy Micro Solar CHP systems
Strengths	Established technology and supply chain within Australia with thousands of building integrated installations. Can be integrated into façade, shade and roof glazed systems. Cost and efficiency of systems still improving. Less dependent on direct solar than concentrated solar power systems	Emerging large scale supply chain through large PV and glass manufacturers. Façade components with integrated thin film PV are now readily available. Cost of thin film systems reducing rapidly	Established utility scale technology and supply chain within Australia Conventional designs are able to replace PV cell as efficiencies improve. Currently two to three times the efficiency of standard PVs. Flat optical CPV technology provides additional opportunities. If scale is correct CPV is cheaper than traditional PV	Better utilisation of space, electrical and thermal energy recovery No duplication of systems in domestic applications (e.g. PV system & solar hot water system) Able to use for domestic space heating as well. Heat removal improves PV efficiency.	OPVs provide power in low solar irradiance levels (e.g. overcast weather) and can operate purely on diffuse solar irradiance. Expect major commercial activity in time frame. Industry is currently targeting $1-$2/Watt generation capacity. Flexible application for roof mounted, facade interlayer, and OPV fabrics for shade structures.	Commercially viable, with established Australian manufacture, supply chain, retail industry Design well suited to building integration Opportunities for industrial process applications where significant thermal energy is required e.g. laundry or baking facilities	Peak output of solar cooling systems occur when cooling demand is highest. Established local manufacture and supply chain. Local research invested in improving the technology. Cost effective for large scale applications Low maintenance, and long lifetime compared with traditional chilling equipment	Established technology. Modular system design. Ability for scale up of operation Combines benefits of concentrated solar thermal electricity, with possibility for high grade heat capture Heat can be used to drive absorption or adsorption chilling process
Weaknesses	Still requires large subsidies to compete economically. Does not perform as well as OPV at low solar irradiance levels	Life span of technology not as good as traditional PV.	Concentrated systems require direct sun light. Overcast weather significantly affects output. Traditional systems are not as land use efficient as conventional PV, however lens technology may overcome this weakness. Limited Australian supply chain for new flat panel designs.	Approximately 20% cost premium over standard PV panels Best utilised where there are significant heating loads to accompany electrical requirements. Limited Australian supply chain exists.	Currently in prototype testing and early commercialisation stages. There are currently only few large scale applications worldwide. No established supply chain for this technology. However some start up companies in partnerships with larger glass, steel and fabric shade companies. Issues with lifespan of technology. Low electrical efficiency (6.5%)	Only offsets electricity and gas use associated with thermal applications: e.g. hot water, space heating, process and cooking.	Smaller domestic scale application is less cost effective Must compete for space with other solar technology	As with other concentrated solar power systems does not operate well in cloudy weather conditions
Shortlist?	IN In areas where there is no requirement for additional heating or PV-T is not feasible.	IN In areas where silicone PVs are not suitable and where price is more important than land use efficiency	IN	IN	IN	IN	IN Specific building typologies (e.g. commercial offices, shopping centres etc)	OUT Number of sites where solar CHP is better suited than either solar thermal or solar cooling is expected to be very small within LGA.

Longlist of building scale technologies






Technology	Ground source heat pump	Piezo electric	Algal walls	Low pressure water turbine	On-site micro anaerobic digestor	Wind turbines
Description	Water is pumped though underground pipes or hoses that are either buried horizontally or vertically. The water is heated or cooled to ground temperature and can then be used as space heating and cooling as well as hot water.	Piezoelectric generators use the vibrations provided by people or vehicles travelling over pads or tiles built into the ground covering to generate electrical current.	Algae grows in specially engineered ponds or enclosed tubes/vessels using solar photosynthesis to drive growth. Algae is then harvested and turned into fossil fuel replacements (e.g. petrol, diesel etc.)	These turbines can be applied to rain water catchment on site. This rainwater catchment would have to be elevated to provide sufficient pressure head.	These systems capture methane produced by the decomposition of organic waste which can then be used as fuel to drive an engine.	Blades or fins are shaped such that they power a generator when forced to move by the wind. Two major technology streams in micro wind turbines: Horizontal Axis (HAWT, pictured), and Vertical Axis wind turbines (VAWT).
Existing examples	Geoscience Australia building in Canberra has a ground source air conditioner. The technology is common for households and commercial buildings in Northern Europe	East Japan Railway Company (JR East) have installed Piezo eletcric pads at Tokyo station. A 25m2 area in the busiest trains station in Japan is expected to generate 1.4MWh per day Small tile systems being commercialised by Powerleap CSIRO working on larger scale applications	There are currently no building integrated algae biofuel growers in Australia. Large fossil fuel companies such as Exxon mobile are currently investing heavily in creating market ready products on a larger scale.	A number of small domestic water type water turbine manufacturers, mainly USA based e.g. WSE Technologies.	Most anaerobic digestors are related to a biomass feedstock (agricultural bi-products or municipal waste). Some small scale examples exist at farms or at sites where the main priority is waste water treatment.	Ballast Point Park, Sydney. 8 X 1kW Ropatech turbines. 385 Bourke St Melbourne 12 x 6kW Quiet revolution wind turbines ANZ Centre Melbourne 6 x 6kW Quiet revolution wind turbines
Strengths	Ground source heat pumps are more efficient than conventional electric, gas, and air heat pump hot water systems. Can be used to cool in summer	As peizo electric systems are building integrated they offset the cost of the building material that would otherwise be required. Generation can be highly predictable if placed in high use roads/footpaths. Generation profile is consistent with peak hour, which lines up with evening peak demand.	The algae can create fuels that feed directly into current vehicles or CHP systems without the need for modification or conversion.	Compact and relatively cheap solution	Provides fuel that can support stationary energy or transport engines Reduces waste going off site.	In appropriate locations can be cost effective solution Site diversity can provide enhanced overall power predictability Integration into architecture
Weaknesses	Ground source heat pumps still require electricity to run. Drilling the wells for the water pipes is expensive, in most cases making it more expensive than either air sourced heat pumps or solar hot water. Not suitable for retrofit to existing buildings as requires substantial sub surface works	Applicable only to high pedestrian traffic areas and low speed roads (e.g. car park entries) Unlikely to generate significant amounts of electricity without significant investment. Products are not currently commercially available in Australia, although there are demonstration projects in Japan.	Low yield compared with other building integrated solutions. Occupies the same space as building integrated solar. Higher maintenance requirements compared with other building integrated renewables. Distribution supply chain not yet fully formed.	Only generates power if next to running water or in domestic applications when water is being used. Would require large tanks to be installed first. Large collection area and water demand needed for significant outputs. May cause issues with plumbing systems if not well integrated. Relatively small potential.	Needs significant organic waste stream Takes up large amounts of space Consequences relating to the risk of venting of toxic compounds are much more serious in an urban setting. There are very few building level applications that would produce a net positive energy balance. Diverts feedstock from CHP.	Only produces power when wind is blowing, predictability not as good as other technologies. Noise is a major issue in urban and sub-urban areas although VAWTs tend to be less noisy. When location is poorly selected turbines significantly under-perform (e.g. Ballast Point Park in Balmain).
Shortlist?	IN While this technology is more suitable to new builds than existing buildings, there is expected to be significant new development of apartments in certain areas of the city.	OUT Very location specific (i.e. train station entries and commercial car park entries).	OUT Lower land use efficiency and technology is not as mature as others.	OUT Potential resource is small and local supply chain does not exist.	OUT Diverts feedstock from CHP system.	IN Location specific (e.g. very tall buildings, ridges in parks, harbour foreshore areas etc).

Longlist of utility scale* technologies









Technology	Solar Photovoltaics	Concentrated PV	Concentrated solar thermal	Onshore wind	Offshore wind	Hydro electric	Wave / ocean energy	Tidal / ocean current energy	Geothermal
Description	PV cells are made of a semi-conductor material, often crystalline silicon, that is stimulated by photons of sunlight to generate an electrical current. Utility scale plants can be either fixed in orientation, have 1 axis tracking or 2 axis tracking.	Heliostats or lens' are used to concentrate solar radiation onto a high efficiency PV module. Existing installed systems in Australia have efficiencies above 30%, new technology developed at UNSW has seen +40% efficiencies in lab testing.	There are several major types of CST including Compact Linear Fresnal Reflectors (CLFR), Parabolic dish and heliostats with sterling engines, all use mirrors to focus sunlight. Temperatures range from 150° C to over 1000° C. Most technologies either drive steam or organic rankine turbines to generate electricity.	Horizontal Axis Wind Turbines ranging from 800kW up to 5MW are typically placed along ridgelines where wind speeds are greatest. Cut-in speed (the speed where turbines begin to generate electricity) is typically around 3.5 to 4 m/s.	Offshore wind involves anchoring wind turbines in the ocean. Established anchoring methods involve building seabed foundation. Newer techniques that are yet to be commercialised involve floating the turbine and anchoring several stay cables which hold the turbine mast in place.	Hydro uses the potential energy from natural water flows and those created by dams to turn turbines and generate electricity.	Surface waves and pressure variations below the ocean's surface can generate intermittent power. Floating buoys, platforms, or submerged devices placed in deep water, generate electricity using the bobbing motion of the ocean's waves.	There are three main technologies considered: Tidal barrage, tidal pool and ocean current. In tidal power as the tide flows in and out, it passes through turbines to generate electricity. Current turbines are slightly different and do not require a barrage or pool. Instead, they use a funnel to force water though a turbine.	Geothermal energy uses heat from underground to generate electricity or for use as heating. Deep geothermal energy involves drilling wells up to 5km deep and pumping water onto hot rocks or resovoirs to capture the heat. Typically the heat must be around 200° C to 300° C in order to generate electricity. Lower temperature heat can be used for other purposes.
Existing examples	Currently there are no PV installations considered to be utility scale in operation in Australia. There are several MW scale plants planned in Australia.	Solar Systems 720kW system at Hermannsburg, Yuendumu and Lajamanu in 2006. Solar Systems 180kW system at Windorah in 2008.	Liddell power station (coal fired) solar augmentation by 9MWth $5m CLFR system. CSIRO has a 250kWth solar tower ($1.5m), set up to increase energy content of natural gas. Many plants overseas on significantly larger scale, notably PS10 (10MW), PS20 (20MW), Andasol 1 and 2 (50MW each) in Spain.	There are currently 6 accredited renewable wind farms in NSW at Kooragang Island 600kW (one turbine), Blayney 9.9MW, Crookwell 4.8MW, Hampton 1.2MW, Cullerin Range 30MW and Capital Hill 132MW. According to ABARE there are another 2.7GW of wind farms currently planned for NSW	Currently there are no offshore wind power installations in commercial operation in Australia.	Hydro is the oldest form of renewable energy and is the most established in NSW. Existing plants in close proximity to Sydney include Glenbawn Dam 5.5MW near Scone, Chichester Dam 110kW, Dungog 350kW, Warragamba 50MW (closest), Sydney Water are planning several hydro schemes that will generate 20GWh p.a..	Currently there are no wave or ocean power installations in commercial operation in Australia. Oceanlinx recently received Commonwealth Government funding for a demonstration scale wave power system at Port Kembla.	Currently there are no tidal power installations in commercial operation in Australia.	Currently there are no geothermal installations in commercial operation in Australia. Geodynamics have the rights to the geothermal resource closest to Sydney (in the Hunter region). Although their plans focus on exploiting the Cooper Basin in SA / West NSW.
Strengths	Very established technology. Trends towards decreasing costs. Predictable energy output. Up to 90% land use efficiency for roof systems. More like 75% for large scale stand alone systems where supporting frames and larger walkways are necessary.	CPV is considerably more efficient than standard PV modules. Latest technology developed at UNSW has efficiencies over 40%. The majority of the capital cost is in the heliostat and supporting structure. The PV modules can be replaced as technology efficiencies increase.	The electricity generation equipment can be upgraded separately to the solar collectors. Costs are predicted to drop dramatically over the next decade. Some technologies have good land use efficiency (between 50% and 80%). Heat can be stored in tanks and used during the night to provide base load power	One of the cheapest technologies for renewable energy generation ($1.6-$2.2/W). However requires strong consistent winds for economic viability. Wind threshold in the order of 7-8m/s average annual wind speed. Agriculture can work effectively around a turbine mast.	Wind resource as close as 10km offshore is considered to be good. Very low visual and noise impact on the City.	The technology is proven and cheap and at a micro scale. Hydro can be environmentally sensitive at a small scale using natural flows.	Semi-predictable output. Demonstrations of wave energy are being conducted within 200km of LGA suggesting there could be a viable resource.	Highly predictable and semi controllable with a tidal barrage or tidal pool	The level of the resource is so huge in some areas of Australia that GW scale plants could be viable in the future. Once wells are drilled the ongoing costs are low. Potential resource and electrical transmission infrastructure exist close to Sydney.
Weaknesses	Very expensive in comparison to other technologies in terms of upfront costs ($7-$10/W) Inefficient in land use compared to other technologies Currently no domestic capacity to provide the technology.	The land use efficiency of CSPV is not as good as conventional PVs at the heliostats need to be spaced to avoid overshadowing. CSPV plants tend to suffer larger decreases in output when the sky is cloudy. High capital costs ($4-$10/W). Requires buffer distance to reduce glare.	As with CSPV, CST suffers major losses in output from cloudy days. Potentially large water usage. Technologies such as parabolic trough and large solar towers can have very low land use efficiency. High capital costs ($4-$6/W). Requires buffer distance to reduce glare.	Where a commercially viable wind farm would operate at 30 - 40% capacity factor, indicative analysis of Sydney wind speeds would result in only 20% (half the energy). Noise issues in populated areas for large turbines. Not as predictable as other resources.	Significantly more costly than on shore wind in terms of capital and operational costs. Requires heavy lift vessels which are not currently available on the east coast of Australia. The capital and maintenance costs of offshore wind are higher than onshore wind.	It is likely that resources in close proximity to Sydney have been exploited.	Not yet commercialised Expensive compared to upfront cost of other technologies Systems operating in Europe are doing so with the benefit of a significant feed-in tariff. Requires a minimum wave energy in the order of 30kW/m to be considered viable.	Tidal is not yet commercialised and is expensive compared to other technologies. Systems operating in Europe are doing so with the benefit of a significant feed-in tariffs. Requires a minimum mean spring tide in the order of 2.5m/s to be considered viable. The nearest viable resource is in the Bass Strait.	Drilling wells is becoming more expensive. Technology is currently expensive ($4-$5/W). Other than the Hunter the nearest resources are approximately 1000km away. Indicative analysis indicates that the Sydney resource is not hot enough for electricity generation.
Shortlist?	IN Within the LGA, utility scale PV will be best suited to large building roofs.	IN The longevity of the structure could make CPV more viable than conventional PV.	IN Within the LGA only where large heating load exists	IN Within the LGA only where there are no noise and visual impact sensitive receivers.	IN The most commercially mature and scalable offshore technology	OUT** Potential resource is likely to be very small within the LGA.	IN Potential resources in areas close to the LGA.	IN Tidal barrages will be analysed based on available physical resource within the harbour.	OUT** Direct heating will be considered but not electricity generation.

*For the purposes of the City of Sydney Renewable Energy Masterplan, utility scale technologies refers to a single installation of renewable energy over 100kW for PV/solar and 10kW for wind turbines as defined by the Office of Renewable Energy Regulator thresholds for Small Generation Units. See http://www.orer.gov.au/publications/pubs/sgowners-guide-1009.pdf

**Arup do not intend to further consider these technologies at this stage, but they may form part of an offsite strategy should the renewable energy target not be able to be reached from technologies physically located within the LGA.

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Longlist of feedstock sources

Technology	Municipal and commercial waste	Industrial waste	Sewage gas	Landfill gas	Agricultural and forestry residues	Energy crops	Existing biodiesel / ethanol supply chain	Coal Seam Methane (CSM)
Description	This category includes household and business generated food waste, refuse derived fuel (sorted solid waste), green waste, mixed solid waste, as well as construction and demolition wood waste.	This category includes paper sludge, food manufacturing waste, abattoir waste, waste vegetable oil, and any other readily available waste stream within the LGA.	Human and industrial waste water can be digested to produce biogas. This is common in current waste water treatment practices, although the biogas is sometimes flared rather than used for energy generation.	A network of perforated pipes buried in a landfill harvest the methane that is emitted by the landfill waste as it biodegrades. This practice is very common in Australian landfills.	Waste products that arise from agricultural and forestry activities include bagasse/sugar cane waste, wheat stalks, animal dung, forest thinings, and saw mill waste. Business as usual practice for these feedstocks would be biodegration or burning.	Energy crops are crops that are grown on arable land, for which the primary purpose is converting to bioenergy or biogas. They can be grown in mono and poly cultures on land and may not necessarily be the primary crop.	Biodiesel and ethanol are fuel products produced from biodegradable materials. Biodiesel can be used in all applications where conventional diesel can be used (many CHP systems), Ethanol can be used in many of the applications for petrol. The market already exists (feedstock collection and fuel conversion) and is readily accessible.	Coal seams commonly contain large amounts of methane molecules that are trapped in the coal. The most common method for extracting CSM is to pump water at high pressure into the coal seam, loosening the methane which is pumped to the surface. Coal seam methane is a fossil fuel and is very similar to natural gas in its global warming potential.
Existing examples	WSN's facilities at Eastern Creek and Lucas Heights. Veolia's facilities Woodlawn Bioreactor. There are numerous waste to energy plants operating in Japan, Europe and the U.S.	Visy Pulp and Paper Mill Tumut (20MW) uses black liquor, bark and wood waste. The energy generated is mostly used onsite.	Cronulla Sewage Treatment Plant (485kW) CHP. Generates 10% of Sewage Treatmant plant's energy requirements Malabar Cogen Facility (3MW) North Head Sewage Treatment Plan supplies 15% of sites energy needs. Bondi waste water treatment plant CHP has just been commissioned.	Eastern Creek 2 X 2.5MW Jack's Gully 1MW Lucas Heights II pipes gas 5km to existing CHP facility Numerous other landfills around Sydney collect biogas to run CHP systems.	Delta Electricity's sites at Broadwater and Condong Size: 30MW each Burn bagasse (waste from Sugar cane)	Several biodiesel and ethanol plants in Australia currently use energy crops for biomass supply (see right).	BIA Biodiesel Plant near Maitland produces 50kL per week from used cooking and vegetable oil. National Biofuels Limited have a Soya Biodiesel production facility at Port Kembla. 80% of soy production goes into meal for cattle feed/ Manildra Ethanol Plant uses waste products from a flour mill to distill ethanol.	Coal seam methane currently supplies several large utility scale CCGT power stations in Queensland. There are plans to pipe CSM from South East Queensland to the Hunter region.
Strengths	Predictable supply of feedstock; not seasonal. Waste treatment facilities that could convert some of these waste streams are already operating in Sydney. Likely to be one of the largest sources of feedstock in within the LGA	Predictable supply of feedstock; not seasonal. Several large packaging manufacturers and food manufacturers in Sydney	Reliable source of waste matter. Fuel conversion technology (digestor) and CHP systems already in place at many waste water treatment facilities in Sydney, including Bondi and Malabar where City of Sydney's sewage is treated.	Currently a reliable source of biogas. Technology is mature and commercially viable. Several existing facilities within 30km of the LGA. Waste heat is not needed onsite, so rationale for onsite energy generation is limited.	Any carbon emissions associated with harvesting and growing are attributed to the primary crop and not to the waste product. Considered carbon neutral at processing plant. Generally quite high energy content. Existing supply chain.	Technology required for growing and harvesting is all very mature and widely used. Crops such as mallee eucalyptus have been shown to reduce the likelihood of salinity. Poly culture farming possible (does not necessarily displace food crops) High to very high yields in terms of land. Supply chain infrastructure exists already to some degree.	When converted from waste products can result in large GHG savings. Typically CHP systems can be fueled by biodiesel. Supply chain already exists.	CSM presents significant quantities of supply. According to the NSW Department of Primary Industries the recoverable gas in the Sydney Basin could amount to over 5,000PJ. Scope 1 emissions factor similar to natural gas (lowest of the fossil fuels)
Weaknesses	Moisture content of feedstock is relatively high. To reduce the collection and sorting costs involved a comprehensive source separation strategy needs to be developed.	Many industrial processes require large amounts of heat which implies that from a carbon perspective the greatest benefit would occur if the feedstock were used in a CHP system at the source.	Sewage treatment plants require large amounts of electricity to run as well as an amount of heat. City of Sydney would be competing with the retail electricity price paid to Sydney Water if purchasing gas from Sydney Water. Decentralised systems are possible but net energy benefit relies heavily on large scale treatment. No current mechanism exists to purchase sewage gas.	Organic waste is expected be sorted out from waste to landfill stream in the future. Once AWTs are more common it may not be as reliable a supply. No current mechanisms exist to purchase landfill gas.	Bagasse and wheat waste products are increasingly being used to generate electricity and or fuel with the majority of waste heat used on site. Forestry waste products are effectively being used to create synthetic wood panel products. Supply is seasonal and future supply to the LGA is not certain. Resources are likley to be over 50km away, which could be cost prohibitive.	Could be expensive to transport the solid fuel to Sydney. Planting crops solely for fuel conversion could lead to the displacement of food crops Has life cycle carbon emissions associated with the growing and harvesting.	Typically CHP engines cannot run on Ethanol unless they are specifically designed; ethanol is more suited to petrol type engines. Can be quite greenhouse gas intensive if produced from some energy crops	CSM is not considered renewable by the Office of Renewable Energy Regulator. The Renewable Energy (electricity) Regulations 2001 as amended September 2009 Division 2.2 section 7 explicit states that CSM is not considered renewable.
Shortlist?	IN One of the largest potential resources within the LGA	IN Only when there is no demand for waste heat at source or when there is no CHP at source.	IN Large resource, supply chain partially exists.	IN Large resource, supply chain potentially exists	IN Potential resource is significant	OUT* To be considered if other feedstocks cannot meet the demand from the CHP systems.	IN Existing supply chain and removal of risk make this very attractive. The use of ethanol is dependent on CHP engine type.	OUT* This resource will not contribute to any significant reduction in carbon emissions within the LGA.

* Arup do not intend to consider these technologies further at this stage, but they may form part of the contingency strategy where renewable feedstocks are not able to be identified from the waste sources.