# Canning Bridge Structure Plan
# Sustainable Infrastructure Study

March 2014

# Executive summary

*This executive summary is subject to, and must be read in conjunction with, the limitations set out in Section 1.3 and the assumptions and qualifications contained throughout the Report.*

## Scope

GHD has been appointed by the City of Melville to investigate sustainable infrastructure opportunities to inform the Structure Plan for the Canning Bridge Activity Centre.

The study has dual objectives:

### *Energy*

To define energy efficiency performance for the built form and to establish economically efficient energy delivery systems that together will deliver a significantly lower energy and greenhouse gas footprint for the Canning Bridge precinct than for conventional development.

### *Water*

To complement the base requirements of local water management strategy with a comprehensive approach to water efficiency and the substitution of scheme water with alternative sources.

## Context

The National Urban policy (Our Cities, Our Future) is aimed at ensuring we have a productive, sustainable and liveable future. This document includes sustainability objectives and priorities, including:

- reduce greenhouse gas emissions and improve air quality; and
- manage our resources sustainably .

State Planning Policy (SPP) 4.2 also recognises the importance of reserves conservation (Section 5.5).

*The planning of activity centres should contribute to the conservation of resources, in particular a reduced consumption of energy and water.*

The demand for energy and water is significantly driven by the urban and built form. The infrastructure required to provide these services in a resource efficient manner needs to be embedded in urban design and reflected in structure planning. The deferment of infrastructure considerations to stages beyond structure planning will lead only to more business as usual outcomes, because it is essentially too late to introduce innovations at that stage.

This report aims to identify how sustainable infrastructure can be incorporated directly into the Structure Plan for the Canning Bridge Activity Centre, and in doing so establish a new benchmark for integrating urban and infrastructure planning.

## Existing system capacity and future demand

### *Power*

Applecross / Mt Pleasant areas

Western Power’s Network Capacity Mapping Tool (NCMT) forecasts limited available capacity at the Myaree and Riverton zone substations for any future growth in these subject areas. NCMT currently shows 15-20MVA forecast available capacity from 2012 and continues to reduce in capacity to 5-10MVA in 2019. From 2020 the forecast capacity reduces down to 5-10MVA until 2027 and then shows <5MVA onward to 2031.

Como, Manning and Manning South areas

The NCMT forecasts limited available capacity at the Collier zone substation for any future growth in these subject areas. NCMT currently shows 15-20MVA forecast available capacity from until 2012 to 2016. The forecast capacity reduces to <5MVA from 2017 up to 2031.

These assessments do not take into account the significant additional demand from the densification envisaged in the draft Structure Plan.

GHD has assessed future demand at full development as outlined below, assuming business-as-usual energy efficiencies apply.

| | |
|---|---|
| Peak power demand | 45 MVA |
| Annual electricity demand | 160,000 MWh |
| Annual greenhouse gas emissions | 100,0000 tCO2-e |

***Water***

Water Corporation has indicated that the existing water network has sufficient capacity at present, and that the existing servicing is adequate for the current zoning from a planning perspective. No upgrades are planned to accommodate increased density, and any upgrades will be driven by the approval of a Scheme/Structure Plan.

Future demand at ultimate development will rise from the present 0.5 GL pa to around 2.5 GL pa, assuming conventional demand patterns.

***Wastewater***

According to the Water Corporation most of the current system has sufficient capacity to cope with the existing demand. Planning work carried out for South Perth in 2010 indicated that there are already a couple of short sections of sewer that are at capacity. Their long term planning includes a doubling of the flow in the main sewer from existing levels, and this would require duplication of many sections of the existing sewer. Implementation of the Structure Plan will likely impact the South Perth Main Sewer.

Future wastewater flows will increase from approximately 0.35 GL pa to around 2.2 GL pa.

## Required infrastructure upgrades

The Canning Bridge Structure Plan servicing report will address the necessary upgrades through discussions with Western Power, ATCO Gas and the Water Corporation. Accordingly the capital cost estimates here are both preliminary and very approximate. They are intended to inform the analysis of servicing options rather than predict capital costs. These costs will be incurred over the development period.

| | | Description | $2014m |
|---|---|---|---|
| Power | Generation | Additional capacity on the SWIS | 85 |
| | Distribution | Substation, feeder and local network upgrades | 17 |
| | | Subtotal | 102 |
| Gas | Distribution | Local upgrades | 3 |
| | | | |
| Water | Source | Upgrades to IWSS source | 54 |

| | | | |
|---|---|---|---|
| | Distribution | Local upgrades | 4 |
| | Reticulation | Local upgrades | 12 |
| | | Subtotal | 70 |
| Wastewater | Treatment | Upgrades to WWTPs | 30 |
| | Distribution & pump stations | Local upgrades | 10 |
| | Reticulation | Local upgrades | 20 |
| | | Subtotal | 60 |
| | | Total | 235 |

## Potential Sustainability Initiatives

***Demand Management***

Reduced demand for energy and water offers the potential to significantly improve sustainability outcomes and reduce both capital and operating costs, irrespective of how utility services are provided. Accordingly demand management should be the foundation of any urban sustainability strategy.

In practical terms this means design guidelines for buildings that require:

- thermal efficiency of the building fabric; and
- energy and water efficient equipment and appliances.

***Decentralised Infrastructure***

There is an increasing interest worldwide in decentralising infrastructure, in other words placing the sources of energy and water closer to their point of consumption. Although the headworks cost per unit service is likely to be higher than for centralised headworks due to scale dis-benefits, the cost of transmission and distribution is reduced, as are the losses. Decentralised systems are not intended to be independent of the centralised systems, rather they complement them, and reduce the scale of the necessary upgrades.

Energy generation options considered potentially viable at the precinct scale at Canning Bridge are considered to be:

- Solar PV – electrical energy
- Trigeneration - electrical and thermal energy
- Geothermal – thermal energy

In respect of decentralised water infrastructure, it is considered that only the recycling of treated wastewater is viable. Under this scheme, wastewater flows from some / all of the existing wastewater pump stations would be diverted to a local recycled water plant (RWP). The RWP would produce a high quality product suitable for non-drinking water (NDW) uses such as toilet flushing, cold water for clothes washing and for irrigation. There is sufficient wastewater supply to meet the NDW demand in both summer and winter, assuming waterwise demand.

The NDW would be conveyed through a dedicated supply network to residential and commercial premises. This would require additional plumbing in buildings to accommodate a second water supply. The wastewater plumbing in buildings would be unaffected.

## Economic viability and performance of options

***Qualification***

Determining the likely costs of the options accurately is not possible with the limited information available on necessary upgrades for conventional servicing, and without a level of concept design for the alternatives. The following should therefore be taken as indicative of the potential relativity of the solutions only. Under no circumstances should the quoted figures be taken as infrastructure budgets for any of the options.

***Decentralised energy options***

The following energy options were evaluated.

| Option title | Thermal efficiency of buildings | Servicing |
|---|---|---|
| BaU | As per Building Code of Australia | Conventional centralised: South West Interconnected System (SWIS) |
| BaU - 5 stars | 5 star NABERS[1] | |
| BaU - 6 stars | 6 star NABERS | |
| 6 stars + solar + storage | 6 star NABERS | Precinct scale solar PV with electrical storage |
| 6 stars + trigen | | Precinct scale trigeneration |
| 6 stars + solar + storage + geothermal | | Precinct scale solar PV with electrical storage |

The options were compared by calculating the net present cost (NPC) over 50 years using the discounted cash flow technique, combining capital and operating costs. The results of the assessment are summarised below (land costs are excluded).

| | NPC without carbon price ($m) | NPC with carbon price ($m) | 50 year emissions (mt CO2-e) |
|---|---|---|---|
| BaU | 355 | 492 | 3.9 |
| BaU - 5 stars | 425 | 527 | 2.9 |
| BaU - 6 stars | 647 | 709 | 1.8 |
| 6 stars + solar + storage | 684 | 713 | 0.8 |
| 6 stars + trigen | 362 | 475 | 2.6 |
| 6 stars + solar + storage + geothermal | 382 | 404 | 0.6 |

The assessment identifies the greenhouse benefits of high performance buildings, solar and geothermal solutions over the fossil fuel based alternatives. Bearing in mind that this assessment excludes some costs for the BaU options (transmission and distribution upgrades), it infers that the 50 year NPC of the decentralised options is similar to conventional servicing with normal efficiency buildings even if a price on carbon is excluded.  If a carbon price is included, the decentralised options are somewhat cheaper than BaU.

[1] National Australian Built Environment Rating System (NABERS) is a national rating system that measures the environmental performance of Australian buildings.

The upfront capital cost of all the alternatives is significantly greater than the cost of business-as-usual. However the savings in building costs (capex and opex) mean that the decentralised options (trigeneration and geothermal) will ultimately be cheaper than the other options over the long term.

The cost of energy infrastructure is only a small percentage of the total built cost (i.e. buildings and infrastructure), the bulk of which occurs by 2025. If the total built cost of the options is compared over this period, the differences are marginal. The decentralised options would add between 4-6% to total built cost (in escalated / discounted dollars), assuming no carbon price. If this is included the differences will be less. This is effectively the economic cost premium for reducing emissions between 33 (trigen) and 80% (solar / geothermal) compared to BaU.

On the basis of this preliminary assessment, it appears that the decentralised solar / geothermal option offers the best emissions performance at the lowest economic cost.

***Decentralised water options***

The following water options were evaluated.

| Option title | Water efficiency | Servicing |
|---|---|---|
| BaU | Conventional | Conventional centralised water supply and wastewater disposal |
| Waterwise | Waterwise | |
| NDW with excess to sewer | Waterwise | Precinct scale wastewater recycling for non-drinking water (NDW) uses. Excess disposal to Water Corporation sewer. |
| NDW with excess disposal | | Precinct scale wastewater recycling for non-drinking water (NDW) uses. Excess disposal to local aquifer. |

The options were again compared by calculating the net present cost (NPC) over 50 years, combining capital and operating costs. The results of the assessment are summarised below (land costs are excluded).

| | NPC ($m) | Scheme water consumption (GL pa) |
|---|---|---|
| BaU | 99 | 2.53 |
| Waterwise | 70 | 1.71 |
| NDW with excess to sewer | 72 | 0.86 |
| NDW with excess disposal | 66 | 0.86 |

The analysis indicates that the cost of all alternatives to BaU will result in considerable economic savings while significantly reducing the demand on the Integrated Water Supply System (IWSS) for scheme water. As not all savings to BaU are captured in the analysis, the alternatives are likely to be more attractive than described above.

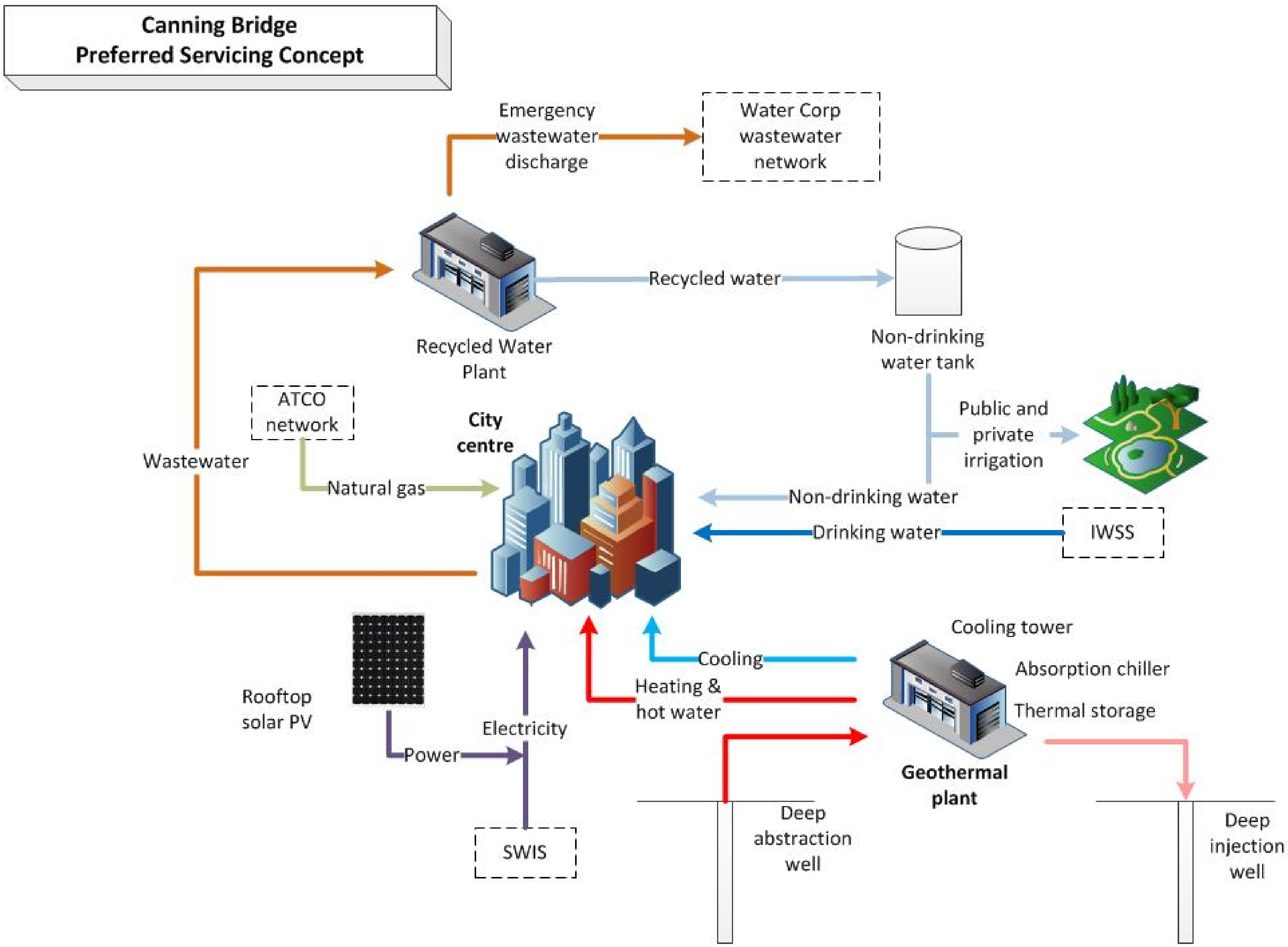
As is the case for the alternative energy solutions, a NDW scheme will incur greater early capital costs than BaU, although these costs are recouped over time. The total cost of water infrastructure is a very small percentage (around 1.2% for BaU), and so the additional investment in alternative water infrastructure is not significant in overall economic terms.

On the basis of this preliminary assessment, the incorporation of an NDW scheme sourced from recycled wastewater appears both economically viable and would lead to reduced demand on the centralised (metropolitan) scale water supply and wastewater networks.

### *Integrated solution*

Decentralised energy and water infrastructure offers the opportunity to integrate these services, e.g. the use of renewable energy to operate the NDW scheme, and the use of recycled water in cooling towers of the thermal energy system. The demand on both sets of infrastructure will increase at the same pace, and initial investment will be required for both networks.

The figure below depicts the potential integrated system.


Canning Bridge
Preferred Servicing Concept
Emergency wastewater discharge
Water Corp wastewater network
Recycled water
Recycled Water Plant
Non-drinking water tank
ATCO network
City centre
Wastewater
Natural gas
Public and private irrigation
Non-drinking water
Drinking water
IWSS
Cooling tower
Cooling
Absorption chiller
Heating & hot water
Thermal storage
Rooftop solar PV
Electricity
Power
Geothermal plant
SWIS
Deep abstraction well
Deep injection well

## Governance Arrangements

Implementation options for the preferred concept are:

- Separate implementation of each component through existing agencies, i.e. electricity (Western Power, Synergy / other retailers and generators), and water (Water Corporation);
- Separate implementation of each component through involvement of the private sector (electricity generation / retail, recycled water); and
- A new utility formed specifically to provide services at Canning Bridge which would provide integrated energy, water and waste services.

Although it would be a novel approach for Western Australia, a local government owned utility providing integrated energy, water and waste services is a logical way of implementing the strategy, and would reflect the approach taken for district energy systems in North America. It would need to be integrated with, and facilitated by the local planning scheme and associated development contribution plan. It is envisaged under such an arrangement that a private sector partner would design, build and operate the facilities as an integrated service contract, offering the additional benefit of risk mitigation and private sector investment.

It is recommended that the findings of this report are canvassed with a range of stakeholders, namely:

- the Cities of Melville and South Perth; and
- the Western Australian Planning Commission (WAPC) Infrastructure Coordination Committee.

Subject to these consultations the following authorities should be consulted:

- the Economic Regulatory Authority; and
- the relevant ministers and departments (Planning, Water, Energy, Local Government).

## Further Studies

This study identifies that the preferred servicing concept offers significant sustainability benefits, is technically feasible and economically viable. However a significant amount of further study and numerous consultations are necessary before the proposed infrastructure concept can be progressed.

***Concept feasibility studies***

- Solar PV
- Geothermal energy
- Recycled water

***Commercial viability studies***

Subject to the concept studies, further work will be required to determine commercial viability.

- Service delivery implementation options

  Examination of these options is a priority as the outcome of the preferred concept as described above is reliant on the identification of one or more service providers.

- Distributed thermal energy

These studies would include the land take and identify potential locations for the infrastructure.

## Development contributions

The implementation of the strategy as outlined above would need to be integrated with a development contribution plan (DCP) for Canning Bridge. The delivery of an integrated, decentralised energy and water scheme would need to be funded via a combination of development contributions and user charges.

There is significant risk to adequate and equitable funding of infrastructure if a Structure Plan is endorsed without a DCP in place. A development contribution plan does not have effect until it is incorporated into a local planning scheme or at least seriously entertained through initiation of the scheme amendment. Accordingly any development that occurs before this point would not be liable to contribute to the DCP.

A DCP is also the logical instrument to seek and incorporate any applicable grants from Commonwealth (e.g. Infrastructure Australia) or State government which will offset developer contributions, and may well be critical to successful implementation of the Structure Plan. A comprehensive DCP incorporating a Capital Plan provides a transparent plan underpinned by the statutory power of a local scheme.

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# 1. Introduction

## 1.1 Background and Purpose

GHD has been appointed by the City of Melville to investigate sustainable infrastructure opportunities to inform the Structure Plan for the Canning Bridge Activity Centre.

The study has dual objectives:

***Energy***

To define energy efficiency performance for the built form and to establish economically efficient energy delivery systems that together will deliver a significantly lower energy and greenhouse gas footprint for the Canning Bridge precinct than for conventional development.

***Water***

To complement the base requirements of the local water management strategy with a comprehensive approach to water efficiency and the substitution of scheme water with alternative sources.

The study area being considered is highlighted in Figure 1.

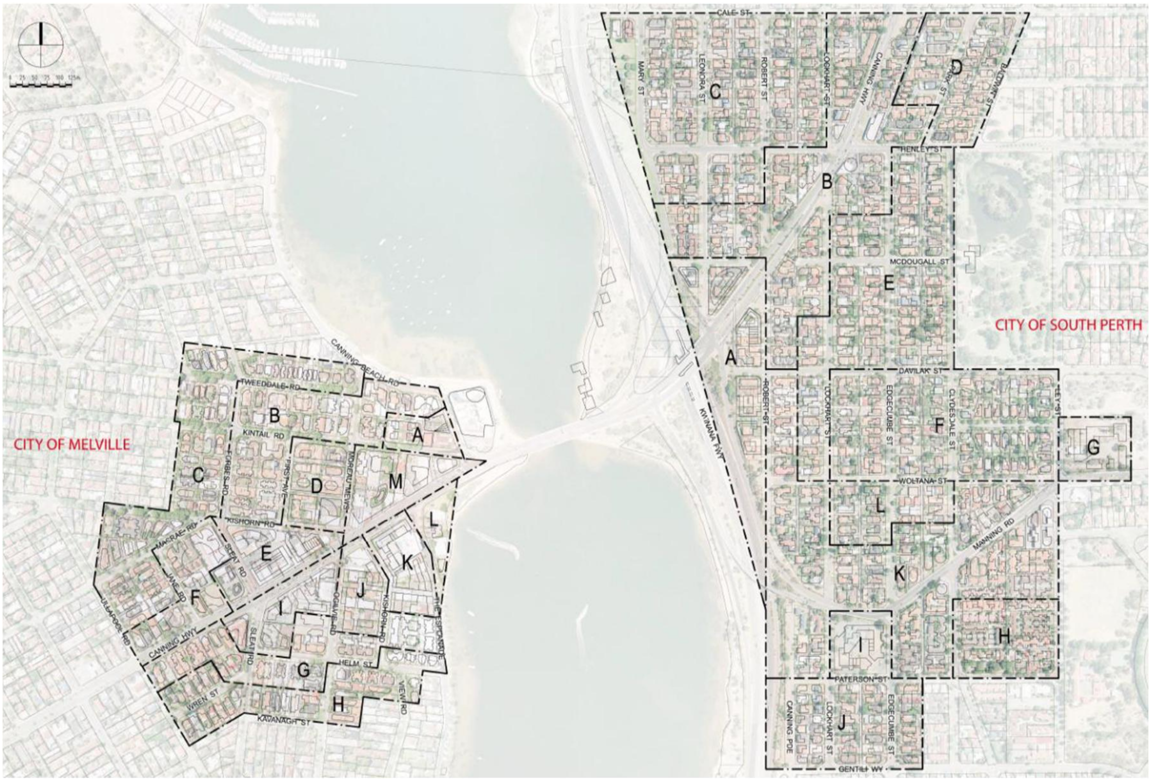



Figure 1: Canning Bridge Activity Centre study area

## 1.2 Scope

### 1.2.1 Energy Study

- Establish a Business as Usual (BaU) case as a baseline against which alternatives can be considered.

- Develop a number of intervention scenarios based on:
  - energy efficient buildings;
  - alternative energy generation and delivery approaches integrating lot, district and grid scale systems;
  - a renewable energy strategy at the lot and district scale;
  - opportunities for a smart grid rollout at Canning Bridge; and
  - the future role of electric vehicles.
- Develop a recommended approach;
- Identify a potential delivery strategy in respect of:
  - roles and responsibilities;
  - institutional arrangements; and
  - risks.
- Identify further work required to progress potential initiatives.

### 1.2.2 Water Study

- Establish a Business as Usual (BaU) case as a baseline against which alternatives can be considered.
- Establish water demand (existing and waterwise patterns of use)
- Establish a base case water balance for each stage, and cumulative development
- Identify alternative water sources including:
  - scheme water;
  - rainwater;
  - stormwater;
  - groundwater; and
  - recycled wastewater.
- Produce a short list of the most suitable combinations.
- Develop a recommended approach
- Identify further work required to progress potential initiatives.
- Identify a potential delivery strategy in respect of:
  - roles and responsibilities;
  - institutional arrangements; and
  - risks.
- Identify further work required to progress potential initiatives.

### 1.2.3 Report Structure

Section 2 of the report contains a brief description of the context of the study in respect of urban sustainability and the role of infrastructure.

Section 3 of the report provides a general outline of the existing water, wastewater and energy infrastructure and demands.

Section 4 identifies the likely future demands based on the draft Structure Plan.

Section 5 describes the nature of centralised system upgrades necessary to service future development.

Section 6 identifies potential sustainability initiatives for Canning Bridge, including demand management strategies and technology options.

Section 7 introduces the concept of decentralised infrastructure and identifies potential alternative approaches to the provision of energy and water services at Canning Bridge.

Section 8 describes the economic and sustainability performance of shortlisted options.

Section 9 describes the regulatory environment and sets out a recommended approach to develop an implementation and delivery strategy.

Section 10 sets out further studies necessary to progress a sustainable infrastructure strategy at Canning Bridge.

## 1.3 Scope and limitations

This report: has been prepared by GHD for City of Melville and may only be used and relied on by City of Melville for the purpose agreed between GHD and the City of Melville as set out in section 1.2 of this report.

GHD otherwise disclaims responsibility to any person other than City of Melville arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this report on the basis of information provided by City of Melville and others who provided information to GHD (including Government authorities)], which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

GHD has prepared indicative preliminary cost estimates set out in this report ("Cost Estimates") using information reasonably available to the GHD employee(s) who prepared this report; and based on assumptions and judgments made by GHD. The Cost Estimates have been prepared mainly for the purpose of comparing the options considered and must not be used for any other purpose.

The Cost Estimates are order of magnitude estimates only. Actual prices, costs and other variables may be different to those used to prepare the Cost Estimates and may change. Unless as otherwise specified in this report, no detailed quotation has been obtained for actions identified in this report. GHD does not represent, warrant or guarantee that the works can or will be undertaken at a cost which is the same or less than the Cost Estimates.

Where estimates of potential costs are provided with an indicated level of confidence, notwithstanding the conservatism of the level of confidence selected as the planning level, there remains a chance that the cost will be greater than the planning estimate, and any funding would not be adequate. The confidence level considered to be most appropriate for planning purposes will vary depending on the conservatism of the user and the nature of the project. The user should therefore select appropriate confidence levels to suit their particular risk profile.

# 2. Urban sustainability – the context

## 2.1 The Global Context

It is expected that 70% of the world's population will be urban dwellers by mid-century which will double the existing urban population globally.

Urban areas currently account for 60-80 per cent of global energy consumption, 75 per cent of carbon emissions, and more than 75 per cent of the world's natural resources.

The global ecological footprint has now reached 1.5, meaning that the annual rate of resource consumption is 1.5 times the regenerative capacity of ecosystems to provide the ecosystem services required to sustain society. It is imperative that city planners and urban designers deal with this challenge, indeed that they become central actors in addressing them.

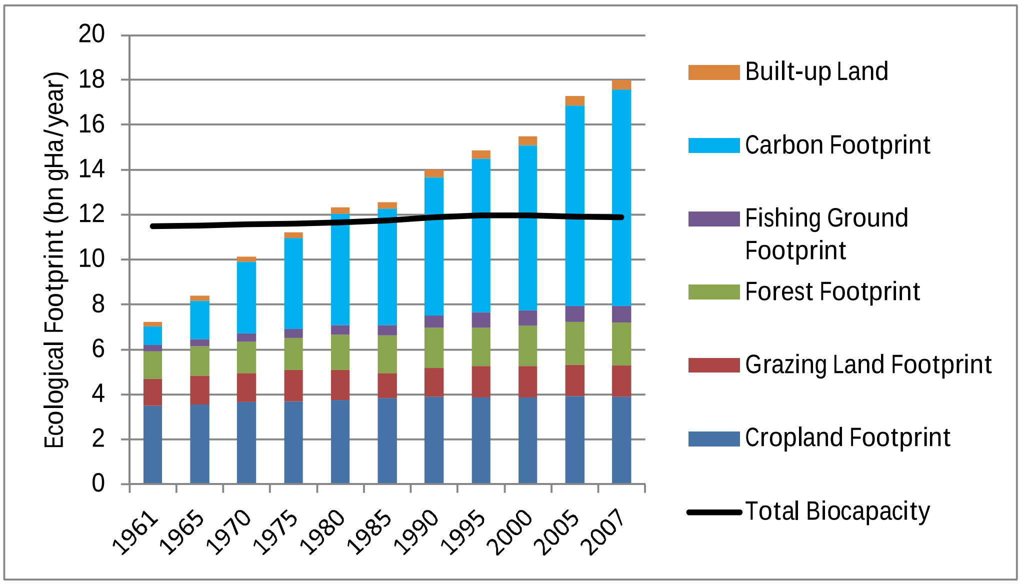



Figure 2 Global ecological footprint

## 2.2 The National Context

The Council of Australian Governments (COAG) has developed an objective and criteria for the future strategic planning of Australia's capital cities.

***To ensure Australian cities are globally competitive, productive, sustainable, liveable and socially inclusive and are well placed to meet future challenges and growth.***

The criteria include the need to address nationally-significant policy issues such as climate change mitigation and adaptation, and efficient development and use of existing and new infrastructure and other public assets.

The Australian government has also produced a National Urban policy (Our Cities, Our Future) aimed at ensuring we have a productive, sustainable and liveable future. This document includes sustainability objectives and priorities:

- reduce greenhouse gas emissions and improve air quality
- manage our resources sustainably

## 2.3 The State Context

Directions 2031 explicitly acknowledges the COAG capital city agenda and sets out objectives (inter-alia) aimed at improving resource efficiency in respect of energy and water. It acknowledges that ….

*The planning and development industry, and local government authorities can make a significant contribution to reducing energy use by designing communities to maximise the opportunities to be climate responsive and energy efficient.*

And in respect of water ….

*This approach is based on total water cycle management which recognises the interconnectedness of all water, including water supply, ground water, stormwater, wastewater, flooding, wetlands, watercourses, estuaries and coastal waters. The urban water cycle should be managed as a single system in which all urban water flows are recognised as an important natural asset and potential resource.*

State Planning Policy (SPP) 4.2 also recognises the importance of resource conservation (Section 5.5).

*The planning of activity centres should contribute to the conservation of resources, in particular a reduced consumption of energy and water.*

However the activity centre structure plan requirements (Section 6.4) require only that the documents:

*1. Establish guidelines for new development to ensure that energy-saving design and technology is incorporated through passive solar building orientation and roof designs that facilitate use of photovoltaic panels, natural ventilation and wind turbines;*

*2. Mandate the use of waterwise plants and trees in all centre landscape plans;*

*3. Establish targets for stormwater and greywater use.*

These requirements in and of themselves will not lead to the levels of resource conservation envisaged in the COAG capital city agenda or Directions 2031 in respect of greenhouse gas reductions or water efficiency.

The demand for energy and water is significantly driven by the urban and built form. GHD believes that infrastructure required to provide these services in an environmentally efficient manner needs to be embedded in urban design and reflected in structure planning. The deferment of infrastructure considerations to stages beyond structure planning will lead only to more business as usual outcomes, because it is essentially too late to introduce innovations at that stage.

This report aims to identify how sustainable infrastructure can be incorporated directly into the Structure Plan for Canning Bridge Activity Centre, and in doing so establish a new benchmark for integrating urban and infrastructure planning.

# 3. Existing Service Infrastructure

The existing energy and water infrastructure is described in detail in the Canning Bridge Structure Plan Services Report - Phase 1 (October 2012). The following sections provide a brief summary of this information.

At the time of writing, work is continuing on assessing the capacity of the existing systems to service future development.

## 3.1 Power

### 3.1.1 Existing Distribution HV Networks

**Distribution Network (West side of Canning Bridge Applecross / Mt Pleasant)**

This area is serviced via 22kV network and as the distribution network on the east side of Canning Bridge is 6.6/11kV there is no interconnection across Canning Bridge as the voltages are not compatible.

There are four 22kV high voltage distribution feeders in the Applecross and Mt Pleasant area that emanate from the Myaree (MYR) Zone Substation in the west

There is one 22kV high voltage distribution feeder that emanates from the Riverton (RTN) Zone Substation in the south to supply Mt Pleasant and southern parts of Applecross area

The high voltage power network in the Applecross and parts of Mt Pleasant were part of a retrospective undergrounding project in mid-1995 and early 2002 respectively. Therefore the high voltage networks are relatively recent upgraded assets.

**Distribution Network (East side of Canning Bridge Como, Manning and Manning South)**

There are two 11kV feeders that supply these areas that emanate from the Colliers Zone Substation approximately 2kms away from the subject sites.

These areas were also part of the Government initiative to underground the aging overhead network which was part funded by the Government, Western Power, Council and Rate payers.

### 3.1.2 Existing Zone Substation Capacity

***Applecross / Mt Pleasant areas***

Western Power's Network Capacity Mapping Tool (NCMT) forecasts limited available capacity at the Myaree and Riverton zone substations for any future growth in these subject areas. NCMT currently shows 15-20MVA forecast available capacity from 2012 and continues to reduce in capacity to 5-10MVA in 2019. From 2020 the forecast capacity reduces down to 5-10MVA until 2027 and then shows <5MVA onward to 2031.

***Como, Manning and Manning South areas***

Western Power's NCMT forecasts limited available capacity at the Collier zone substation for any future growth in these subject areas. NCMT currently shows 15-20MVA forecast available capacity from until 2012 to 2016. The forecast capacity reduces to <5MVA from 2017 up to 2031.

The Western Power assessments do not take into account the significant additional demand from the densification envisaged in the draft Structure Plan.

## 3.2 Gas

The precinct areas are connected by a gas service pipe across Canning Bridge.

On the Melville side, a larger diameter system (100mm-150mm) distributes gas just south of Canning Highway from where it reticulates into Applecross to the north and Mount Pleasant to the south.

The gas network is serviced by medium/low pressure mains. While the detailed Asset Management assessment from ATCO Gas is not yet available, it has been indicated that the existing network may have limited capacity for load expansion.

## 3.3 Water supply

A 610 mm diameter steel pressure main runs through the study area. This line has its origin at the Melville Reservoir on French Road, approximately 6 km to the west-south-west of the City of Melville precincts. The reservoir has an indicative capacity of 88 Ml. The 610 steel pipe runs within the Canning Highway road reserve within Melville, crosses the Canning Bridge eastwards, diverts south-east directly past the bridge, crosses the Kwinana Freeway, and then continues eastward within the Wooltana Street reserve (Figure 3).


Figure 3 – Water Pressure Main

From this central corridor, this pressure main branches off into smaller distributor mains. This pressure main is the primary provider of bulk water for all the precincts within the study area.

Water Corporation has indicated that the existing water network has sufficient capacity at present, and that the existing servicing is adequate for the current zoning from a planning perspective.

According to Water Corporation, there are no upgrades planned to accommodate increased density, and any upgrades will be driven by the approval of a Scheme/Structure Plan.

## 3.4 Wastewater

### 3.4.1 Bulk Sewer Infrastructure

Whereas the water network shares a link over Canning Bridge, the sewer network does not share any link between Melville and South Perth. The sewer network consists of a complex link of gravity systems, pump stations and pressure mains. In most cases, a gravity system from one catchment is pumped into the gravity system of another. All of the sewer pump stations within or directly impacting on the study area are operated and maintained by Water Corporation.

### 3.4.2 Local Sewer Systems

***Melville***

The Melville sewer network consists of two catchment areas (C1 & C2). Catchment 1 receives upstream effluent from area directly north, of which the Dunvegan Road pump station (PS1) is a contributor. Catchment 1 gravitates to the Canning Beach Road pump station (PS2), and effluent is pumped across Canning Highway and into the Catchment 2 gravity system. Subsequently, C2 gravitates to the Rookwood Street pump station (PS3) which falls outside of the Activity Centre precincts. From PS3, effluent is transported via a transfer system all the way to the Woodman Point Waste Water Treatment Plant.

***South Perth***

The South Perth study area is broken down into 6 sub-catchments (C3-C8), but ultimately form part of one large catchment C7. This catchment leaves the precinct as a gravity sewer towards the north, and is collected into pump station Thelma Street in West Como. From here the effluent is transferred to the Victoria Park Pump Station.

According to the Water Corporation most of the current system has sufficient capacity to cope with the existing demand. Planning work carried out for South Perth in 2010 indicated that there are already a couple of short sections of sewer that are at capacity. Their long term planning includes a doubling of the flow in the main sewer from existing levels, and this would require duplication of many sections of the existing sewer. Implementation of the Structure Plan will likely impact the South Perth Main Sewer.

The existing sewer catchments are set out in in Figure 4.

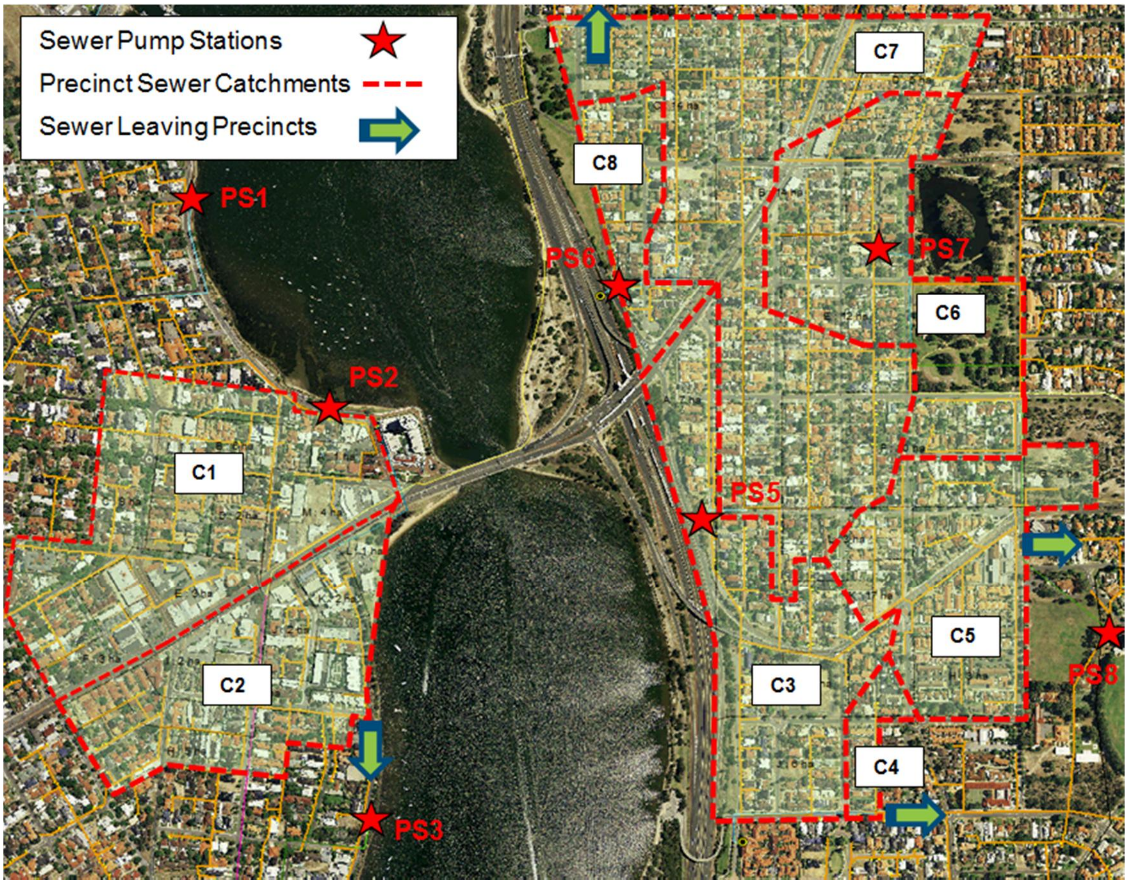



Figure 4 – Sewer catchments

# 4. Future Demand Assessment

## 4.1 Existing Demands

### 4.1.1 Power

No information is directly available on the existing electricity load on the two networks that supply the Structure Plan area from the east and west.

The total area presently has approximately 1,840 dwellings, plus a small number of commercial and other uses. Based on GHD demand assessments the expected load would be approximately:

- Peak demand: 4 - 6 MVA
- Annual energy: 10,000 - 15,000 MWh per annum

### 4.1.2 Gas

Again no information is directly available from ATCO Gas on existing demand. GHD would expect the current population to consume approximately:

- 20,000 - 25,000 GJ per annum

### 4.1.3 Water

Comprehensive information was received from the Water Corporation on water consumption in the period 2008-2012. This information is summarised below.

Table 1 Existing Water Consumption

| | | 2008 | 2009 | 2010 | 2011 | 2012 | Average |
|---|---|---|---|---|---|---|---|
| | | ANNUAL CONSUMPTION (kL) | | | | | |
| RESIDENTIAL | | | | | | | |
| | Houses | 106,230 | 113,594 | 115,916 | 110,380 | 106,981 | 110,620 |
| | Other | 276,000 | 276,542 | 287,820 | 281,451 | 258,731 | 276,109 |
| COMMERCIAL | | 50,493 | 50,298 | 49,708 | 44,428 | 46,997 | 48,385 |
| OTHER | | 22,167 | 21,239 | 21,787 | 16,227 | 17,275 | 19,739 |
| VACANT LAND | | 2,935 | 3,143 | 2,298 | 2,382 | 1,047 | 2,361 |
| | Total | 457,825 | 464,816 | 477,529 | 454,868 | 431,031 | 457,214 |

### 4.1.4 Wastewater

Wastewater is not directly measured. However based on the water consumption figures identified above, the likely wastewater flows in the existing development are likely to be approximately:

- 320,000 – 365,000 kL per annum

## 4.2 Future Energy Demand

### 4.2.1 Yield

The yield for the draft Structure Plan has been assessed and reported elsewhere. A summary of this information used for the purposes of assessing utility demand is summarised below.

### Table 2 Expected Yield

| | Populatio n | Residential | | | Commercial | Retail | Total |
|---|---|---|---|---|---|---|---|
| | | Dwellings | | m2 GFA | | | |
| Melville service precincts | 10,555 | 6,764 | | 1,015,097 | 132,991 | 47,200 | 1,195,288 |
| South Perth service precincts | 15,839 | 10,152 | | 1,523,172 | 49,749 | 19,728 | 1,592,649 |
| Total | 26,394 | 16,916 | | 2,538,269 | 182,740 | 66,928 | 2,787,937 |

#### 4.2.2 Electricity

GHD has assessed the range of possible demands arising from the expected yield set out above.

National Australian Built Environment Rating System (NABERS)[2] is a national rating system that measures the environmental performance of Australian buildings. NABERS measures the energy efficiency, water usage, waste management and indoor environment quality of a building or tenancy and its impact on the environment.

The NABERS Energy rating scale ranges from 1 star (poor performance) to 6 stars (market leading performance).

The energy demand estimates are set out in detail in Appendix A, and summarised in the figures below for:

- Building Code of Australia (BCA) compliant business as usual (BaU) demand
- The demand expected from higher performance buildings (beyond BCA compliance) – denoted as 5 star NABERS
- High performance buildings – denoted as 6 star NABERS

Figure 5 and Figure 6 illustrate the approximate thermal energy demands arising from final development at Canning Bridge.

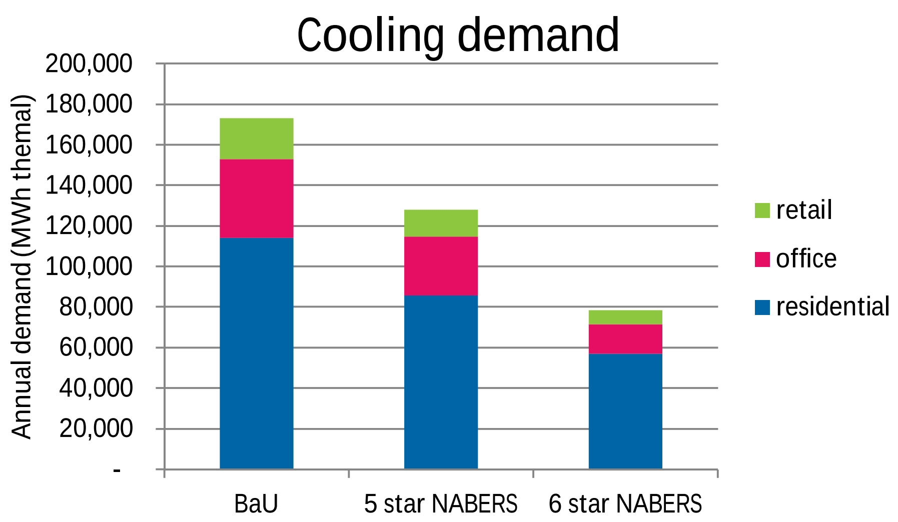



Figure 5 – Projected annual space cooling demand

[2] http://www.nabers.gov.au/

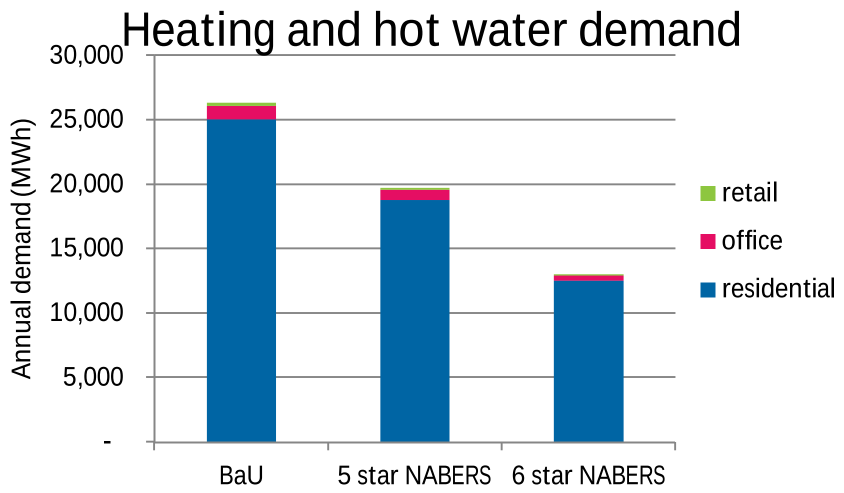



Figure 6 – Projected annual space heating / hot water demand

The electricity demand is dependent on the proportion of the thermal loads that are met by electrical energy. In conventional development it would be assumed that most cooling loads would be electrical, while heating and hot water loads could be either electricity or gas derived.

Figure 7 depicts the approximate electrical load excluding heating and cooling loads, while shows the effect of including both heating / hot water and cooling loads.

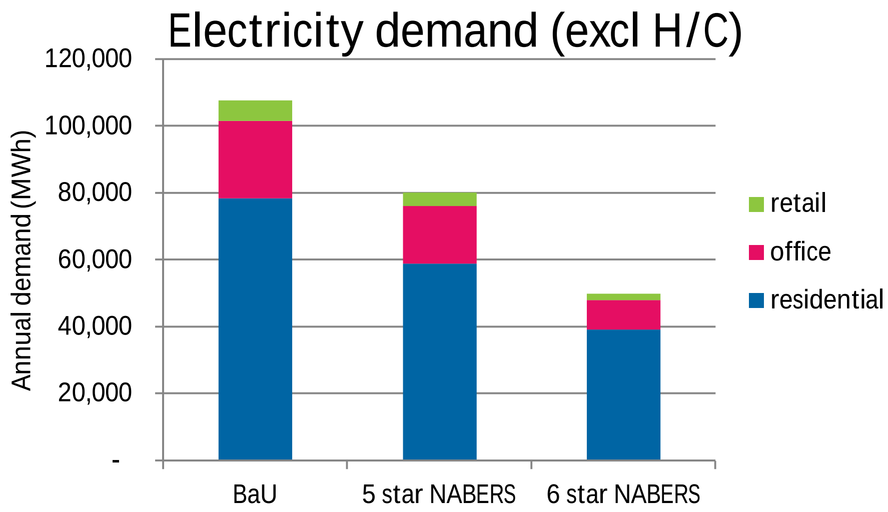



Figure 7 – Annual electrical demand (excluding heating and cooling)

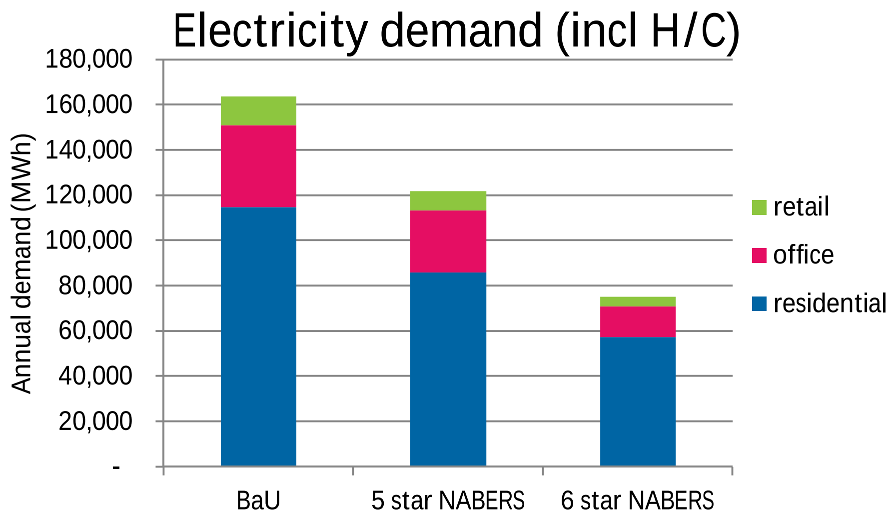



Figure 8 – Annual electrical demand (including heating and cooling)

The actual electrical load will be somewhere in between, i.e.:

| | MWh pa |
|---|---|
| BaU | 100,000 – 160,000 |
| 5 star NABERS | 80,000 – 120,000 |
| 6 star NABERS | 50,000 – 75,000 |

Accordingly the electricity load is expected to increase by 5 to 10 times the current demand.

Greenhouse gas emissions for each of these scenarios have been calculated based on these demands and assuming an average greenhouse intensity of electricity on the SWIS of 631 kg CO2-e / MWh[3] (Figure 9).

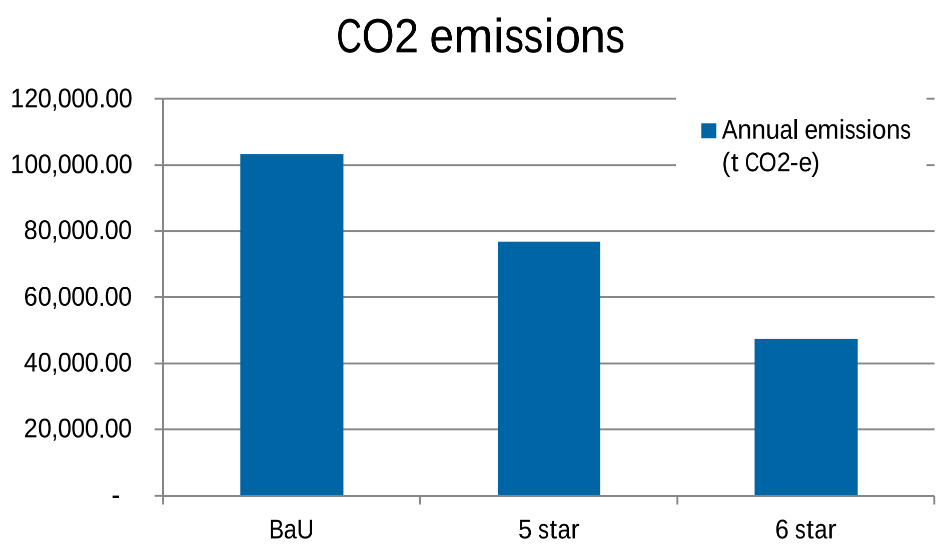



Figure 9 – Annual greenhouse gas emissions

The peak electricity demand is expected to occur around 8pm during the summer, and be dominated by the residential load. Figure 10 illustrates the impact of improved building performance on the peak demand. This figure is particularly important as it indicates the

[3] Australian Energy Technology Assessment (2012) Bureau of Resources and Energy Economics

necessary capacity of the electricity network, including generation, transmission and distribution of power. This indicates that ultimately, peak demand will be 4 - 7 times the existing demand.

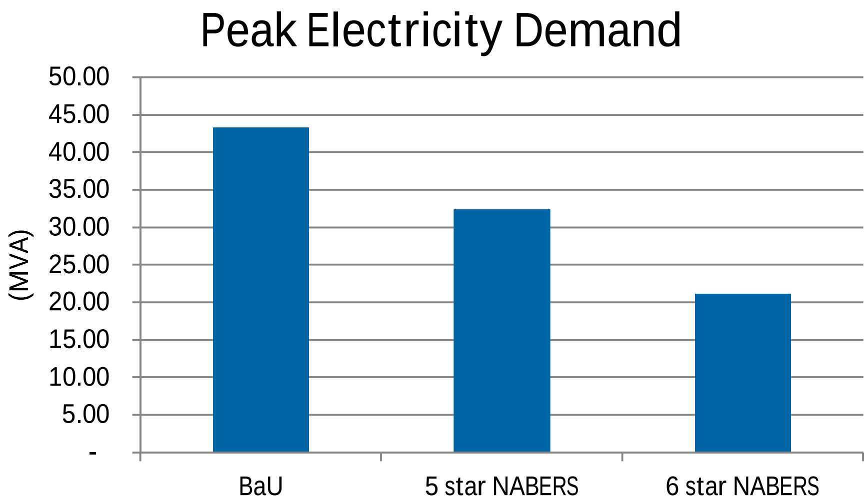



Figure 10 – Peak electrical demand (including heating and cooling)

#### 4.2.3 Gas

As noted above, the gas demand will be dependent on the future energy mix in the area, in particular whether gas is used for cooking, hot water and space heating.

Based on the mix elsewhere it is expected that gas consumption will increase at ultimate development to around 225,000 GJ per annum.

### 4.3 Future Water Demand

The future water demand at ultimate development has been estimated as follows. The unit demands have been sourced from the Water Corporation's H2Options water balance tool[4]. Public open space has been calculated from the draft Structure Plan (all within the South Perth precincts) and road verges estimated as a proportion of suburban road reserves.

Table 3 Projected unit water demand – conventional water efficiency

| | | UNIT DEMANDS - Conventional | | | |
|---|---|---|---|---|---|
| | | Drinking water | NDW - internal | NDW - Irrigation | Total |
| Dwellings | kL/dw/yr | 60 | 54 | 17 | 131 |
| Commercial | kL/m2/yr | 0.80 | 0.47 | 0.07 | 1.34 |
| Retail | kL/m2/yr | 0.64 | 0.32 | 0.11 | 1.06 |
| Public Open space | kL/ha/yr | | | 7,500 | 7,500 |
| Verges | kL/ha/yr | | | 5,000 | 5,000 |

4 http://www.watercorporation.com.au/Home/Builders%20and%20developers/Subdividing/Non%20drinking%20water%20options

### Table 4 Projected total water demand – conventional water efficiency

| | ANNUAL DEMANDS (kL/year) | | | |
|---|---|---|---|---|
| | Drinking water | NDW - internal | NDW - Irrigation | Total |
| Dwellings | 1,014,960 | 913,464 | 287,572 | 2,215,996 |
| Commercial | 146,923 | 85,705 | 12,244 | 244,872 |
| Retail | 42,566 | 21,283 | 7,094 | 70,944 |
| Public Open space | | | 102,000 | 102,000 |
| Verges | | | 34,500 | 34,500 |
| Totals | 1,204,449 | 1,020,452 | 443,410 | 2,668,311 |
| | | | | |
| Drinking water supply | 1,204,449 | 1,020,452 | 306,910 | 2,531,811 |
| Wastewater | 1,204,449 | 1,020,452 | | 2,224,901 |

It has been assumed that domestic irrigation will be sourced from the Water Corporation drinking water supply, and public open space (POS) and verge irrigation from groundwater sources.

New development offers the opportunity to ensure water efficient (waterwise) fixtures, fittings and practices are mainstreamed. The water demand arising from this scenario has also been determined and is set out below.

### Table 5 Projected unit water demand – wasterwise efficiency

| | | UNIT DEMANDS - Conventional | | | |
|---|---|---|---|---|---|
| | | Drinking water | NDW - internal | NDW - Irrigation | Total |
| Dwellings | kL/dw/yr | 43 | 34 | 11 | 88 |
| Commercial | kL/m2/yr | 0.48 | 0.28 | 0.04 | 0.8 |
| Retail | kL/m2/yr | 0.60 | 0.30 | 0.10 | 1.0 |
| Public Open space | kL/ha/yr | | | 5,000 | 5,000 |
| Verges | kL/ha/yr | | | 5,000 | 5,000 |

### Table 6 Projected total water demand – waterwise efficiency

| | ANNUAL DEMANDS (kL/year) | | | |
|---|---|---|---|---|
| | Drinking water | NDW - internal | NDW - Irrigation | Total |
| Dwellings | 727,388 | 575,144 | 191,709 | 1,494,241 |
| Commercial | 87,715 | 51,167 | 7,310 | 146,192 |
| Retail | 40,157 | 20,078 | 6,693 | 66,928 |
| Public Open space | | | 68,000 | 68,000 |
| Verges | | | 34,500 | 34,500 |
| Totals | 855,260 | 646,390 | 308,211 | 1,809,861 |
| | | | | |
| Drinking water supply | 855,260 | 646,390 | 205,711 | 1,707,361 |
| Wastewater | 855,260 | 646,390 | | 1,501,650 |

This assessment indicates that the scheme water demand will increase from around 460 ML per annum to between 1,700 – 2,500 ML per annum. Wastewater demand will grow from 350 ML per annum to between 1,500 – 2,200 ML per annum.

# 5. Infrastructure Upgrades

GHD's Phase 2 servicing report will address the necessary upgrades in detail through discussions with Western Power, ATCO Gas and the Water Corporation. Accordingly the capital cost estimates in this section are both preliminary and very approximate. They are intended to inform the analysis of servicing options rather than predict capital costs.

## 5.1 Power

Upgrades to the electricity system caused by demand growth depend on a number of factors (Figure 11).

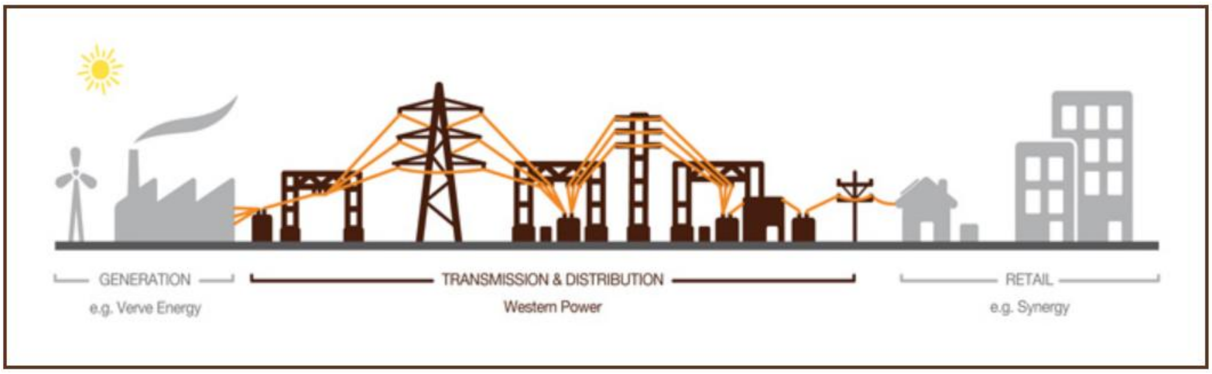



Figure 11 – South West Interconnected Network [Source: Western Power]

### 5.1.1 Generation

Irrespective of the location of the load and the transmission and distribution capacity, additional power demand requires additional generation of electricity, most of which in the case of the South West Interconnected System (SWIS) occurs remotely from Perth. Power stations feeding the SWIS are owned by Verve and private power generators.

Using current costs of generation on the SWIS, the additional 40 MVA required under BaU development will cost approximately $85m in capital costs (in $2012)[5] spread over the life of the development build out. Ensuring energy efficiency could reduce this figure to around $35m.

### 5.1.2 Transmission

Increased loads also incur a cost in respect of transmission upgrades. However as transmission lines service a much more dispersed area than the Canning Bridge Activity Centre, it is difficult to determine the exact impact and hence attribute a share of costs to the development.

### 5.1.3 Distribution

Western Power distributes electricity on the SWIS. This system includes high voltage transmission lines, terminals, high voltage distribution lines, substations, low voltage distribution lines and local transformers. Upgrades to these assets depend very on the available capacity, which can vary quite widely. As noted in Section 3.1.2, at present there is approximately 30 – 40 MVA of capacity in the local system, reducing to 10 – 15 MVA by 2030. Some of the additional expected demand will be development at Canning Bridge under the current planning provisions, and these will be superseded by the Activity Centre Structure Plan. However some will also derive from development outside the Canning Bridge Activity Centre.

[5] Australian Energy Technology Assessment (2012) Bureau of Resources and Energy Economics

With conventional development, upgrades of the system capacity in the long term of up to 30 MVA will likely be necessary costing in the order of $12m, but could be limited to less than 10 MVA if energy efficiency measures are implemented. Savings of approximately $8m could possibly accrue from the reduced capacity requirement.

The increased demand will also require local upgrades including additional transformers, switch gear and low voltage distribution. With BaU demand, the cost of transformers and switch gear alone will be approximately $4-5m. This could be reduced to $1.5m with reduced demand.

## 5.2 Gas

The Canning Bridge Activity Centre Structure Plan servicing report will consider the necessary upgrades and associated costs for BaU development. The preliminary assessment is that the existing local network may have limited capacity for load expansion. Upgrades of this system are likely to be in the order of $2-3m also.

Again energy efficiency measures could reduce the scale of the upgrades, as could substitution of gas with electricity for cooking, space heating and hot water.

## 5.3 Water

### 5.3.1 Source

The increased water demand will require additions to source of the Integrated Water Supply Scheme (IWSS) operated by the Water Corporation. At an approximate capital cost of $21.60 / kL pa (based on the cost of desalination in $2014) this will incur a capital cost of some $54m for BaU demand, reducing to around $37m for waterwise development. Again this cost will be spread over the development period.

### 5.3.2 Distribution

The Water Corporation has advised that the existing 610 mm diameter pressure main that runs through the study area has sufficient capacity to meet the current planning scheme. However with the projected increase in demand of 370 – 540%, it is highly likely that additional water distribution will be required, and local reticulation upgrades will certainly be necessary. The capital cost of the distribution upgrades (based on GHD’s experience in other Activity Centres) could be in the order of $3.5m and for local reticulation $12m. Again these costs could be reduced if waterwise development is implemented, although savings are difficult to estimate without more detailed assessment.

Whether the development will trigger upgrades to local storage at the Melville Reservoir is unknown at this stage and will require more detailed assessment.

## 5.4 Wastewater

### 5.4.1 Wastewater Treatment

Additional wastewater flows will be in the order of 350 ML per annum to between 1,150 – 1,800 ML per annum at ultimate. Upgrades to the Water Corporation wastewater treatment plants (WWTPs) are estimated to cost around $6m per ML per day. This translates to a capital cost of around $30m in $2013 spread over the development phase. Waterwise development could reduce this cost to around $20m.

### 5.4.2 Distribution

The local wastewater network will likely require significant upgrades as a result of the Canning Bridge development, including to the distribution network and pump stations and potentially to the South Perth main sewer. Detailed assessment is required to estimate the costs of these upgrades. However based on GHD's experience elsewhere the pump station and distribution costs could be in the range of $10m and local reticulation $20m. Pump station and distribution costs would be lower for waterwise development but the scale of the benefit is difficult to assess without detailed investigation. It has been assumed here that around $4m of savings could accrue.

## 5.5 Summary of Required Upgrades

The following table summarises the indicative (very approximate) capital cost of upgrades with both BaU and efficient demand profiles.

### Table 7 Indicative capital costs of infrastructure upgrades

| | | | Capital Costs (2013$m) | |
|---|---|---|---|---|
| | | Description | BaU demand | Reduced demand |
| Power | Generation | Additional capacity on the SWIS | 85 | 35 |
| | Distribution | Substation, feeder and local network upgrades | 17 | 6 |
| | | Subtotal | 102 | 41 |
| Gas | Distribution | Local upgrades | 3 | 3 |
| | | | | |
| Water | Source | Upgrades to IWSS source | 54 | 37 |
| | Distribution | Local upgrades | 4 | 3 |
| | Reticulation | Local upgrades | 12 | 10 |
| | | Subtotal | 70 | 50 |
| Wastewater | Treatment | Upgrades to WWTPs | 30 | 20 |
| | Distribution & pump stations | Local upgrades | 10 | 8 |
| | Reticulation | Local upgrades | 20 | 18 |
| | | Subtotal | 60 | 46 |
| | | Total | 235 | 140 |

It can be seen that the bulk of the capital cost is related to the upgrading of power and wastewater.

# 6. Potential Sustainability Initiatives

## 6.1 Overview

There are many potential sustainability initiatives that could be considered for the Canning Bridge Activity Centre in respect of energy and water. Appendix A contains a comprehensive outline of these possibilities under the following categories:

| **Energy** | **Water** |
|---|---|
| Demand management | Demand management |
| Energy production | Water supply |
| Fuel Production | Water storage |
| Energy Delivery | Wastewater treatment |
| Energy Storage | Stormwater management |
| Waste to energy | |

The following sections outline those initiatives shortlisted for consideration at Canning Bridge.

## 6.2 Demand Management

As identified in Section 5, reduced demand for energy and water offers the potential to significantly improve sustainability outcomes and reduce both capital and operating costs, irrespective of how utility services are provided. Accordingly demand management should be the foundation of any urban sustainability strategy.

### 6.2.1 Buildings

High performance buildings are designed and built to be resource efficient throughout the buildings life. This is achieved through energy, water and material efficiency, waste reduction and improved indoor environment quality.

Measurement tools for high performance buildings include GreenStar and NABERS. High performance buildings will achieve 6 star Green Star and 6 Star NABERS.

From an energy point of view high performance buildings reduce the peak demand and overall energy consumption. Many new office, residential, retail and commercial buildings are being designed and built to achieve high Green Star and NABERS energy ratings.

Although there is an increase in the capital cost of green buildings (range of 3-10%), this is offset by lower operating costs, particularly in respect of energy costs.

### 6.2.2 Electricity smart meters / smart grids

A smart meter is essentially an enhanced electricity meter as it has far greater functionality than a conventional electricity meter for measuring and recording production and consumption of electricity. A smart meter is also capable of including functional requirements such as load management ability, tamper detection, remote access and communication, and customer interaction interfaces. This results in greater control and awareness of energy consumption.

Smart meters would be installed in households and buildings in place of a standard retailer meter. Western Power does not yet have a specified smart meter to purchase however other smart meters are available on the market.

Smart meters would be essential in establishing a smart grid network within Canning Bridge. Smart grids involve the installation of smart distribution networks, smart infrastructure such as car charging stations and software for sophisticated control energy management; network shut downs, network stability and network reliability.

### 6.2.3 Energy Efficient Appliances

The Energy Rating Label (www.energyrating.gov.au) is now mandatory in all Australian states for refrigerators, freezer, clothes washers, clothes dryers, dishwashers, televisions and air-conditioners (single phase only). These appliances must carry the label when they are offered for sale.

The Energy Rating Label has two main features that provide consumers with the following information:

- The star rating gives a comparative assessment of the model’s energy efficiency.
- The comparative energy consumption (usually kilowatt hours/year) provides an estimate of the annual energy consumption of the appliance based on the tested energy consumption and information about the typical use of the appliance in the home. Air Conditioners show the power consumption of the appliance (kW or kWh/hour).

The label gives the appliances a star rating between one and ten stars. The greater the number of stars the higher the efficiency.

High efficiency appliances cannot be mandated for any post-occupancy purchases, but can be specified for those appliances included in new buildings.

### 6.2.4 Water smart meters

A smart water meter is a normal water meter connected to a data logger that allows for continuous monitoring of water consumption. The purpose of smart meters is to collect water consumption data in a timely manner and allow for the analysis of the data by water managers to assist with water demand management and water efficiency. In addition, the timely relaying of this data to the water user can result in significant changes in water use behaviour (see consumer education). Other benefits of smart metering include immediate leak detection and remedial action that can save quantities of water.

Typically, smart metering has features such as real time monitoring, high resolution interval metering, automated data transfer and access to the data via the internet.

Smart meters can be applied at the building scale across the development area. The data collected by smart meters can be aggregated across the Activity Centre or development area as part of water consumption analysis.

Smart water meters are a proven technology. The Water Corporation have retrofitted smart meters to all properties in a number of townsites in Western Australia served by the Water Corporation, including Kalgoorlie-Boulder (2 year trial commencing July 2010) and a number of townsites in the Pilbara (Pilbara Smart Metering Program, commenced October 2012 and still in progress).

### 6.2.5 Water Efficient Appliances

Water efficient appliances have been and continue to be used across Australia. The Water Efficiency Labelling and Standards (WELS) Scheme (www.waterrating.gov.au) is Australia’s water efficiency labelling scheme. WELS rates certain products with their water efficiency in accordance with the standard set under the national Water Efficiency Labelling and Standards Act 2005.

The WELS scheme uses a star rating to label the water efficiency of an appliance, the more stars the more water efficient the appliance. Products that are included in the scheme include showers, tap equipment, flow controllers, toilet equipment, urinal equipment, clothes washing machines and dishwashers.

Again, high efficiency appliances cannot be mandated for any post-occupancy purchases, but can be specified for those appliances included in new buildings.

### 6.2.6 Sub-Surface Irrigation Systems

Sub-surface irrigation systems, which rely on irrigation of plants via relatively closely spaced small bore subsurface pipework that incorporates in-line drippers, are an alternative to conventional surface spray systems. If coupled with appropriate soil improvement where required (e.g. areas with sandy soil having poor water retention capacity), losses associated with sub-surface irrigation systems are significantly lower than those with surface spray systems due to its superior uniformity of application, and because spray drift and evaporation losses are reduced.

Whilst this technology can be used at any scale, there is an argument that sub-surface irrigation is more appropriate for POS areas managed by local authorities rather than residential irrigation areas, on the grounds that some residents may not undertake the routine maintenance required to prevent blockage or other problems.

Sub-surface irrigation systems are a proven technology, and are used in many parts of the world. Locally, a good example of irrigation turf using a sub-surface irrigation system is at the Shire of Mundaring's Harry Riseborough Oval. Approximately 1.6 ha of this oval is irrigated in this manner, with treated wastewater from the Water Corporation's Mundaring WWTP. Use of this technology for irrigation of turf in residential settings does however remain uncommon, possibly stemming from the lower cost of conventional spray irrigation systems, or due to other factors (e.g. ongoing maintenance needs, greater difficulty in establishing turf with these systems).

If labour costs are included, irrigation of turf sub-surface irrigation systems are more costly than conventional spray irrigation systems. An additional consideration is that newly laid turf requires spray irrigation for the establishment period, which can add to the overall cost of using sub-surface systems for irrigation of turf in new developments.

## 6.3 Energy generation

The energy alternatives that offer the most potential for urban areas in general, and for Canning Bridge in particular are

- Solar photovoltaic (PV)
- Wind
- Geothermal Energy
- Co / Trigeneration

Waste to energy (WtE) technologies are unlikely to be either viable or feasible at the Canning Bridge Activity Centre scale. Information on these technologies is included in the appendix for completeness. The utilisation of waste at the whole of LGA scale would be necessary to sufficient energy for use at the urban scale. Consideration of this is beyond the scope of this report.

### 6.3.1 Solar PV

Solar Photovoltaic (Solar PV) modules produce emissions free, renewable energy by converting sunlight directly into electricity. The capital cost of Solar PV panels has dropped significantly in recent years and the cost of producing electricity via Solar PV is rapidly approaching the cost of energy supplied by the grid (grid parity).

Building scale systems can export excess electricity back into the utility grid and offer a potential revenue source if the utility offers a feed in tariff.

The modular format of Solar PV systems' allow them to be scaled from individual houses/buildings to large, precinct scale power stations. Precinct scale Solar PV systems are limited in size by available space (Solar PV systems require approximately 5-7m$^2$/kW).

Global solar photovoltaic (PV) demand for 2012 reached a record 29.0 GW. By the end of 2010, the total installed capacity of PV based solar power systems in Australia was over 570 MW.

The largest building scale Solar PV system in Perth at the time of this report was recently installed at Perth zoo with a capacity of 237.4kW (approximately one third of the Zoo's current energy consumption. The system was integrated into a walkway shelter in the adjacent Windsor Park. A notable Western Australian precinct installation is the Carnarvon Solar Power Plant, with a capacity of 290kW.

Building scale solar PV capital costs have dropping steadily, and at the time of writing are in the range $1.30 - $1.93 / W[6]. Larger, precinct scale installations are likely to be in the range $1.80 - $2.50.

### 6.3.2 Wind

Wind turbines use kinetic energy from the wind to drive a generator and produce electricity. Wind turbines can be horizontal or vertical axis configuration. Horizontal axis turbines are the most common arrangement and must point directly into the wind to operate. Vertical axis turbines can operate with wind coming from any direction, and therefore perform well in urban environments, but require a larger drive train, limiting their practical size.

Wind turbines are available from building size, in the order of 1 to 15kW, to precinct scale turbines up to 5MW. Wind turbines can produce noise in operation and visible impact which should be considered when selecting and placing units.

Wind energy has a long history and is now become a viable energy source on a large scale which can compete with traditional fossil fuel energy sources. Large scale wind farms have been installed in many areas of WA however large turbines are advised not to be installed within 2km of residential houses. Opportunities on an urban scale are more difficult to capture due to wind being obstructed by buildings and trees etc. and small scale wind is still expensive.

Capital Cost - $10,000 - $15,000/kW

Operating Costs - $300 - $500 per year

### 6.3.3 Geothermal

Geothermal is a very low emission thermal energy source. Although geothermal energy is most commonly exploited in volcanic areas where magma nears the surface and brings heat from greater depths, the opportunity in the Perth Basin derives from aquifers in deep sedimentary basins. Potential uses include:

- Electricity production

[6] http://www.solarchoice.net.au/blog/solar-pv-price-index-september-2013/

- Space heating and cooling
  - Geothermal heat for district scale heating and cooling systems (utilising absorption or adsorption chillers).
- Water heating
  - Low temperature geothermal heat used (for example) for pool heating.
  - Domestic hot water could potentially be sourced directly from the geothermal aquifer or heated via this source through heat exchangers.
- Thermal water treatment processes
  - Desalination of water using multi-effect distillation processes driven by geothermal heat.
  - Wastewater treatment using membrane distillation bioreactor operating at elevated temperatures supplied by geothermal energy.

Tapping the geothermal resource requires bores to produce extraction and injection wells with associated pumping infrastructure. The output is water at temperatures determined by the extraction depth (approx. 100°C at 3,000m).

The potential application scale depends on geothermal applications:

- Electricity production and thermal network – structure plan area + area of influence
- Lower grade heat applications – smaller scale

Costs [7]

| | |
|---|---|
| Electricity generation | $4m per MWel |
| District Cooling network | $540-640k per kWth |

These costs do not include drilling, commissioning and maintaining the production and injection wells. A cost estimate for a 3 km well doublet is in the order of 20 Million AUD.

### 6.3.4 Co / Trigeneration

Gas engines and turbines combust natural gas or biogas to spin a generator to produce electricity. Waste heat from the exhaust can also be captured and used for space heating or process heat in a combined heat and power (CHP) arrangement. The heat can also be used for space cooling via an absorption chiller in Trigeneration configuration. Gas produces around half the emissions as coal per unit of energy and installed in a distributed energy system, with higher transmission efficiency, is a much cleaner energy source than connecting to a coal fired energy grid.

Gas engines / turbines can be installed in building or precinct scale. The CSIRO national energy centre is operating a building scale gas micro-turbine with 30kW capacity and similar in size to a household refrigerator. Precinct scale High Efficiency Gas Turbines (HEGTs) can be scaled up to precinct and Structure Plan Area.

Mini-CHP systems are available at the house scale, mainly to provide hot water but also produce small amounts of electricity.

At the large scale, gas turbines are responsible for a significant proportion of WA's energy generation on the SWIS. They have a long history, are reliable, low emission and are used for many different applications with a combination of other technologies.

Costs:

[7] Source: WA Geothermal Centre of Excellence

Capital Cost - $2m/MW

Operating Cost - $50/MWh

### 6.3.5 Solar thermal

Solar Thermal systems capture heat from the sun's radiation and use it to provide heat or power conventional turbines to produce electricity. Solar Thermal systems for heat generation typically consist of a cell with a circulating fluid circuit that is directly heated by the sun's rays. Power production from solar thermal is not a feasible option for electricity generation but is certainly feasible as a thermal energy source at the building scale for hot water, and potentially at the precinct scale for space heating and hot water.

As noted above heat energy can also be used for space cooling via absorption chillers.

## 6.4 Energy storage

### 6.4.1 Electricity storage

Electrical storage refers to methods used to store energy when demand is lower than supply. The energy can then be used during times of peak periods. There are many options for storing energy with battery banks, pumped hydro, flywheels and compressed air.

Examples of storage in Western Australia include the wind diesel system in Coral Bay which contains flywheel storage and many off grid systems containing battery storage.

Battery technology is a longstanding and widespread application of energy storage. In future it is recognised that a broad range of energy storage technologies can help manage the large-scale deployment of intermittent generation and the electrification of space heating / cooling.

New energy storage technologies are unlikely to be deployed on a large scale under current market and regulatory conditions. Both technology cost reductions, and a market framework which recognises the benefits of energy storage, are required.

**Approx Capital Costs**

Batteries - $290/kWh - $1,350/kWh

Pumped Hydro - $250/kWh - $430/kWh

Flywheel - $7,700/kWh - $8,800/kWh

### 6.4.2 Electric vehicles

A transition to electric vehicles is motivated both by the opportunity to reduce emissions and mitigate future fuel shortages and cost increases.

Many automotive manufacturers are or have been releasing full electric vehicles in the past 2 years. Electric vehicles plug in to the grid and charge whilst not in use. They will require specific electric vehicle charging stations to be installed next to each designated electric vehicle parking bay.

A number of organisations in Perth either have electric trial vehicles or have started installing infrastructure to prepare for electric vehicles. City of Perth have begun installing car charging stations within its car parks and Water Corporation, UWA and Western Power have a number of trial full electric vehicles and charging stations for staff.

With the implementation of smart grids, electric vehicles will also be able to be used for energy storage and called upon when plugged in to the grid to provide energy during peak periods.

Until recently the majority of vehicles available for the road have been fuelled with petrol. However with the increase in petrol and diesel prices in the last 10 years, car manufacturers have started to turn to electric powered cars. Most manufacturers now have at least one electric hybrid vehicle in their range. Barriers that exist for electric vehicles include the vehicle range and infrastructure development.

### 6.4.3 Thermal energy storage

Thermal energy storage systems are analogous to a battery for thermal energy and can be used in any application that requires heating or cooling. Thermal energy storage can capture energy and reuse it at the opportune moment. Common applications are thermal energy storage for building air conditioning and heat storage for electricity generation, such as solar thermal plants.

Buildings can use chilled water storage, ice storage or phase change material to store cooling energy generated at cheaper off peak periods to be released during on peak periods. This can also reduce peak power demand across the grid by reducing day time air conditioning loads.

Solar thermal plants can use thermal energy storage to store excess heat and continue generating electricity when there is no heat from the sun, enabling the plant to deliver renewable base load power supplies.

Thermal energy storage systems are available at household, building and precinct scale.

Solar thermal storage has been used since the nineteenth century. There is a growing number of facilities that use Seasonal thermal energy storage (STES), enabling solar energy to be stored in summer (primarily) for space heating use during winter.

Curtin University has a large thermal storage tank to produce chilled water overnight in cheaper off-peak periods to be stored and used during the day.

Melbourne City Council’s CH2 building employs thermal energy storage to cool the building during the day. A tank containing Phase Change Material (PCM) is cooled overnight and produces chilled water during the day to cool the building.

## 6.5 Heating and Cooling

### 6.5.1 Air / ground source heat pumps

Heat pumps use the refrigeration cycle to transfer, or ‘pump’ heat from one space/medium to another. Reverse cycle air conditioners are a form of heat pump, transferring heat from inside a building to the outside to cool it down or transferring heat from outside to inside to warm it up. Heat pumps are also able to source or reject heat mediums other than air, such as earth or water, to enhance efficiency.

Heat pumps require electricity to operate a compressor and emit or absorb heat in cooling or heating mode respectively. Heat pumps can operate at household, building or precinct scale.

Air source heat pumps form the foundation technology of reverse cycle air conditioning systems and have been in use for many years. Ground source heat pumps are less common.

Air source heat pumps for air conditioning costs are in the order of $1000/kW cooling capacity and cost approximately $0.05/hour per kW cooling capacity to operate.

### 6.5.2 Absorption chillers

Absoption chillers use an external heat source as part of a chemical process to generate cooling, compared to a standard refrigeration chiller which uses a mechanical compressor. If the external heat for the absorption chiller is sourced from waste heat of another process, cooling can be provided with a relatively small amount of electricity compared to a standard chiller.

Utilising absorption chillers are a key element in creating a tri-generation system which uses waste heat from an electricity generator as heating or as cooling via an absorption chiller, therefore generating three forms of useful energy: electricity, heating or cooling.

Absorption chillers are available at the building and precinct scales.

Absorption chillers are a well-established technology but have increased in popularity in recent years due to the adoption of tri-generation systems and the ability to utilise waste heat to provide cooling.

**Approx Capital Cost**

$500,000/MW cooling capacity

## 6.6 Alternative Water Supply

### 6.6.1 Groundwater

Groundwater abstraction is one of the easiest and usually most cost effective method of providing an alternative to scheme water for non-drinking water uses such as irrigation. It is generally acknowledged that the consumption of groundwater by households owning a private bore is greater than for those households irrigating from scheme water, and thus it is considered that encouraging private bore use within the study area would not lead to achievement of the water conservation objectives. However, if a centralised system were to be installed, supplying groundwater via a third pipe network and with central management, this could be implemented in such a way as to minimise the use of irrigation water and help achieve the water conservation objectives.

Groundwater could also potentially be used as an alternative water supply for in-house non-potable uses. The use of groundwater presents only a small health risk due to water quality. With respect to irrigation, the presence of significant iron concentrations, hardness, alkalinity, nutrients or salinity can impact upon the receiving vegetation and soils and/or contribute to scaling or scour of irrigation pipework. Potential water quality issues of concern for in-house use include the presence of suspended solids and pathogens. If contamination is present in the aquifer, the use of groundwater will pose a risk for both irrigation and in-house uses and may lead to environmental problems due to mobilisation of contaminants. It is understood that DoH would require disinfection of groundwater if it was proposed for non-potable uses inside the house.

Existing groundwater allocation planning by the Department of Water indicates that within the City of South Perth and the City of Melville groundwater sub-areas, the Superficial aquifer is currently 87% and 76% allocated respectively (including requested allocations)[8]. As such, there may be some groundwater available for use for POS irrigation, although it is unlikely to be sufficient for other non-potable uses.

### 6.6.2 Rainwater tanks connected to non-potable water supply

This option involves collection of rainwater from the available roof area to supply an alternative water source for non drinking water purposes (e.g. irrigation of gardens, internal non drinking water uses or both).

Rainwater tanks can be applied at the building scale within the development area (single dwelling, multi- dwelling or commercial). Rainwater tanks have been used in Western Australia for many years. In metropolitan areas where scheme drinking water is available, rainwater tanks can provide a valuable alternate water source.

[8] DoW advice January 2014

The 2007 report by Marsden Jacobs *The cost-effectiveness of rainwater tanks in Urban Australia* (for the National Water Commission) indicated the following costs:

- a rainwater tank for indoor/outdoor use ranges from $3.25/kL - $8.85/kL
- a rainwater tank for outdoor use only ranges from $2.87/kL - $5.74/kL

The report indicated that the cost efficiency and yield from rainwater tanks varies considerably between individual properties and is influenced significantly by the connected roof area as well as end use.

### 6.6.3 Stormwater treatment

This option involves detaining and treating the stormwater generated from impervious areas on site using wetlands or underground tanks to store the stormwater for later use. Uses may include irrigation or other non-potable uses.

Sludge removal from wetlands or tanks as sediment settles out of the stormwater would be required.

Stormwater harvesting schemes are in operation in the eastern states of Australia, particularly Victoria and New South Wales. Some examples of stormwater harvesting projects include:

- Blackmans Swamp Creek Stormwater Harvesting Scheme in Orange which is capable of providing 1300ML – 2100ML/year of additional water. This scheme cost of $5m (which included extensive consultation)
- Afton Street Stormwater Project in Melbourne

### 6.6.4 Treated wastewater recycling for non-drinking water supply purposes

Subject to being treated to a quality adequate to protect human health and the environment, treated effluent from wastewater treatment plants can be used for irrigation purposes and to meet a range of other non-drinking water demands including toilet flushing, car washing, clothes washing (typically cold supply only), etc. It can also be used by industry, for instance in cooling towers and to meet some process water demands.

Significant potable water consumption savings can be achieved where the treated wastewater is used to meet water demands that would otherwise be met with potable water. If the area of public open space (POS) able to be irrigated would otherwise be constrained by the availability of irrigation water, or treated wastewater is supplied to householders at a lower cost than potable water (of note there are negatives of such a pricing approach), treated wastewater recycling can also increase the area of POS and private land that is irrigated.

Treated wastewater can be recycled at a range of scales, from on-premises (for the case of on-lot wastewater treatment), to community-scale (where a community scale WWTP and associated “third-pipe” scheme supplies the treated wastewater), to a regional scale (where treated wastewater is supplied by a major centralised plant and associated treated wastewater distribution and reticulation infrastructure).

Treated wastewater recycling for non-drinking water supply purposes is widely practiced in many parts of the world. Many such recycling schemes are in operation in Western Australia, though these schemes are primarily used to meet irrigation demands at parks, sporting fields, golf courses and the like. Treated wastewater is also used for irrigation of numerous woodlots in regional areas (e.g. Albany, Manjimup, Margaret River). Highly treated wastewater from the Water Corporation’s Kwinana Water Recycling Plant, used to meet industrial water demands in the Kwinana Industrial area, is another notable local treated wastewater recycling example.

Whilst no such residential schemes of any notable scale exist in Western Australia at this time, there are a number of significant “third-pipe” treated wastewater recycling schemes elsewhere in Australia where treated wastewater is used to meet POS and domestic irrigation demands as well as a range of in-house non-drinking water demands. Examples include the Rouse Hill scheme in Sydney, and the Pimpama-Coomera Scheme in the Gold Coast.

The cost of treated wastewater recycling is a function of the application scale. For a major third-pipe recycling scheme to serve the Canning Bridge Activity Centre, the unit cost of recycled water is likely to be at least $3/kL, with a significant portion of the cost associated with the recycled water distribution and reticulation infrastructure.

# 7. Decentralised Infrastructure

## 7.1 Overview

While the prime motivation for urban consolidation worldwide has been transport related (connected city), the implications for other key elements of infrastructure, namely energy supply, water / wastewater and urban waste management have received little attention.

Perth, like nearly all cities, has a highly centralised approach to the provision of energy and water supply. For many years, this approach has meant the outward extension of transmission and distribution to new suburban areas from large scale headworks. In such an arrangement the assets that convey the water, electricity and gas are optimally designed for the loads they carry. In layman's terms the pipes and wires get smaller, the further they extend. The same holds for wastewater, except the direction of flow is reversed. Accordingly when an existing suburban area is densified, as is planned for Perth's Activity Centres, the local loads increase, requiring not only upgrades to the headworks sources (i.e. more electricity generation, more water supply and more wastewater treatment capacity), but also to the transmission and distribution systems. The costs are high because the capacity of the "pipes and wires" in many cases needs to be upgraded all the way back to the headworks.

The existing service pattern has arisen for good reasons. Economies of scale are significant for power, water and wastewater infrastructure, and while the city is expanding radially outwards it is logical to merely expand the networks and supplement the sources. However this approach is not without its problems. Transmitting electricity over long distances leads to significant losses, meaning increased greenhouse gas emissions and wastage of (finite sources of) fossil fuels. Our increasing reliance on desalination remote from Perth means that the supply of water is also a significant energy problem.

Because of these factors there is an increasing interest worldwide in decentralising infrastructure, in other words placing the sources of energy and water closer to their point of consumption, and dealing with waste locally. Although the headworks cost per unit service is likely to be higher than for centralised headworks due to scale dis-benefits, the cost of transmission and distribution is reduced, as are the losses. Decentralised systems are not intended to be independent of the centralised systems, rather they complement them, and reduce the scale of the necessary upgrades.

Most importantly from the perspective of sustainability, decentralised infrastructure offers an ideal opportunity to significantly reduce the carbon footprint of development. Local renewable energy solutions ease pressure on the SWIS, reduce reliance on finite stocks of fossil fuels and reduce greenhouse gas emissions. Local wastewater recycling for non-drinking water uses reduces dependence on the IWSS as a water source, and on the centralised wastewater system. Powering this infrastructure with renewable energy reduces the carbon footprint of the water cycle.

Furthermore the localisation of these services also brings investment and jobs to the locale, itself an objective of the Activity Centres policy.

Many of the technologies described in Sections 6.3 - 6.6 can be configured at the precinct scale. The following section sets out the likely most feasible options for further consideration at Canning Bridge.

## 7.2 Potential decentralised energy options for Canning Bridge

Energy generation options considered potentially viable at the precinct scale at Canning Bridge are considered to be:

- Solar PV – electrical energy
- Trigeneration - electrical and thermal energy
- Geothermal – thermal energy

Although there is potentially a significant wind resource in the Canning Bridge area, the turbine(s) necessary to make a significant contribution to the peak electricity demand of 20+ MVA would be of very significant scale with consequent visual and noise impacts. Accordingly wind has not been considered further at this stage as a precinct scale resource.

The remaining technologies can be configured / combined in a number of ways. The following represents some options that can potentially be incorporated at a precinct scale to meet the identified demand and complement the grid scale electricity / gas networks.

### 7.2.1 Option 1 – Solar PV

| | Grid scale | Precinct scale | Building scale |
|---|---|---|---|
| Electricity | SWIS | Solar PV | |
| Space heating / hot water | | | Electric heating and cooling plant |
| Cooling | | | |

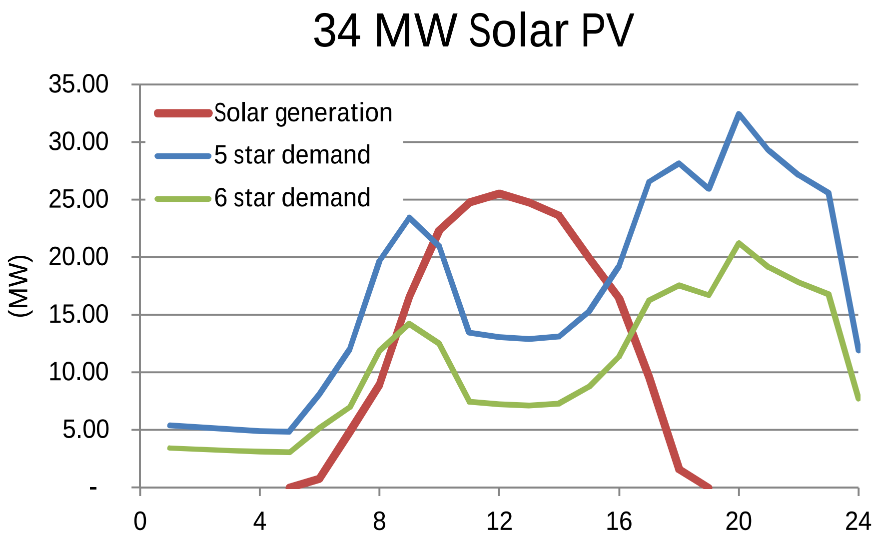
In this option the main energy source is electricity. The grid would be supplemented by roof top solar PV. The building footprint in the draft Structure Plan is around 420,000 $m^2$. Conservatively assuming that 40% of this area would be available / suitable for rooftop solar, an installed capacity of some 34 MW would be achievable. Such a system would likely achieve the following performance:

Peak power delivery: 25 MW

Annual generation: 41,000 MWh

Figure 12 depicts the approximate supply and demand of electricity on the peak summer day that will govern the design capacity of the upgraded network, known as after-diversified-maximum-demand (ADMD). This demand assumes that all heating / hot water and cooling energy within buildings is electrically supplied.

This indicates that 34 MW of solar capacity would meet the peak morning demand, exceed middle of the day demand, but not change the ADMD figure which is governed by the evening peak demand. In this circumstance, solar PV would be a major contributor to the annual electricity consumption but not reduce the necessary capacity of the SWIS, either in terms of generation or distribution. Accordingly no capital savings would accrue from reducing capacity on the grid.




### Figure 12 – Solar power generation

The cost of storing electricity is dropping steadily in line with increasing penetration of renewable energy which is sporadic in nature (wind / solar in particular). If electrical storage was used in conjunction with the solar PV, and sized to store all excess solar energy during the middle of the day, it could be discharged to offset the evening peak.

This arrangement would require about 100 MWh of storage and would reduce the additional demand on the grid to about 10 MVA for 6 star demand. If the demand was only 5 stars, significant additional PV (approximately 55 MW) and storage (160 MWh) would be required to reduce the grid demand to about 20 MVA.

### 7.2.2 Option 2 – Trigeneration

| | Grid scale | Precinct scale | Building scale |
|---|---|---|---|
| Electricity | SWIS | Trigeneration | Solar PV |
| Space heating / hot water | | | |
| Cooling | | | |

In this option trigeneration units would be housed in precinct scale energy stations. Each station would comprise a gas engine that produces electricity and heat, absorption chillers to convert the heat energy into chilled water, and cooling towers to reject heat from the chillers. The electricity would be fed into the grid at each station. Hot and chilled water pipes would connect each station together and circulate thermal energy to buildings in a closed loop network to form a district energy system. For the purposes of identifying the viability of the solution, it is assumed here for simplicity that this arrangement would apply throughout the Structure Plan area.

The trigeneration units would not be sized to meet the peak loads. They can be configured in a number of ways, here it is assumed they would be sized to meet about 80% of the average summer day load, with the balance of the peak load met by electric chillers. All heating / hot water demands would be met by the heat energy from the trigeration units.

This arrangement would negate the requirement for heating and cooling plant in the buildings, a major capital and operating cost. This plant would be replaced by heat exchangers connecting the buildings to the district energy system.

As the loads vary significantly throughout the day and the year the number of units operational each day and in each season would vary.

Preliminary estimates indicate that such an arrangement would involve the following scale of plant and equipment.

Table 8 Indicative trigeneration system capacity

| | 5 star demand | 6 star demand |
|---|---|---|
| Gas engine capacity: | 32 MWe / 40 MWth | 21 MWe / 26 MWth |
| Absorption chiller output: | 24 MWth | 15 MWth |
| Electric chiller output: | 36 MWth | 26 MWth |

During periods of peak summer demand when the trigeneration system was operating at full capacity, electricity output would approximately match demand. This would mean that no additional capacity would need to be added to the SWIS upstream of the district (although the local network would require strengthening).

In other seasons, when the trigeneration units were operating at below full capacity, electricity would be needed from the grid to supplement that generated locally.

### 7.2.3 Option 3 Geothermal / Solar

Although geothermal energy can be used to produce electricity, very high temperatures are required. Based on research by the WA Geothermal Centre of Excellence at the University of WA, the groundwater temperature increases from around 20°C at the water table to around 50-80°C at 1500 m depths. Extrapolating this geothermal gradient, the groundwater temperature may reach well in excess of 100°C at 3000 m depth. This temperature is suitable to drive absorption chillers for air-conditioning purposes, but not for power production. This would require temperatures well in excess of 100°C. Accordingly here, geothermal is considered as thermal energy source for a district heating and cooling system.

No specific information on the suitability of the geothermal resource is available for this location. It has been assumed that suitable temperatures can be achieved at depths of between 1500 and 3000 m.

In this option the heat energy provided by trigeneration in the previous option would be replaced by geothermal energy. A single geothermal doublet (abstraction and injection wells) would feed hot water to energy stations housing absorption chillers and cooling towers. It has been assumed here that the geothermal energy system would be sized to meet the average summer thermal load, with peak loads again met by electric chillers. As for trigeneration, hot and chilled water pipes would connect each station together and circulate thermal energy to buildings in a closed loop network to form a district energy system.

Electricity in this option would be provided by solar PV in the same configuration described in Option 1. As the peak summer electrical demand is about one third lower than shown in Figure 12 (because the thermal load component is removed), a much smaller PV installation (around 20 MW – 6 stars) would be required to achieve the same net outcome.

As for Option 1, significant electrical storage would be required to reduce the electricity system upgrades required to meet the peak demand, but again smaller that for Option 1 (around 65 MWh). With the inclusion of storage, grid upgrades would be virtually eliminated.

### 7.2.4 Summary

The following table summarises each of the three options set out above.

Table 9 Summary of energy options

| Option | Electricity source | Heating / Coooling energy | SWIN implications | | Annual greenhouse emssions (tCO2-e) |
|---|---|---|---|---|---|
| | | | Additional peak power (MVA) | Additional annual energy (GWh) | |
| BaU | SWIS | Building scale - electricity / gas | 15-30 | 50 - 110 | 50 - 105 |
| 1a | **Solar PV** / SWIS | Building scale - electricity | 15-30 | 10 - 70 * | 10 - 70 |
| | with electrical storage | | 10 - 20 | 10 - 70 | 10 - 70 |
| 2 | **Trigeneration** / SWIS | District scale - trigeneration / electric chillers | 0 | < 10 | 30 - 70 |
| 3 | Solar PV / SWIS | District scale - **Geothermal** | 15 - 25 | 10 - 65 * | 10 - 65 |
| | with electrical storage | | 0 -10 | 10 - 65 | 10 - 65 |

* assumes excess solar electricity is returned to the grid

## 7.3 Potential decentralised water options for Canning Bridge

Of the district scale options noted in Section 6.6, it is considered that only the recycling of treated wastewater is viable. Several studies undertaken by GHD previously have indicated that stormwater or rainwater use is not feasible in Perth. Neither source is available during the long summer period and the storage volumes necessary to retain winter rains are excessive. Although stormwater / rainwater could potentially be used for in-house non-drinking water uses during winter, this would not reduce the capacity of the water supply network which is governed by summer peak flows.

Similarly groundwater is not considered as a viable non-potable supply. There is limited groundwater availability, and the cost and energy involved in groundwater treatment is significant.

Perhaps more importantly, these alternative water sources do not reduce the quantity of wastewater required collection and transport.

Accordingly these options have not been considered further in this report.

### 7.3.1 Local wastewater recycling

Local recycling of wastewater offers a number of potential benefits, simultaneously reducing:

- the demand on the downstream wastewater system (sewers, treatment plants and ocean outfalls);
- the demand on the upstream water supply system (source, treatment, distribution and storages);

Additionally, if the energy required by the recycling plant is provided by renewable energy, a further benefit is accrued in terms of greenhouse gas reductions.

Under this scheme, wastewater flows from some / all of the existing wastewater pump stations would be diverted to a local Recycled Water Plant (RWP). At this stage it is envisaged that the RWP will be a membrane bioreactor type (MBR) type wastewater treatment plant, complete with:

- fine screens and grit removal facilities;
- MBR type secondary treatment process units (process reactor comprising aerobic and anoxic zones and associated recycles, submerged or pressure type membrane solids separation facilities);
- disinfection facilities (e.g. chlorination and UV disinfection systems);
- sludge stabilisation and dewatering facilities (or pump station to export waste activated sludge [WAS] to WC sewer);
- associated chemical dosing facilities; and
- odour control facilities to minimise the required buffer distance, full enclosure of all process units and sludge storage tanks is proposed, with a forced air ventilation system, scrubbing of collected foul air and released on scrubbed air via a stack.

The odour control facilities will be designed to ensure that odour concentrations at the nearest existing/future odour sensitive premises comply with regulatory requirements.

Clearly the viability of the solution is dependent on the identification of a suitable site.

The treatment process would produce a high quality product suitable for non-drinking water (NDW) uses such as toilet flushing, cold water for clothes washing and for irrigation.

The NDW would be produced by the RWP, stored in a tank and then conveyed through a dedicated supply network to residential and commercial premises. This would require additional plumbing in buildings to accommodate a second water supply. The wastewater plumbing in buildings would be unaffected.

As the recycled water network is expensive this arrangement may only be viable in the densest precincts. For the purposes of identifying the viability of the solution, it is assumed here for simplicity that this arrangement would apply throughout the Structure Plan area.

The table below indicates that there is sufficient wastewater supply to meet the NDW demand in both summer and winter, assuming waterwise demand.

Table 10 Non-drinking water supply / demand (kL/year)

| | Drinking water | NDW - internal | NDW - Irrigation | Total |
|---|---:|---:|---:|---:|
| NDW demand | | | | |
| - Summer | | 375,437 | 308,211 | 683,649 |
| - Winter | | 270,952 | | 270,952 |
| | | 646,390 | 308,211 | 954,601 |
| Wastewater produced | | | | |
| - Summer | 496,754 | 375,437 | | 872,191 |
| - Winter | 358,506 | 270,952 | | 629,459 |
| | 855,260 | 646,390 | | 1,501,650 |
| | | | | |
| Excess wastewater | | | | |
| - Summer | | | | 188,542 |

| | | | | |
|---|---|---|---|---|
| - Winter | | | | 358,506 |
| | | | | 547,049 |

The excess NDW could be locally discharged, or alternatively returned to the Water Corporation wastewater network at locations with sufficient capacity. In either case, emergency overflow to the Water Corporation network would be required in the event of a failure at the RWP.

The adoption of a waterwise strategy plus the NDW scheme would reduce the demand on scheme water and wastewater systems as set out below.

### Table 11 Potential water and wastewater reductions (kL/year)

| | kL / year | |
|---|---|---|
| Conventional water supply | 2,531,811 | |
| savings from waterwise practices | - 721,950 | |
| savings from NDW scheme | - 954,601 | |
| Net supply | 855,260 | 66% reduction |
| | | |
| Conventional wastewater demand | 2,224,901 | |
| savings from waterwise practices | - 723,252 | |
| savings from NDW scheme | - 954,601 | |
| savings from local discharge | - 547,049 | |
| Net demand | 0 | 100 % reduction |

# 8. Economic viability and performance

## 8.1 Qualification

Determining the likely costs of the options accurately is not possible with the limited information available on necessary upgrades for conventional servicing, and without a level of concept design for the alternatives. The following should therefore be taken as indicative of the potential relativity of the solutions only. Under no circumstances should the quoted figures be taken as infrastructure budgets for any of the options.

## 8.2 Energy options

### 8.2.1 Description of assessment

***Options***

Based on the commentary in Sections 6.3, 6.4 and 6.5 above the following alternatives were selected for consideration in this assessment.

Table 12 Energy supply options

| Option title | Thermal efficiency of buildings | Servicing |
|---|---|---|
| BaU | As per Building Code of Australia | Conventional centralised: SWIS |
| BaU - 5 stars | 5 star NABERS | |
| BaU - 6 stars | 6 star NABERS | |
| 6 stars + solar + storage | 6 star NABERS | Precinct scale solar PV with electrical storage |
| 6 stars + trigen | | Precinct scale trigeneration |
| 6 stars + solar + storage + geothermal | | Precinct scale solar PV with electrical storage |

These options fall into 2 broad categories:

- Conventional centralised servicing with various levels of energy efficient buildings; and
- Decentralised precinct scale servicing with “best practice” energy efficient buildings.

***Cost Basis***

Because of the difficulty of assessing the cost of both transmission and the local upgrades to substations and distribution, these costs have not been included. Accordingly the figures only relate to the cost of generating electricity at source, and are therefore conservative. The basis for the costs is the Australian Energy Technology Assessment (2012) – a report prepared by the Bureau of Resources and Energy Economics (BREE).

The cost basis for the alternative solutions derive from a number of sources, including a recently completed study for the Stirling Alliance for the Stirling City Centre, GHD’s experience from other projects, literature reviews and market intelligence.

***Discounted cash flow***

The economic assessment begins in 2016 and (simplistically) assumes development, and therefore demand, will proceed at a rate of 4% of the potential yield for 25 years. In the case of the conventional servicing options it has been assumed (again simplistically) that infrastructure capacity is added to the SWIS simultaneously with demand increases.

The decentralised options assume that the structure plan area will be serviced for thermal loads by a thermal network of pipes, delivering heating / hot water and cooling energy directly to buildings in lieu of plant and equipment in each building. It has been assumed that the thermal network will be built in tranches: 50% in 2016, 25% in 2021 and 2026.

The assessment does not include for plant replacement for any of the options.

#### *Assumptions*

The options have been compared by determining the approximate capital and operating costs of each options, and converting these to a 50 year Net Present Cost (NPC) figure assuming a discount rate of 7% and a general escalation rate of 3%, and 5% for fossil fuels. As the costs of solar PV and electricity storage are falling, it has been assumed that the escalation rate for these will reduce at 3% per annum until 2027 (presently the annual reduction rate for solar PV is more like 5-8%).

The greenhouse gas emissions resulting from energy generation have been calculated assuming greenhouse gas coefficients taken from the Australian National Greenhouse Accounts (2012).

#### *Building Costs*

The assessment includes the impact of additional measures to improve thermal efficiency over and above the existing BCA requirements. The impact of these has been taken as a premium of:

- 2.5% to achieve 5 star NABERS
- 7.5% to achieve 6 star NABERS

The introduction of a thermal network obviates the need for separate heating and cooling plant in each building. This equipment would be replaced by much cheaper heat exchangers. It has been assumed that this will result in savings of approximately $196 / m2 (around 5.6% of building costs).

#### *Carbon costs*

BREE (2012) includes an assessment of likely carbon costs ($ per tonne CO2-e) into the future based on existing Australian government policy. This assessment assumes that the present cost of $24 will rise to $135 / tCO2-e by 2050. It is the current government's policy to abolish a direct price on carbon and so the assessment has been prepared with, and without a carbon price.

#### *Land costs*

The cost of land for infrastructure is not included in the assessment.

### 8.2.2 Results of assessment

The full discounted cash flow is set out in Appendix C. The following table and figures summarise the results.

Table 13 contains the results of the discounted cash flow analysis of the options.

Table 13 Net present cost of energy options ($m)

| Option | Cost item | Capex ($2014) | NPC (Capex + Opex) | NPC with carbon price |
|---|---|---|---|---|
| | | | | |
| BaU | Grid costs | 99 | 355 | 492 |
| | | | | |
| BaU - 5 stars | Grid costs | 75 | 264 | |
| | Addtl building costs | 245 | 161 | |
| | | 320 | 425 | 527 |
| BaU - 6 stars | Grid costs | 47 | 163 | |
| | Addtl building costs | 735 | 483 | |
| | | 782 | 647 | 709 |
| 6 stars + solar + storage | | | | |
| | Grid costs | 23 | 75 | |
| | Solar | 78 | 47 | |
| | Storage | 91 | 79 | |
| | Addtl building costs | 735 | 483 | |
| | | 926 | 684 | 713 |
| 6 stars + trigen | Grid costs | 0 | 0 | |
| | Trigen | 58 | 195 | |
| | Thermal network | 150 | 225 | |
| | Addtl building costs | 735 | 483 | |
| | Building savings | -549 | -540 | |
| | | 394 | 362 | 475 |
| 6 stars + solar + storage + geothermal | | | | |
| | Grid costs | 11 | 53 | |
| | Solar | 44 | 27 | |
| | Storage | 59 | 51 | |
| | Geothermal | 74 | 83 | |
| | Thermal network | 150 | 225 | |
| | Addtl building costs | 735 | 483 | |
| | Building savings | -549 | -540 | |
| | | 525 | 382 | 404 |

Figures 12 and 13 depict the cost and greenhouse performance of the options, with and without a carbon price directly applied to energy.

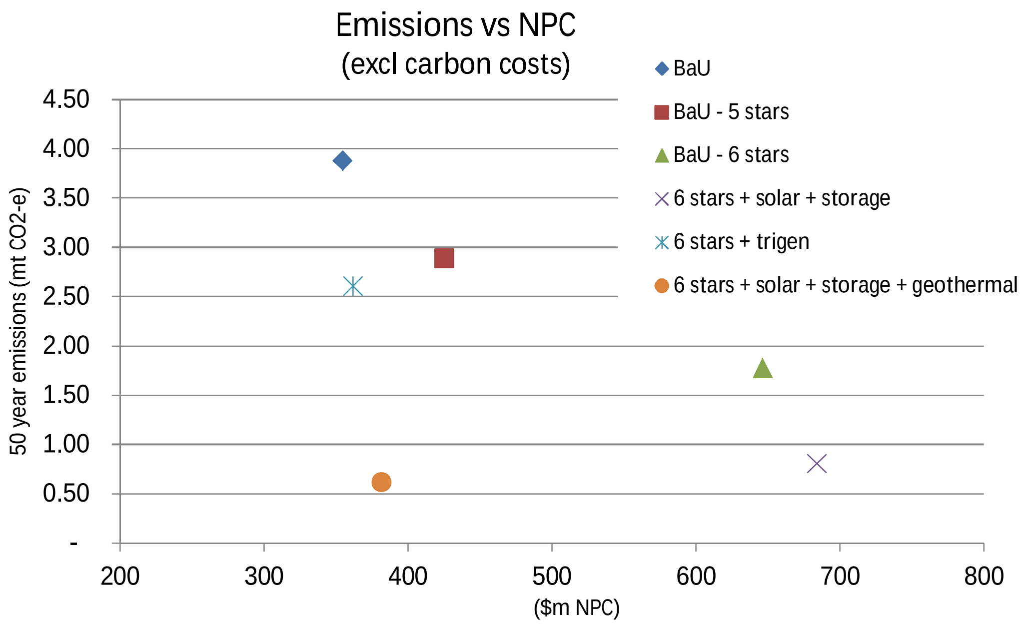



Figure 13 – Cost and performance of energy options (excluding carbon price)

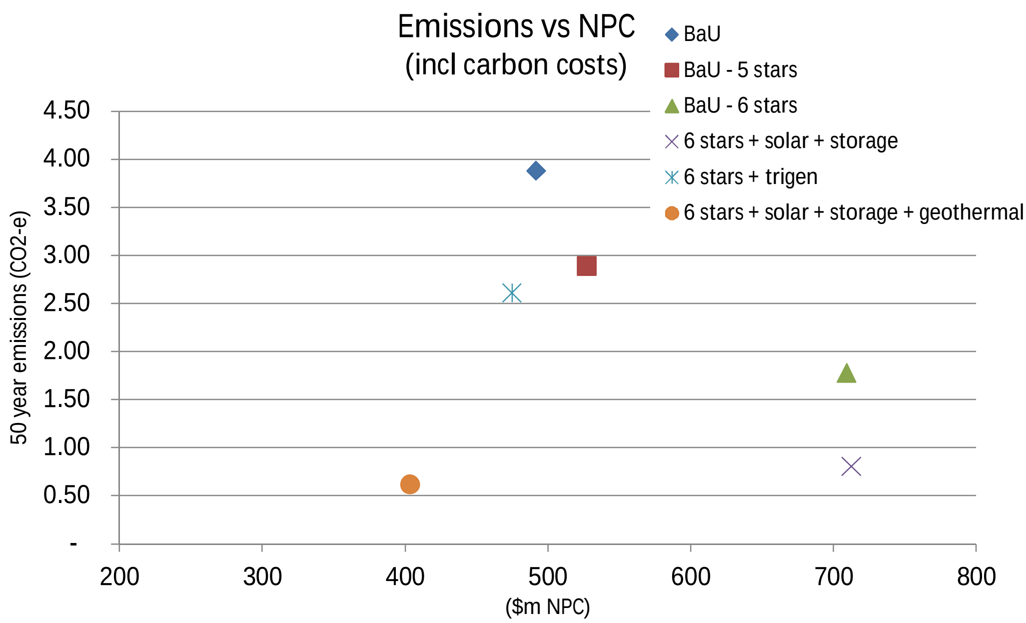



Figure 14 – Cost and performance of energy options (including carbon price)

The assessment highlights the greenhouse benefits of high performance buildings, solar and geothermal solutions over the fossil fuel based alternatives. Bearing in mind that this assessment excludes some costs for the BaU options (transmission and distribution upgrades), it infers that the 50 year NPC of the decentralised options is similar to conventional servicing with normal efficiency buildings even if a price on carbon is excluded. If a carbon price is included, the decentralised options may be somewhat cheaper than BaU.

While the greenhouse performance of 6 star building efficiencies with conventional servicing is apparent, the economic cost of achieving this benefit is higher.

Figure 15 sets out the cash flow over time for the options (excluding a carbon price).

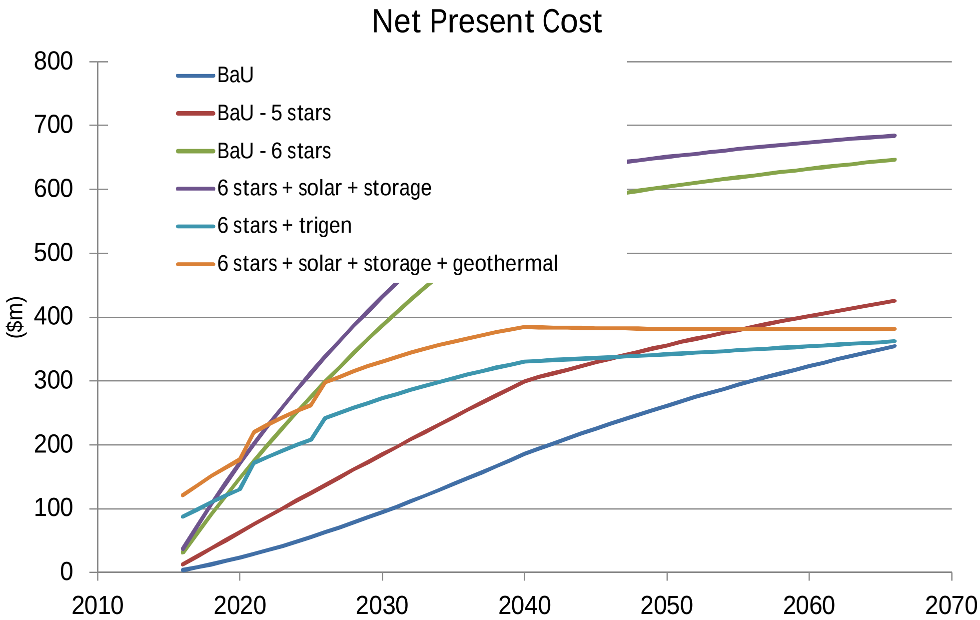



Figure 15 – Cash flow of energy options (excluding carbon price)

This figure illustrates that the upfront capital cost of all the alternatives is significantly greater than the cost of business-as-usual. However the savings in building costs (capex and opex) mean that the decentralised options (trigeneration and geothermal) will ultimately be cheaper than the other options over the long term.

The cost of energy infrastructure is only a small percentage of the total built cost (i.e. buildings and infrastructure), the bulk which occurs by 2025. If the total built cost of the options is compared over this period, the differences are marginal (see Figure 16). The decentralised options would add between 4-6% to total built cost (in escalated / discounted dollars), assuming no carbon price. If this is included the differences will be less. This is effectively the economic cost premium for reducing emissions between 33% (trigen) and 80% (solar / geothermal) compared to BaU.

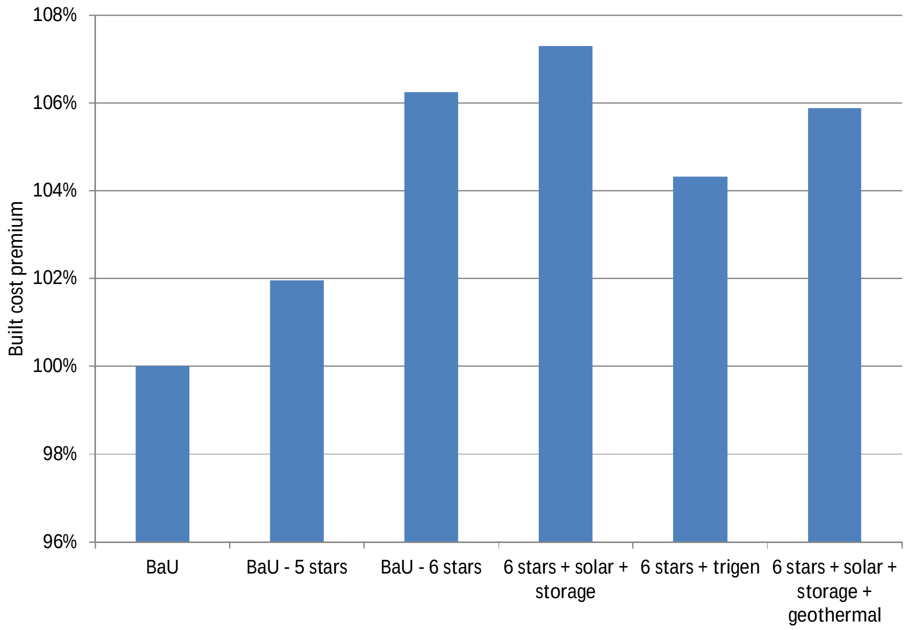



Figure 16 – 2025 Total building costs of energy options (excluding carbon price)

On the basis of this preliminary assessment, it appears that the decentralised solar / geothermal option offers the best emissions performance at the lowest economic cost. While decentralised trigeneration results in similar economic costs, the greenhouse performance of this option is substantially inferior, although offering significant improvements over BaU. The ongoing cost of trigeneration is also dependent on the price of gas. The solar / geothermal solution is much less reliant on the grid for backup, and so is much less sensitive to increasing fuel costs.

## 8.3 Water Options

### 8.3.1 Description of assessment

Based on the commentary in Section 6.6 above the following alternatives were selected for consideration in this assessment.

Table 14 Water supply options

| Option title | Water efficiency | Servicing |
|---|---|---|
| BaU | Conventional | Conventional centralised water supply and wastewater disposal |
| Waterwise | Waterwise | |
| NDW with excess to sewer | Waterwise | Precinct scale wastewater recycling for non-drinking water (NDW) uses. Excess disposal to Water Corporation sewer. |
| NDW with excess disposal | | Precinct scale wastewater recycling for non-drinking water (NDW) uses. Excess disposal to local aquifer. |

These options fall into 2 categories:

- Conventional servicing infrastructure (water and wastewater) with conventional and water efficient (waterwise) demand; and
- Decentralised (local) wastewater recycling) for non-drinking water (NDW) uses: toilet flushing, cold water for clothes washing and public / private irrigation. These options assume waterwise demand.

***Cost Basis***

Because of the difficulty of assessing the cost of local upgrades to water supply infrastructure (storage and distribution), these costs have not been included. Accordingly the figures only relate to the cost of water source, and are therefore conservative. The basis for the costs is the reported long run marginal cost of water (LRMC) identified by the Water Corporation. Two figures are produced for LRMC, one for additions to the IWSS in excess of current planning and one for reductions. As an approximation the average of these figures has been used, escalated from the reported 2012 figures.

Similarly wastewater costs for the centralised schemes do not include the potential savings to downstream wastewater conveyance at the district and main sewer scale, or the cost of disposal of treated wastewater from WWTPs to ocean. They are therefore also conservative. It has been assumed that the NDW scheme will lead to modest savings ($5m) in upgrades to the local pump stations and associated network.

The waterwise option involves an additional cost to consumers for water efficient fixtures, fittings and irrigation systems. This cost has been assumed as $300 per dwelling.

Although the cost of energy is embedded in the IRMC, the cost of energy for all other elements of the options is also neglected.

The cost basis for wastewater and for the alternative solutions derive from a number of sources, including a recently completed study for the Stirling Alliance for the Stirling City Centre, GHD's experience from other projects, literature reviews and market intelligence.

#### *Discounted cash flow*

The economic assessment begins in 2016 and (simplistically) assumes development, and therefore demand, will proceed at a rate of 4% of the potential yield for 25 years. In the case of the conventional servicing options it has been assumed (again simplistically) that infrastructure capacity is added to the IWSS simultaneously with demand increases.

The decentralised options assume that the structure plan area will be serviced by an additional network of pipes, delivering NDW directly to buildings in addition to drinking water. It has been assumed that the recycled water network will be built in tranches: 50% in 2016, 25% in 2021 and 2026.

The assessment does not include for plant replacement for any of the options.

#### *Assumptions*

The options have been compared by determining the approximate capital and operating costs of each option, and converting these to a 50 year Net Present Cost (NPC) figure assuming a discount rate of 7% and a general escalation rate of 3%.

#### *Building Costs*

The assessment excludes the impact of the NDW scheme on plumbing costs in each building.

#### *Land costs*

The cost of land for infrastructure is not included in the assessment.

### 8.3.2 Results of assessment

The full discounted cash flow of each option is set out in Appendix C. The following table summarises the results.

Table 15 Net present cost of water options ($m)

| Options | Cost items | Capex ($2014) | NPC |
|---|---|---|---|
| | | | |
| BaU | Upgrade source / treatment / conveyance | 54 | 65 |
| | Upgrade WWTP | 40 | 33 |
| | | 94 | 99 |
| | | | |
| Waterwise | Upgrade source / treatment / conveyance | 36 | 44 |
| | Upgrade WWTP | 27 | 22 |
| | Waterwise fixtures and fittings | 5 | 3 |
| | | 68 | 70 |
| NDW with excess to sewer | | | |
| | Upgrade source / treatment / conveyance | 18 | 22 |
| | Upgrade WWTP | 10 | 8 |
| | Waterwise fixtures and fittings | 5 | 3 |
| | Pump station savings | -5 | -8 |
| | Recycled Water Plant | 23 | 26 |

| | | | |
|---|---|---|---|
| | RW distribution & reticulation | 21 | 20 |
| | | 72 | 72 |
| NDW with excess disposal | | | |
| | Upgrade source / treatment / conveyance | 18 | 22 |
| | Upgrade WWTP | | |
| | Waterwise fixtures and fittings | 5 | 3 |
| | Pump station savings | -5 | -8 |
| | Recycled Water Plant | 23 | 26 |
| | RW distribution & reticulation | 21 | 20 |
| | RW disposal | 2 | 3 |
| | | 64 | 66 |

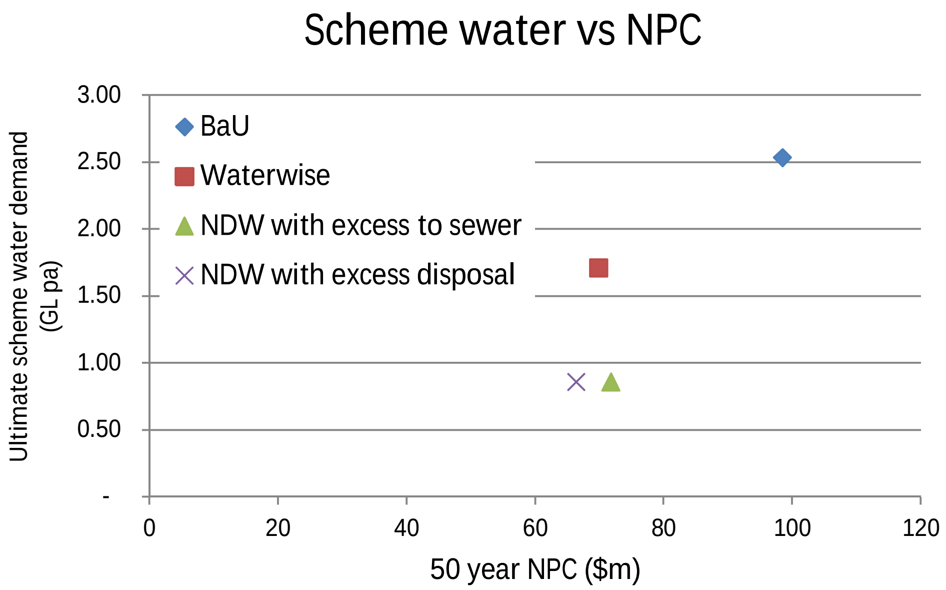



Figure 17 – Cost and performance of water options

The analysis indicates that the cost of all alternatives to BaU will result in considerable economic savings while significantly reducing the demand on the IWSS for scheme water. As not all savings to BaU are captured in the analysis, the alternatives are likely to more attractive than described here.

As is the case for the alternative energy solutions, a NDW scheme will incur greater early capital costs than BaU (see Figure 18), although these costs are recouped over time. The total cost of water infrastructure is a very small percentage (around 1.2% for BaU), and so the additional investment in alternative water infrastructure is not significant in overall economic terms.

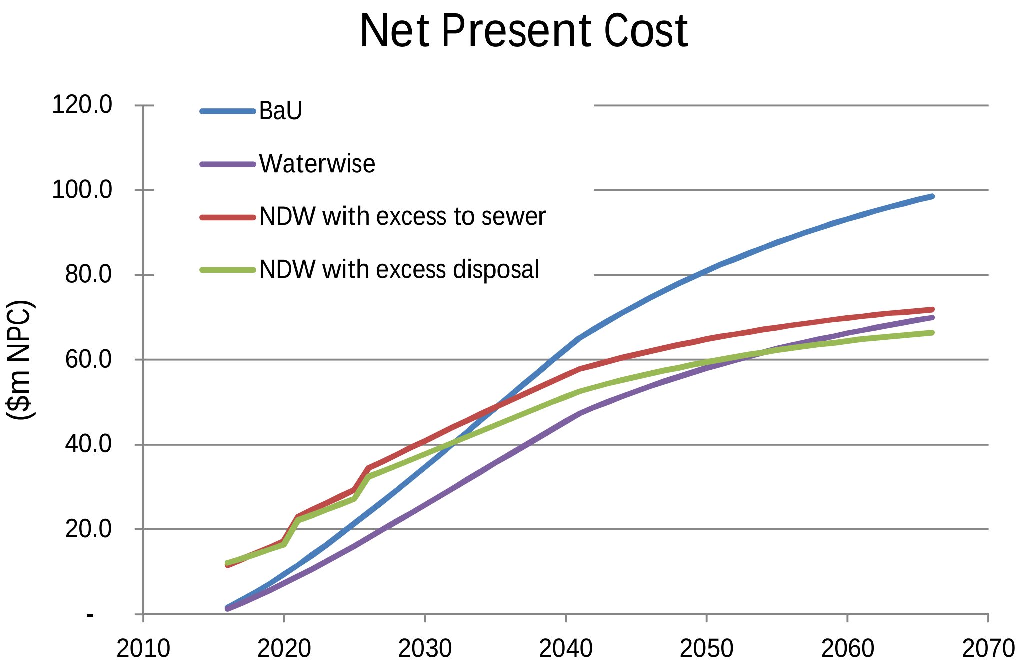



Figure 18 – Cash flow of water options

On the basis of this assessment, the incorporation of an NDW scheme sourced from recycled wastewater is both economically viable and would lead to reduced demand on the centralised (metropolitan) scale water supply and wastewater networks.

## 8.4 Integrated solution

Decentralised energy and water infrastructure offers the opportunity to integrate these services, e.g. the use of renewable energy to operate the NDW scheme, and the use of recycled water in cooling towers of the thermal energy system. The demand on both sets of infrastructure will increase at the same pace, and initial investment will be required for both networks.

Figure 19 depicts the potential integrated system.

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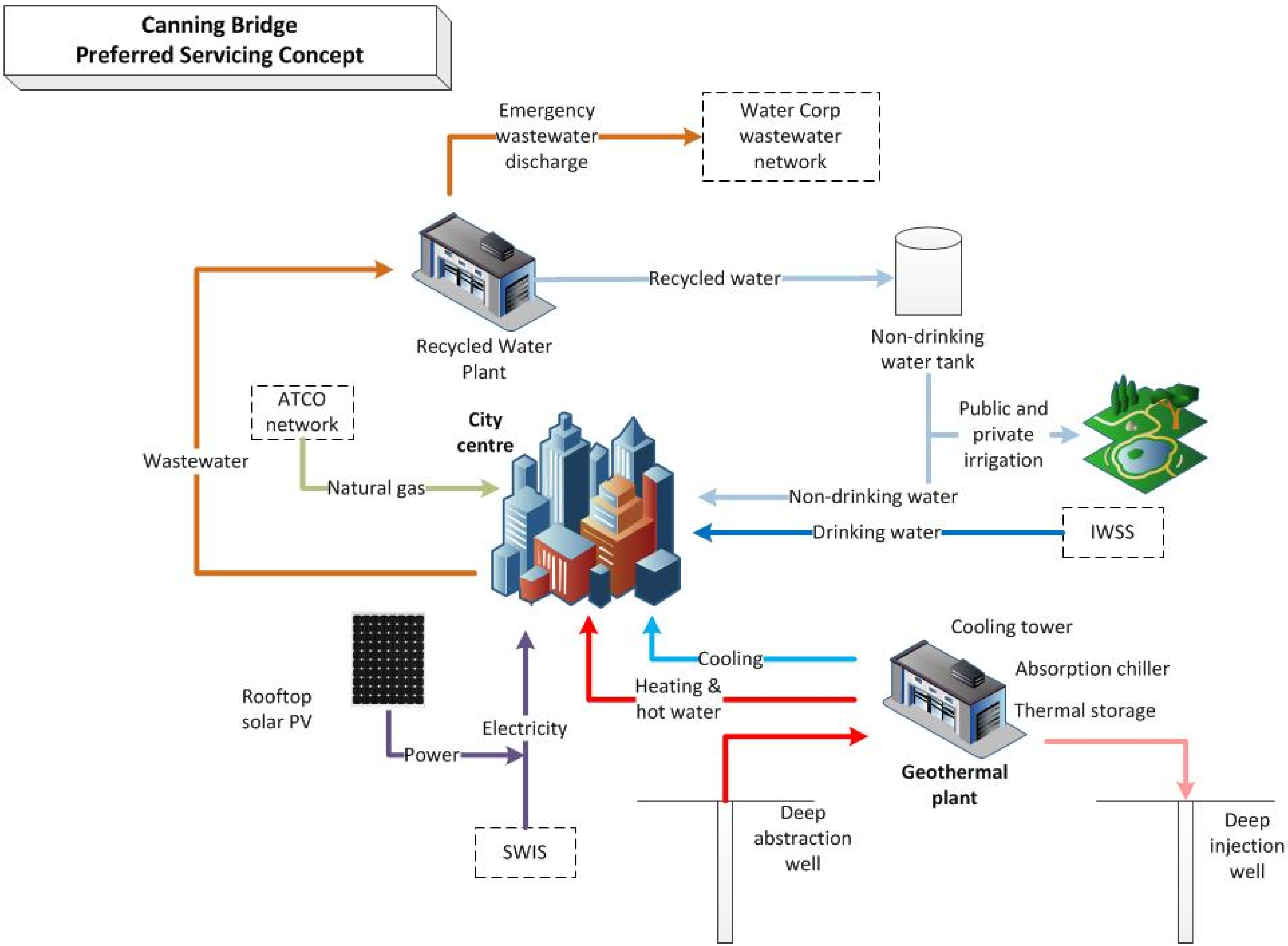


Figure 19 – Integrated energy and water servicing concept

# 9. Governance and implementation

## 9.1 Governance Arrangements

Identifying an implementation strategy for delivery of the preferred concept is beyond the scope of this study. The options are:

1. Separate implementation of each component through existing agencies, i.e. electricity (Western Power, Synergy / other retailers and generators), and water (Water Corporation);
2. Separate implementation of each component through involvement of the private sector (electricity generation / retail, recycled water); and
3. A new utility formed specifically to provide services at Canning Bridge which would provide integrated energy, water and waste services.

Under the first option each utility would implement the strategy, i.e.:

- Verve / Synergy would deliver the energy elements with ATCO / Alinta cooperation;
- Water Corporation to fully own, operate and maintain the water recycling plant and NDW system.

The complexity of realising the identified opportunities through conventional means (option 1) is likely to be very high, requiring cooperation between local government and several utilities, each with their own business strategies centred on business as usual practices, and most with a much broader geographical focus.

The second option would likely to be more complex, as even more interfaces would be required, i.e. not only between the providers but also with the existing agencies whose networks and assets will remain integral to the system.

The third option would reduce the complexities significantly with energy and water flows all occurring within a single business entity, although interface agreements with the broader network providers (Western Power and Water Corporation) would still be required. Such a utility could be formed through a special purpose vehicle involving existing utilities, other private sector firms, local government, or a combination of the above. However if development contributions are to provide some of the funding for assets, these assets must be held by publicly owned authorities under the requirements of State Planning Policy 3.6 Development Contributions for Infrastructure.

Although it would be a novel approach for Western Australia, a local government owned utility providing integrated energy and water services is a logical way of implementing the strategy, and would reflect the approach taken for district energy systems in North America. It would need to be integrated with, and facilitated by the local planning scheme and associated development contribution plan. It is envisaged under such an arrangement that a private sector partner would design, build and operate the facilities as an integrated service contract, offering the additional benefit of risk mitigation and private sector investment.

Larger councils with higher levels of financial capacity and service delivery capability are an objective of the government's amalgamation strategy[9]. The expansion of their service delivery from waste to energy and water would involve considerable upgrading of existing capacity. However, a partnership with a private utility offers the attraction of the requisite skills together

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http://www.mediastatements.wa.gov.au/pages/StatementDetails.aspx?listName=StatementsBarnett&StatId=7607

with private investment and risk sharing. Increasing the involvement of the private sector is also an objective of the state government. Such a model is potentially applicable to Activity Centres more generally in the metropolitan area.

It is recommended that the findings of this report are canvassed with a range of stakeholders, namely:

- the Cities of Melville and South Perth; and
- the WAPC Infrastructure Coordination Committee.

Subject to these consultations the following authorities should be consulted:

- the Economic Regulatory Authority; and
- the relevant ministers and departments (Planning, Water, Energy, Local Government).

## 9.2 Regulatory Issues

The Economic Regulation Authority (ERA) is the independent economic regulator for Western Australia. The ERA was established under section 4 of the Economic Regulation Authority Act 2003.

The ERA regulates monopoly aspects of the gas, electricity and rail industries and licenses providers of gas, electricity and water services. The ERA also has a range of responsibilities in the retailing of gas and surveillance of the wholesale electricity market in Western Australia.

### 9.2.1 Electricity

It is anticipated that licences would be needed under the Electricity Industry Act 2004 (not including normal licensing of the centralised energy and water agencies), these include:

- to construct or operate generating works (electricity generation licence or an integrated regional licence); and
- to sell electricity to customers except under the authority of a retail licence or an integrated regional licence.

This assumes that a local utility generates electricity at Canning Bridge and retails to all eligible customers, i.e. those that consume more than 50MWh per annum (which could include multi-residential buildings with individual sub-metering of premises).

The Public Utilities Office (PUO) within the Department of Finance provides advice on energy matters to the Minister for Energy and the Western Australian Government. Amongst other functions, the Public Utilities Office supports the performance of the statutory functions (Energy Coordination Act 1994) of the Coordinator of Energy. Accordingly the PUO will have a role in establishing the alternative arrangements under which electricity would be supplied as set out here.

### 9.2.2 Water

Under the recommendations in this report, a local utility would provide sewerage and non-potable water services to customers, and accordingly licences would be required for both. This will require the utility to demonstrate:

- sufficient financial and technical ability to operate the service;
- that the application is not contrary to public interest; and
- it can meet the minimum service and performance standards set by ERA in respect of:
  - sewerage service standards;

- non-drinking water quality standards;
- non-drinking water pressure and flow standards;
- non-drinking water continuity standards;
- irrigation water quality and delivery standards;
- customer service and complaint handling standards.

The DoW and DoH will be consulted by the ERA in considering a licence, and will a have direct regulatory role in some cases.

- The DoW is responsible for protecting and managing the State's water resources, including management of the licensing system for water source allocation; and
- The DoH regulates health standards for water supplied by the service providers.

### 9.2.3 Thermal energy

Under the recommendations in this report, a local utility would retail thermal energy to customers in the form of hot water (for space and water heating) and cold water (for space cooling).

For a thermal energy scheme to be financially viable, take up of the service would need to be mandated by the planning and development approval processes, noting that the scheme will result in reduced building equipment capital costs. A possible exemption from this arrangement would be for building owners that can demonstrate they can supply the same service within the building at an equivalent / lower cost and with equivalent / lower greenhouse gas emissions.

There are presently no regulations governing the supply of thermal energy in Western Australia or in any other state. Although cogeneration and trigeneration schemes are operating at the building level, the resulting energy supplies are the subject of private contracts between the system owner and building occupants.

A new regime will need to be established for setting a price per unit energy for thermal energy, and establishing minimum service and performance standards. Following practices in Europe for district heating systems, it is recommended that the principle is established that the aggregate cost to the consumer should be no more than it otherwise would be if the heating / cooling service was supplied in a conventional manner. For heating this could be determined as the equivalent of natural gas use for space and water heating, and electricity for space cooling.

# 10. Further Studies

This preliminary study identifies that the preferred servicing concept offers significant sustainability benefits, is technically feasible and economically viable. However a significant amount of further study and numerous consultations are necessary before the proposed infrastructure concept can be progressed.

The following assumes that business as usual infrastructure upgrades and costs are established in parallel with the cooperation of the service providers.

## 10.1 Concept feasibility studies

### 10.1.1 Feasibility study – solar PV

This study will:

- examine in detail the demand / supply balance and identify more accurately the contribution of solar to meet peak and annual electrical demands;
- examine in detail the types of electrical storage that are feasible for the site (centralised or distributed);
- develop a strategy for locating PV panels on rooftops (including access options);
- devise the inverter, grid connection and metering design;
- identify the implications for the Western Power high-voltage network at and downstream of the substation; and
- identify capital and operating costs.

### 10.1.2 Feasibility study – geothermal energy

This report identifies geothermal energy as a potential source of thermal energy.

Further examination of the viability of geothermal energy to provide thermal energy should be progressed through the interpretation of available geophysical data followed by a trial bore. This trial would establish the depth at which suitable temperatures exist and the hydraulic characteristics of the aquifer which will determine potential pumping rates.

The area required, and a location for the geothermal bore would be a component of the study.

Subject to the outcome of this trial a concept design could be progressed and costed for the geothermal energy headworks.

### 10.1.3 Feasibility study – recycled water

The proposed approach to recycled water set out in this report should be reviewed. In particular the following issues need to be progressed:

- concept design of the rerouting of sewers;
- concept design of the recycled water plant including layout/footprint and location;
- the ongoing interface with the Water Corporation system including emergency discharge;
- concept design of the recycled water distribution and reticulation network;
- concept design of the excess water discharge arrangements;
- the implications for buildings of the non-drinking water system; and

- capital and operating costs and prices.

If viability is confirmed, the recycled water initiative can be progressed.

## 10.2 Commercial viability studies

Subject to the concept studies, further work will be required to determine commercial viability.

### 10.2.1 Service delivery implementation options

This report suggests three alternative delivery options are available:

1. Separate implementation of each component through existing agencies, i.e. electricity (Western Power, Synergy / other retailers and generators), and water (Water Corporation).
2. Separate implementation of each component through involvement of the private sector (electricity generation / retail, recycled water).
3. A new utility formed specifically to provide services at Canning Bridge which would provide integrated energy and water services.

Examination of these options is a priority as the outcome of the preferred concept as described above is reliant on the identification of one or more service providers.

### 10.2.2 Distributed thermal energy

The feasibility of providing a service that delivers heating and cooling to buildings requires further study. This study would consider:

- concept design of the proposed heating and cooling, i.e. absorption and electric chillers and thermal storage;
- concept design of the proposed heat rejection system;
- concept development of the thermal network including extent, sizing and the location / layout of energy stations;
- the cost / benefit to building owners of such an arrangement;
- whether the planning system can mandate developers to connect to and purchase thermal energy from a utility;
- any exemptions that would apply to such arrangements;
- implications for buildings;
- costs of providing the service;
- pricing of the service; and
- regulation of the service.

The results of this study will determine the feasibility of the thermal energy distribution concept.

## 10.3 Development contributions

The implementation of the strategy as outlined above would need to be integrated with a development contribution plan (DCP) for Canning Bridge. The delivery of an integrated, decentralised energy and water scheme would need to be funded via a combination of development contributions and user charges.

It is recommended that standard headworks for both water and power are not applied at Canning Bridge, rather that costs for all infrastructure is incorporated in the DCP. Standard headworks charges have been devised for greenfield developments and are not readily transferable to Activity Centre development.

There is significant risk to adequate and equitable funding of infrastructure if a Structure Plan is endorsed without a DCP in place. A development contribution plan does not have effect until it is incorporated into a local planning scheme or at least seriously entertained through initiation of the scheme amendment. Accordingly any development that occurs before this point would not be liable to contribute to the DCP. Clearly it will be necessary to articulate the total capital costs of infrastructure and devise a methodology for equitable sharing of costs through subsequent development to ensure the Structure Plan is fully implementable.

A DCP is also the logical instrument to seek and incorporate any applicable grants from Commonwealth (e.g. Infrastructure Australia) or State government which will offset developer contributions, and may well be critical to successful implementation of the Structure Plan. A comprehensive DCP incorporating a Capital Plan provides a transparent plan underpinned by the statutory power of a local scheme.

# Appendices

# Appendix A – Energy demand estimates

| | | Total Energy Demand - BaU | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Summer | | | Mid season | | | Winter | | | Annual | | | |
| | GFA (m2) | Peak (MVA) | Average (MVA) | P/A | Peak (MVA) | Average (MVA) | P/A | Peak (MVA) | Average (MVA) | P/A | Peak (MVA) | Average (MVA) | P/A | Total (MWh) |
| Cooling | | | | | | | | | | | | | | |
| residential | 2,538,269 | 104.27 | 38.81 | 2.69 | 55.75 | 15.85 | 3.52 | 7.35 | 1.14 | 6.43 | 104.27 | 17.92 | 5.82 | 156,949 |
| office | 182,740 | 18.87 | 7.74 | 2.44 | 11.95 | 4.37 | 2.73 | 5.77 | 1.65 | 3.50 | 18.87 | 4.53 | 4.16 | 39,695 |
| retail | 66,928 | 8.03 | 4.85 | 1.66 | 8.03 | 4.55 | 1.76 | 5.35 | 2.50 | 2.14 | 8.03 | 4.11 | 1.95 | 36,032 |
| entertainment and community | | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - |
| | | 109.90 | 51.40 | 2.14 | 60.57 | 24.78 | 2.44 | 12.31 | 5.29 | | 109.90 | 26.56 | | 232,676 |
| Heating and hot water | | | | | | | | | | | | | | |
| residential | 2,538,269 | 8.17 | 1.29 | 6.32 | 8.28 | 1.99 | 4.17 | 27.45 | 10.44 | 2.63 | 27.45 | 3.93 | 6.99 | 34,393 |
| office | 182,740 | 0.27 | 0.10 | 2.53 | 0.27 | 0.10 | 2.53 | 1.65 | 0.17 | 9.57 | 1.65 | 0.12 | 13.51 | 1,066 |
| retail | 66,928 | 0.03 | 0.02 | 2.03 | 0.03 | 0.02 | 2.03 | 0.33 | 0.16 | 2.03 | 0.33 | 0.05 | 6.26 | 468 |
| entertainment and community | - | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - |
| | | 8.46 | 1.41 | 5.98 | 8.46 | 2.11 | 4.01 | 27.45 | 10.77 | 2.55 | 27.45 | 4.10 | 6.69 | 35,928 |
| Electricity incl H&C | | | | | | | | | | | | | | |
| residential | 2,538,269 | 54.94 | 21.70 | 2.53 | 42.36 | 16.80 | 2.52 | 39.36 | 16.63 | 2.37 | 54.94 | 17.98 | 3.06 | 157,537 |
| office | 182,740 | 10.26 | 5.45 | 1.88 | 8.18 | 4.18 | 1.96 | 6.13 | 3.19 | 1.92 | 10.26 | 4.25 | 2.41 | 37,207 |
| retail | 66,928 | 4.45 | 2.64 | 1.68 | 4.45 | 2.68 | 1.66 | 4.45 | 2.48 | 1.80 | 4.45 | 2.62 | 1.70 | 22,959 |
| entertainment and community | - | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - |
| | | 59.16 | 29.79 | 1.99 | 47.45 | 23.66 | 2.01 | 44.45 | 22.30 | 1.99 | 59.16 | 24.85 | 2.38 | 217,702 |
| Electricity excl H&C | | | | | | | | | | | | | | |
| residential | 2,538,269 | 37.39 | 11.28 | 3.31 | 33.18 | 12.17 | 2.73 | 37.57 | 13.62 | 2.76 | 37.57 | 12.31 | 3.05 | 107,837 |
| office | 182,740 | 7.63 | 2.83 | 2.69 | 6.51 | 2.69 | 2.42 | 5.03 | 2.58 | 1.95 | 7.63 | 2.70 | 2.83 | 23,620 |
| retail | 66,928 | 2.30 | 1.02 | 2.25 | 2.03 | 1.16 | 1.75 | 2.91 | 1.59 | 1.83 | 2.91 | 1.23 | 2.36 | 10,792 |
| entertainment and community | - | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - |
| | | 39.45 | 15.13 | 2.61 | 36.38 | 16.01 | 2.27 | 40.78 | 17.79 | 2.29 | 40.78 | 16.24 | 2.51 | 142,249 |

| | Total Energy Demand - 4 star | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Summer | | | Mid season | | | Winter | | | Annual | | |
| | Peak (MVA) | Average (MVA) | P/A | Peak (MVA) | Average (MVA) | P/A | Peak (MVA) | Average (MVA) | P/A | Peak (MVA) | Average (MVA) | P/A | Total (MWh) |
| 73% | 75.93 | 28.26 | 2.69 | 40.60 | 11.54 | 3.52 | 5.35 | 0.83 | 6.43 | 75.93 | 13.05 | 5.82 | 114,282 |
| 98% | 18.45 | 7.57 | 2.44 | 11.68 | 4.27 | 2.73 | 5.64 | 1.61 | 3.50 | 18.45 | 4.43 | 4.16 | 38,814 |
| 56% | 4.49 | 2.71 | 1.66 | 4.49 | 2.54 | 1.76 | 2.99 | 1.40 | 2.14 | 4.49 | 2.30 | 1.95 | 20,138 |
| 25% | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - |
| | 82.83 | 38.54 | 2.15 | 45.40 | 18.36 | 2.47 | 9.32 | 3.84 | 2.43 | 82.83 | 19.78 | 4.19 | 173,234 |
| 73% | 5.95 | 0.94 | 6.32 | 6.03 | 1.45 | 4.17 | 19.99 | 7.60 | 2.63 | 19.99 | 2.86 | 6.99 | 25,043 |
| 98% | 0.26 | 0.10 | 2.53 | 0.26 | 0.10 | 2.53 | 1.61 | 0.17 | 9.57 | 1.61 | 0.12 | 13.51 | 1,043 |
| 56% | 0.02 | 0.01 | 2.03 | 0.02 | 0.01 | 2.03 | 0.19 | 0.09 | 2.03 | 0.19 | 0.03 | 6.26 | 262 |
| 25% | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - |
| | 6.22 | 1.05 | 5.91 | 6.22 | 1.56 | 3.99 | 20.32 | 7.86 | 2.59 | 20.32 | 3.01 | 6.76 | 26,348 |
| 73% | 40.01 | 15.80 | 2.53 | 30.84 | 12.23 | 2.52 | 28.66 | 12.11 | 2.37 | 40.01 | 13.09 | 3.06 | 114,710 |
| 98% | 10.03 | 5.32 | 1.88 | 8.00 | 4.09 | 1.96 | 5.99 | 3.12 | 1.92 | 10.03 | 4.15 | 2.41 | 36,381 |
| 56% | 2.49 | 1.48 | 1.68 | 2.49 | 1.50 | 1.66 | 2.49 | 1.39 | 1.80 | 2.49 | 1.46 | 1.70 | 12,832 |
| 25% | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - |
| | 44.62 | 22.60 | 1.97 | 35.66 | 17.82 | 2.00 | 33.06 | 16.61 | 1.99 | 44.62 | 18.71 | 2.38 | 163,922 |
| 73% | 27.22 | 8.22 | 3.31 | 24.16 | 8.86 | 2.73 | 27.35 | 9.92 | 2.76 | 27.35 | 8.96 | 3.05 | 78,522 |
| 98% | 7.46 | 2.77 | 2.69 | 6.36 | 2.63 | 2.42 | 4.92 | 2.52 | 1.95 | 7.46 | 2.64 | 2.83 | 23,095 |
| 56% | 1.28 | 0.57 | 2.25 | 1.14 | 0.65 | 1.75 | 1.63 | 0.89 | 1.83 | 1.63 | 0.69 | 2.36 | 6,032 |
| 25% | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - |
| | 29.99 | 11.55 | 2.60 | 27.61 | 12.13 | 2.28 | 30.38 | 13.33 | 2.28 | 30.89 | 12.29 | 2.51 | 107,648 |

Total Energy Demand - 5 star

| | Summer Peak (MVA) | Summer Average (MVA) | Summer P/A | Mid season Peak (MVA) | Mid season Average (MVA) | Mid season P/A | Winter Peak (MVA) | Winter Average (MVA) | Winter P/A | Annual Peak (MVA) | Annual Average (MVA) | Annual P/A | Total (MWh) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 55% | 56.95 | 21.20 | 2.69 | 30.45 | 8.66 | 3.52 | 4.02 | 0.62 | 6.43 | 56.95 | 9.78 | 5.82 | 85,711 |
| 73% | 13.85 | 5.68 | 2.44 | 8.77 | 3.21 | 2.73 | 4.24 | 1.21 | 3.50 | 13.85 | 3.33 | 4.16 | 29,137 |
| 37% | 2.99 | 1.81 | 1.66 | 2.99 | 1.70 | 1.76 | 1.99 | 0.93 | 2.14 | 2.99 | 1.53 | 1.95 | 13,426 |
| 17% | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - |
| | 61.82 | 28.68 | 2.16 | 33.76 | 13.56 | 2.49 | 6.82 | 2.76 | 2.47 | 61.82 | 14.64 | 4.22 | 128,274 |
| 55% | 4.46 | 0.71 | 6.32 | 4.52 | 1.09 | 4.17 | 14.99 | 5.70 | 2.63 | 14.99 | 2.14 | 6.99 | 18,783 |
| 73% | 0.19 | 0.08 | 2.53 | 0.19 | 0.08 | 2.53 | 1.21 | 0.13 | 9.57 | 1.21 | 0.09 | 13.51 | 783 |
| 37% | 0.01 | 0.01 | 2.03 | 0.01 | 0.01 | 2.03 | 0.12 | 0.06 | 2.03 | 0.12 | 0.02 | 6.26 | 175 |
| 17% | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - |
| | 4.67 | 0.79 | 5.91 | 4.67 | 1.17 | 3.99 | 15.23 | 5.89 | 2.59 | 15.23 | 2.25 | 6.76 | 19,740 |
| 55% | 30.01 | 11.85 | 2.53 | 23.13 | 9.18 | 2.52 | 21.49 | 9.08 | 2.37 | 30.01 | 9.82 | 3.06 | 86,033 |
| 73% | 7.53 | 4.00 | 1.88 | 6.01 | 3.07 | 1.96 | 4.50 | 2.34 | 1.92 | 7.53 | 3.12 | 2.41 | 27,311 |
| 37% | 1.66 | 0.98 | 1.68 | 1.66 | 1.00 | 1.66 | 1.66 | 0.92 | 1.80 | 1.66 | 0.98 | 1.70 | 8,554 |
| 17% | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - |
| | 33.29 | 16.83 | 1.98 | 26.57 | 13.24 | 2.01 | 24.61 | 12.35 | 1.99 | 33.29 | 13.92 | 2.39 | 121,898 |
| 55% | 20.42 | 6.16 | 3.31 | 18.12 | 6.64 | 2.73 | 20.52 | 7.44 | 2.76 | 20.52 | 6.72 | 3.05 | 58,891 |
| 73% | 5.60 | 2.08 | 2.69 | 4.78 | 1.97 | 2.42 | 3.69 | 1.89 | 1.95 | 5.60 | 1.98 | 2.83 | 17,337 |
| 37% | 0.86 | 0.38 | 2.25 | 0.76 | 0.43 | 1.75 | 1.08 | 0.59 | 1.83 | 1.08 | 0.46 | 2.36 | 4,021 |
| 17% | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - |
| | 22.41 | 8.62 | 2.60 | 20.63 | 9.05 | 2.28 | 22.67 | 9.93 | 2.28 | 23.06 | 9.16 | 2.52 | 80,250 |

| | Total Energy Demand - 6 star | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Summer | | | Mid season | | | Winter | | | Annual | | | |
| | Peak (MVA) | Average (MVA) | P/A | Peak (MVA) | Average (MVA) | P/A | Peak (MVA) | Average (MVA) | P/A | Peak (MVA) | Average (MVA) | P/A | Total (MWh) |
| 36% | 37.96 | 14.13 | 2.69 | 20.30 | 5.77 | 3.52 | 2.68 | 0.42 | 6.43 | 37.96 | 6.52 | 5.82 | 57,141 |
| 37% | 6.93 | 2.84 | 2.44 | 4.38 | 1.60 | 2.73 | 2.12 | 0.60 | 3.50 | 6.93 | 1.66 | 4.16 | 14,569 |
| 19% | 1.50 | 0.90 | 1.66 | 1.50 | 0.85 | 1.76 | 1.00 | 0.47 | 2.14 | 1.50 | 0.77 | 1.95 | 6,713 |
| 8% | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - |
| | 38.86 | 17.88 | 2.17 | 20.94 | 8.22 | 2.55 | 3.86 | 1.49 | 2.60 | 38.86 | 8.95 | 4.34 | 78,422 |
| 36% | 2.97 | 0.47 | 6.32 | 3.02 | 0.72 | 4.17 | 9.99 | 3.80 | 2.63 | 9.99 | 1.43 | 6.99 | 12,522 |
| 37% | 0.10 | 0.04 | 2.53 | 0.10 | 0.04 | 2.53 | 0.60 | 0.06 | 9.57 | 0.60 | 0.04 | 13.51 | 391 |
| 19% | 0.01 | 0.00 | 2.03 | 0.01 | 0.00 | 2.03 | 0.06 | 0.03 | 2.03 | 0.06 | 0.01 | 6.26 | 87 |
| 8% | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - |
| | 3.08 | 0.51 | 6.01 | 3.08 | 0.77 | 4.02 | 9.94 | 3.89 | 2.55 | 9.94 | 1.48 | 6.70 | 13,000 |
| 36% | 20.00 | 7.90 | 2.53 | 15.42 | 6.12 | 2.52 | 14.33 | 6.05 | 2.37 | 20.00 | 6.55 | 3.06 | 57,355 |
| 37% | 3.76 | 2.00 | 1.88 | 3.00 | 1.53 | 1.96 | 2.25 | 1.17 | 1.92 | 3.76 | 1.56 | 2.41 | 13,655 |
| 19% | 0.83 | 0.49 | 1.68 | 0.83 | 0.50 | 1.66 | 0.83 | 0.46 | 1.80 | 0.83 | 0.49 | 1.70 | 4,277 |
| 8% | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - |
| | 20.89 | 10.39 | 2.01 | 16.61 | 8.15 | 2.04 | 15.49 | 7.69 | 2.02 | 20.89 | 8.59 | 2.43 | 75,288 |
| 36% | 13.61 | 4.11 | 3.31 | 12.08 | 4.43 | 2.73 | 13.68 | 4.96 | 2.76 | 13.68 | 4.48 | 3.05 | 39,261 |
| 37% | 2.80 | 1.04 | 2.69 | 2.39 | 0.99 | 2.42 | 1.85 | 0.95 | 1.95 | 2.80 | 0.99 | 2.83 | 8,669 |
| 19% | 0.43 | 0.19 | 2.25 | 0.38 | 0.22 | 1.75 | 0.54 | 0.30 | 1.83 | 0.54 | 0.23 | 2.36 | 2,011 |
| 8% | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - | - | #DIV/0! | - |
| | 14.04 | 5.34 | 2.63 | 12.95 | 5.63 | 2.30 | 14.40 | 6.20 | 2.32 | 14.43 | 5.70 | 2.53 | 49,940 |

# Appendix B – Technology Review

# Energy

## Demand management

### High performance buildings

#### Purpose

High performance buildings are designed and built to be environmentally responsible and resource efficient throughout the buildings life. This is achieved through energy, water and material efficiency, waste reduction and improved indoor environment quality.

Measurement tools for high performance buildings include GreenStar and NABERS. High performance buildings will achieve 6 star Green Star and 6 Star NABERS.

From an energy point of view high performance buildings should be mandated to reduce the peak demand and overall energy consumption.

#### Potential application scale

Building scale

#### History of application

Many new office, residential, retail and commercial buildings are being designed and built to achieve high Green Star and NABERS ratings.

Government accommodation policies stipulate minimum building performance requirements.

#### Approx Capital Operating Cost

Increase in Capital costs against business as usual:

5 Star – 3 to 5% Increase

6 star – further 5%

#### References

www.gbca.com.au

www.nabers.com.au

Davis Langdon "The Cost and Benefit of Achieving Green Buildings".

### Smart meters/smart grids

#### Purpose

A smart meter is essentially an enhanced electricity meter as it has far greater functionality than a conventional electricity meter for measuring and recording production and consumption of electricity. A smart meter is also capable of including functional requirements such as load management ability, tamper detection, remote access and communication, and customer interaction interfaces. This results in greater control and awareness of energy consumption.

Smart meters would be installed in households and buildings in place of a standard retailer meter. Western Power does not yet have a specified smart meter to purchase however other smart meters are available on the market.

Smart meters will be essential in establishing a smart grid network within Canning Bridge. Smart grids involve the installation of smart distribution networks, smart infrastructure such as car charging stations and software for sophisticated control energy management; network shut downs, network stability and network reliability.

#### Potential application scale

Smart meters - Installed at household / building level.

Smart grid – established at district level.

#### History of application

Western power has been running a smart grid trial as part of the Solar City program since 2009. As part of the trial 9,000 meters were rolled out. Smart meters are now an established technology and are available as an option to purchase when installing or replacing a meter.

#### Costs

There are a number of smart meter options available on the market. Minimum $150 per meter

#### References

Solar City 2012

http://www.perthsolarcity.com.au/annual-report/

http://www.smartgridsmartcity.com.au/

## Energy production

### Solar Photovoltaic

#### Purpose

Solar Photovoltaic (Solar PV) modules produce emissions free, renewable energy by converting sunlight directly into electricity.

The capital cost of Solar PV panels has dropped significantly in recent years and the cost of producing electricity via Solar PV is rapidly approaching the cost of energy supplied by the grid (grid parity).

Building scale systems can export excess electricity back into the utility grid and offer a potential revenue source if the utility offers a feed in tariff.

#### Inputs and outputs

Solar PV systems collect sunlight and convert solar energy directly into electricity. There are no emissions generated by the Solar PV process.

#### Potential application scale

The modular format of Solar PV systems' allow them to be scaled from individual houses/buildings to large, precinct scale power stations. Precinct scale Solar PV systems are limited in size by available space (Solar PV systems require approximately 7m$^2$/kW).

#### History of application

Global solar photovoltaic (PV) demand for 2012 reached a record 29.0 GW. By the end of 2010, the total installed capacity of PV based solar power systems in Australia was over 570 MW.

The largest building scale Solar PV system in Perth at the time of this report was recently installed at Perth zoo with a capacity of 237.4kW (approximately one third of the Zoo's current energy consumption. The system was integrated into a walkway shelter in the adjacent Windsor

Park. A notable Western Australian precinct installation is the Carnarvon Solar Power Plant, with a capacity of 290kW.

### Approx Capital Operating Cost

| Scale | Technology | Capital Costs | Operational Costs |
|---|---|---|---|
| Building | Solar PV | $1500/kW-Installed Capacity | Up to $150/year |
| Precinct | Solar PV | $2000/kW | $6000/year per. MW-Installed Capacity |

### References

Perth Zoo – Photovoltaic Installation

Central Institute of Technology – PV Installation

## Solar Thermal

### Purpose

Solar Thermal systems capture heat from the sun's radiation and use it to provide heat or power conventional turbines to produce electricity. Solar Thermal systems for heat generation typically consist of a cell with a circulating fluid circuit that is directly heated by the sun's rays.

Solar Thermal electricity plants consist of an array of heliostats (mirrors that track the sun) which concentrate the suns heat onto a working fluid, which heats up, converts to steam and powers a turbine that produces electricity.

### Inputs and outputs

Solar Thermal systems require only solar energy to produce heat or electricity.

### Potential application scale

Solar Thermal systems designed to produce heat energy are suitable to provide heating to buildings, for example a solar hot water system. Solar Thermal electricity generators are capable of providing electricity at precinct or larger scale, but are not efficient at building level.

### History of application

Solar thermal technology has been available for a long time with a history that started with cooking applications. Solar concentrators are now used to capture heat energy to produce steam for turbine to produce energy or to produce cooling via an absorption chiller. Large installations have been installed in Spain and the US with generation capacity in the 100's of MW's. In 2007 a solar thermal system was installed at Liddel Power Station in NSW to replace some of the power stations boiler feed water.

### Costs

Solar thermal on a large scale is still a relatively new technology and costs can vary significantly. According to a report prepared for the Australian Solar Research Institute "Realising the Potential for Concentrating Solar Power in Australia", present costs average $5,450/kWe installed cost.

### References

CSIRO – Solar Brayton Cycle

"Realising the Potential for Concentrating Solar Power in Australia", ITP Power (Australia) for the Australian Solar Research Institute http://www.itpau.com.au/realising-the-potential-of-concentrating-solar-power/

### Wind

#### Purpose

Wind turbines use kinetic energy from the wind to drive a generator and produce electricity. Wind turbines can be horizontal or vertical axis configuration. Horizontal axis turbines are the most common arrangement and must point directly into the wind to operate. Vertical axis turbines can operate with wind coming from any direction, and therefore perform well in urban environments, but require a larger drive train, limiting their practical size.

#### Inputs and outputs

Wind turbines use wind energy to produce electricity with no emissions.

#### Potential application scale

Wind turbines are available from building size, in the order of 1 to 15kW, to precinct scale turbines up to 5MW. Wind turbines can produce noise in operation and visible impact which should be considered when selecting and placing units.

#### History of application

Wind energy has a long history and is now become a viable energy source on a large scale which can compete with traditional fossil fuel energy sources. Large scale wind farms have been installed in many areas of WA however large turbines are advised not to be installed within 2km of residential houses. Opportunities on an urban scale are more difficult to capture due to wind being obstructed by buildings and trees etc. and small scale wind is still expensive.

#### Costs

Capital Cost - $10,000 - $15,000/kW

Operating Costs - $300 - $500 per year

#### References

Sustainability Victoria - Melbourne Urban Wind Viability Report

### Geothermal Energy

#### Purpose

Geothermal is a very low emission thermal energy source. Although geothermal energy is most commonly exploited in volcanic areas where magma nears the surface and brings heat from greater depths, the opportunity the Perth Basin derives from aquifers in deep sedimentary basins. Potential uses include:

- Electricity production
  - Dry Steam Systems - are applicable to fields that produce steam from wells sited in reservoirs that are predominantly steam-filled in the ground. This is the most economical geothermal power generation system.
  - Flash Power Systems - work on separated steam at saturation conditions from wells that produce mixtures of steam, water and gases. They employ conventional steam turbines working at very low inlet pressures and temperatures.

- Binary Systems - the binary geothermal plant (also called Organic Rankine Cycle (ORC) power generation system) is totally different from the steam units because the hot geothermal fluid is not used in the power cycle directly. The hot water passes through a heat exchanger where an organic liquid, e.g. pentane or isobutane, is vaporized and used to drive a turbine.

- Space heating and cooling
  - Geothermal heat for district scale heating and cooling systems (utilising absorption or adsorption chillers).
- Water heating
  - Low temperature geothermal heat used (for example) for pool heating.
  - Domestic hot water could potentially be sourced directly from the geothermal aquifer or heated via this source through heat exchangers.
- Thermal water treatment processes
  - Desalination of water using multi-effect distillation processes driven by geothermal heat.
  - Wastewater treatment using membrane distillation bioreactor operating at elevated temperatures supplied by geothermal energy.

### Inputs and outputs

Input – Electricity to power pumps

Outputs – Heat energy in the form of hot water, electricity

Tapping the geothermal resource requires bores to produce extraction and injection wells with associated pumping infrastructure. The output is water at temperatures determined by the extraction depth (approx. 100°C at 3,000m).

### Potential application scale

Depends on geothermal applications:

Electricity production and thermal network – structure plan area + area of influence

Lower grade heat applications – smaller scale

### History of application

International projects

In 2010 it is estimated that 67,246 GWh of electricity was produced from some 10,715 MW of installed geothermal capacity. The top five countries in terms of installed capacity are : USA (3,060 MW), PHILIPPINES (1,904 MW), INDONESIA (1,197 MW), MEXICO (958 MW), and ITALY (843 MW). [10]

A recent project in Unterhaching, Germany, has shown that a 3,300 m deep well with water at 125° C can provide electricity in a non-volcanic sedimentary aquifer setting. The Kalina power plant in Unterhaching provides 3.36 MW electric (since 2008) and 40 MW thermal energy (since 2007) used for district heating. [11]

Australian projects [12]

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[10] Source: Ruggero Bertani, Geothermal Power Generation in the World, 2005–2010 Update Report
[11] Source: WA Geothermal Centre of Excellence
[12] Source: Australian Geothermal Industry Association

Power The Birdsville Organic Rankine Cycle Geothermal Power Station (Birdsville Plant) which produces 80kW, which is enough energy to power the town of Birdsville. The Plant is Australia's only Hot Sedimentary Aquifer project currently producing electricity. www.ergon.com.au.

Low grade heat Numerous swimming pools, schools, commercial scale and domestic buildings across Australia use geothermal heat pumps for heating and cooling. One of the largest and best known systems is installed at the Geoscience Australia building in Canberra. www.ga.gov.au

Deep drilling projects currently underway

Paralana -The 30 MW Paralana project is located adjacent to the Beverley Uranium Mine.

Cooper Basin - The 25 MW Cooper Basin demonstration project will demonstrate the potential of hot-rock geothermal energy for zero-emission, base-load power.

Jurien-Woodada - owned by New World Energy Limited, is the most advanced geothermal play in Western Australia for electricity production. The project is adjacent to transmission infrastructure and large resource-driven energy markets in the mid-west region. The project area has the potential to contain both hot sedimentary aquifer and EGS styles and is being assessed for delivery of electricity into Western Australia's South West Interconnected System.

Otway Basin - The Penola Project is part of Panax's Limestone Coast Project and is the largest of only three known Measured Geothermal Resources in Australia.

Panax's Salamander-1 well, drilled in 2010 is the first deep geothermal well drilled in the Otway Basin. It was completed in record time and is the first to demonstrate conventional geothermal technology in Australia. First steam was produced and the well-testing programme was also completed on the project in 2010.

The Salamander-1 well met its primary objectives. At 4,000 metres projected geothermal temperatures were exceeded by more than 10°C and target reservoir rocks met the requirements for the development of a geothermal demonstration plant.

### Costs [13]

| | |
|---|---|
| Electricity generation | $4m per MWel |
| District Cooling network | $540-640k per kWth |

Note that these costs do not include drilling, commissioning and maintaining the production and injection wells. A cost estimate for a 3 km well doublet is in the order of 20 Million AUD.

### References to websites / papers / relevant documents

Geothermal Energy - Renewable Energy World

www.renewableenergyworld.com/rea/tech/geothermal-energy

Australian Geothermal Energy Association

www.agea.org.au/

Geothermal Energy Resources - Geoscience Australia

www.ga.gov.au/energy/geothermal-energy-resources.html

WA Geothermal Centre of Excellence

[13] Source: WA Geothermal Centre of Excellence

www.geothermal.org.au/

### Gas turbines

#### Purpose

Gas turbines combust natural gas or biogas to spin a generator and produce electricity. Waste heat from the turbine exhaust can also be captured and used for space heating or process heat in a combined heat and power (CHP) arrangement. The heat can also be used for space cooling via an absorption chiller in Trigeneration configuration. Gas produces nearly half the emissions as coal per unit of energy and installed in a distributed energy system, with higher transmission efficiency, is a much cleaner energy source than connecting to a coal fired energy grid.

#### Inputs and outputs

Gas turbines require a gas supply and can operate on natural gas or biogas. The turbines produce electricity, heat and release emissions during operation.

#### Potential application scale

Gas turbines can be installed in building or precinct scale. The CSIRO national energy centre is operating a building scale gas microturbine with 30kW capacity and similar in size to a household refrigerator. Precinct scale High Effeciency Gas Turbines (HEGTs) can be scaled up to precinct and Structure Plan Area.

#### History of application

Gas turbines are responsible for a major proportion of WA's energy generation. They have a long history, they are reliable, low emission and are used for many different applications with a combination of other technologies.

#### Costs

Capital Cost - $2m/MW

Operating Cost - $50/MWh

#### References

Verve Energy – high efficiency gas turbines

### Fuel cells

#### Purpose

A fuel cell generates electricity through a chemical reaction between oxygen and a hydrogen rich fuel. Typically natural gas or hydrogen and air are used as the fuel. Fuel cells come in a range of types and sizes ranging from 1 kWe household level up to multi MW sized commercial installations.

#### Inputs and outputs

Inputs - Hydrogen/natural gas/methanol and air

Outputs – Electricity and heat

#### Potential application scale

Installed at household / building level / district level.

### History of application

Fuel cells have a long history and have been used for many applications including base load power generation, distributed generation, uninterrupted power supplies, cogeneration systems and fuel cell powered vehicles.

Companies which have installed fuel cells to power their operations include Google, Coca Cola, UPS and Michelin

### Costs

$45,000 for household sized BlueGen system (operates at about 8.7c/kWh)

### References

Woking Fuel Cell Document

http://www.fuelcelltoday.com/news-events/news-archive/2012/may/fuel-cells-are-the-real-thing-for-coca-cola

http://www.woking.gov.uk/environment/climate/Greeninitiatives/sustainablewoking/fuelcell

## Micro hydro

### Purpose

Micro hydro requires a small flow of water to pass through a turbine to produce electricity. These are typically installed in streams and rivers but can be installed in water distribution networks in place of pressure reduction valves.

### Inputs and outputs

Inputs – Water flow

Outputs – Electricity

### Potential application scale

Building level / district level. Micro hydro generally refers to hydro generation up to 100kW

### History of application

Micro hydro applications have been around for centuries and this is not a new technology. Generally they are installed in streams and rivers. More recently the application has extended to water distribution networks.

### Costs

$3/W installation and $100/MWh operation costs

### References

*http://www.greentechmedia.com/articles/read/micro-hydro-a-hidden-source-of-urban-megawatts-5878/*

*http://www.rentricity.com/about_mission.html*

## Fuel production

See also waste to energy solutions

### Gasification

#### Purpose

Gasification is a process by which biomass, waste sources or fossil fuel is reacted with oxygen or steam at very high temperatures to produce syngas. The Syngas can then be used itself as a fuel to produce electricity.

#### Inputs and outputs

Inputs –fossil fuels, waste wood and wood pellets, municipal solid waste, certain waste streams and sewage

Outputs – syngas, heat

#### Potential application scale

Industrial / district

#### History of application

A new GDF Suez power plant in Polaniec, Poland is now in commercial operation, delivering over 200 MWe of electricity to the country's electricity grid solely from biomass.

A pilot plant in Narrogin was constructed in 2006 to process Mallee trees to produce energy, activated carbon and eucalyptus oil. Steam is produced from the gasification of biomass to produce electricity. The plant had a number of issues including handling of the feedstock and the high initial capital costs.

#### Costs

Capital - $600 - $800 per tonne of waste treated

Operating Cost - $30 - $40 per tonne of waste treated

#### References

Narrogin Integrated Mallee Processing Plant

### Biofuel

#### Purpose

Biofuels are fuels that are produced or derived from organic matter. There are a number of methods for producing biofuel including fermentation, transesterification, anaerobic digestion, pyrolysis and gasification. Different methods produce different biofuels ranging from bioethanol to biodiesel and syngas.

Feed stocks to produce biofuels include algae, vegetable oils, animal fats, sewage, wood pellets and agricultural waste.

#### Inputs and outputs

Inputs –fossil fuels, bagasse, corn, algae, waste wood and wood pellets, municipal solid waste, certain waste streams and sewage.

Outputs – bioethanol, biodiesel, syngas, heat

#### Potential application scale

Industrial / district

### History of application

Biofuels have been used for over 100 years. More recently biofuels have been developed to blend with or replace petroleum products in vehicles. Biofuels have run in to ethical issues in the past with the argument that they take away important food stocks.

In Western Australia companies such as Australian Renewable Fuels produce biofuels from waste oil products.

### Costs

Dependent upon technology

### References

ARfuels Biodiesel – Picton WA

## Anaerobic digestion

### Purpose

Anaerobic Digestion is a process by which biodegradable material is broken down in the absence of oxygen. This produces a renewable energy (biogas) which can be used in a gas turbine to produce electricity.

### Inputs and outputs

Input – waste products, sludge, wastewater

Output – biogas, biosolids

### Potential application scale

District scale

### History of application

Water Corporation's Woodman Point Wastewater Treatment Plant has been utilising anaerobic digestion for the production of biogas since 2008. The gas is produced in large anaerobic digestors and utilised on site for power generation.

### Costs

See above

### References

Woodman Point WWTP

# Energy delivery

## Hydronic heating / cooling

### Purpose

Hydronic heating and cooling uses radiant and convective heat transfer methods to maintain internal comfort conditions. Instead of heating or cooling air and circulating it through the space to maintain temperature, hydronic heating/cooling circulates water through pipes embedded in building elements (walls, floors, wall mounted radiators, etc.) which radiate heat in heating mode or absorb heat in cooling mode. Hydronic heating is an efficient form of space heating.

### Inputs and outputs

Hydronic heating requires heated/cooled water to operate, supplied by a boiler and chiller or reverse cycle heat pump. These pieces of equipment require natural gas or electricity to operate, releasing emissions.

### Potential application scale

Hydronic heating cooling can operate at household/building scale.

### History of application

Hydronic heating is common in Europe and has been in use for many years. It is considered uncommon in Australia, but is gradually gaining more attention as an option for space heating. Hydronic cooling systems, including chilled beam air conditioning systems, are being implemented in projects in the Eastern states, but there has been limited application in Western Australia.

### Approx Capital Operating Cost

Chilled beam systems cost approximately 10% more than conventional air conditioning systems in commercial office projects and can offer operational expenditure savings of up to 30%.

### References

2 Victoria Ave Active Chilled Beams. WA's first certified 6-star Green Star project.

http://www.dadanco.com.au/pdf/Case%20Studies/3_13%20Case%20Study_6%20Star%20New%20Bldg_ACB_2%20Victoria%20Ave.pdf

## Air / ground source heat pumps

### Purpose

Heat pumps use the refrigeration cycle to transfer, or 'pump' heat from one space/medium to another. Reverse cycle air conditioners are a form of heat pump, transferring heat from inside a building to the outside to cool it down or transferring heat from outside to inside to warm it up. Heat pumps are also able to source or reject heat mediums other than air, such as earth or water, to enhance efficiency.

### Inputs and outputs

Heat pumps require electricity to operate a compressor and emit or absorb heat in cooling or heating mode respectively.

### Potential application scale

Heat pumps can operate at household, building or precinct scale.

### History of application

Air source heat pumps form the foundation technology of reverse cycle air conditioning systems and have been in use for many years. Ground source heat pumps are less common.

### Approx Capital Operating Cost

Air source heat pumps for air conditioning costs are in the order of $1000/kW cooling capacity and cost approximately $0.05/hour per kW cooling capacity to operate.

### References

Australian Institute of Energy, Defining Austrlalia's Geothermal Heat Pump Industry

http://aie.org.au/Content/NavigationMenu/MelbourneBranch/PastEvents/Don_Payne.pdf

### Absorption chillers

#### Purpose

Absoption chillers use an external heat source as part of a chemical process to generate cooling, compared to a standard refrigeration chiller which uses a mechanical compressor. If the external heat for the absorption chiller is sourced from waste heat of another process, cooling can be provided with a relatively small amount of electricity compared to a standard chiller.

Utilising absorption chillers are a key element in creating a tri-generation system which uses waste heat from an electricity generator as heating or as cooling via an absorption chiller, therefore generating three forms of useful energy: electricity, heating or cooling.

#### Inputs and outputs

Absorption chillers require electricity and a heat source to produce cooling.

#### Potential application scale

Absorption chillers are available at household, building and precinct scale.

#### History of application

Absorption chillers are a well-established technology but have increased in popularity in recent years due to the adoption of tri-generation systems and the ability to utilise waste heat to provide cooling.

#### Approx Capital Operating Cost

$500,000/MW cooling capacity

#### References

http://www.aesmith.com.au/ae-smith-install-one-of-australias-first-double-effect-direct-gas-fired-absorption-chillers

## Energy storage

### Electricity storage

#### Purpose

Electrical storage refers to methods used to store energy when demand is lower than supply. The energy can then be used during times of peak periods. There are many options for storing energy with battery banks, pumped hydro, flywheels and compressed air.

Examples of storage in Western Australia include the wind diesel system in Coral Bay which contains flywheel storage and many off grid systems containing battery storage.

#### Inputs and outputs

Inputs – electrical energy

Outputs – electrical energy

### Potential application scale

Building/Industrial/precinct

### History of application

Battery technology is a longstanding and widespread application of energy storage. In future it is recognised that a broad range of energy storage technologies can help manage the large-scale deployment of intermittent generation and the electrification of space heating / cooling.

New energy storage technologies are unlikely to be deployed on a large scale under current market and regulatory conditions. Both technology cost reductions, and a market framework which recognises the benefits of energy storage, are required.

### Approx Capital Operating Cost

Batteries - $290/kWh - $1,350/kWh

Pumped Hydro - $250/kWh - $430/kWh

Flywheel - $7,700/kWh - $8,800/kWh

### References

*Coral Bay Flywheel*

Marchment Hill - The future of energy storage in Australia

http://www.marchmenthill.com/docs/mhc-perspectives/MHC%20Perspective%20-%20The%20future%20of%20energy%20storage%20in%20Australia.pdf

CSIRO Report

http://www.electricitystorage.eu/

## Electric vehicles

### Purpose

A transition to electric vehicles is motivated both by the opportunity to reduce emissions and mitigate future fuel shortages and cost increases.

Many automotive manufacturers are or have been releasing full electric vehicles in the past 2 years. Electric vehicles plug in to the grid and charge whilst not in use. They will require specific electric vehicle charging stations to be installed next to each designated electric vehicle parking bay.

A number of organisations in Perth either have electric trial vehicles or have started installing infrastructure to prepare for electric vehicles. City of Perth have begun installing car charging stations within its car parks and Water Corporation, UWA and Western Power have a number of trial full electric vehicles and charging stations for staff.

With the implementation of smart grids, electric vehicles will also be able to be used for energy storage and called upon when plugged in to the grid to provide energy during peak periods.

### Inputs and outputs

Inputs – electrical energy

Outputs – motive power

### Potential application scale

Household / building / public infrastructure

### History of application

Until recently the majority of vehicles available for the road have been fuelled with petrol. However with the increase in petrol and diesel prices in the last 10 years, car manufacturers have started to turn to electric powered cars. Most manufacturers now have at least one electric hybrid vehicle in their range. Barriers that exist for electric vehicles include the vehicle range and infrastructure development.

The City of Perth recently began installing car charging stations in their City of Perth carparks.

### Approx Capital Operating Cost

Cars - $50,000

Residential - $500 - $600 per charging point

Commercial – dependant on a site evaluation.

### References

*http://www.chargepoint.com.au/support/frequently-asked-questions/*

## Thermal energy storage

### Purpose

Thermal energy storage systems are analogous to a battery for thermal energy and can be used in any application that requires heating or cooling. Thermal energy storage can capture energy and reuse it at the opportune moment. Common applications are thermal energy storage for building air conditioning and heat storage for electricity generation, such as solar thermal plants.

Buildings can use chilled water storage, ice storage or phase change material to store cooling energy generated at cheaper off peak periods to be released during on peak periods. This can also reduce peak power demand across the grid by reducing day time air conditioning loads.

Solar thermal plants can use thermal energy storage to store excess heat and continue generating electricity when there is no heat from the sun, enabling the plant to deliver renewable base load power supplies.

### Inputs and outputs

Thermal energy storage systems require an input of heat or cooling (depending on the application). They store the thermal energy and release it on demand.

### Potential application scale

Thermal energy storage systems are available at household, building and precinct scale.

### History of application

Solar thermal storage has been used since the nineteenth century. There is a growing number of facilities that use Seasonal thermal energy storage (STES), enabling solar energy to be stored in summer (primarily) for space heating use during winter.

Curtin University has a large thermal storage tank to produce chilled water overnight in cheaper off-peak periods to be stored and used during the day.

Melbourne City Council's CH2 building employs thermal energy storage to cool the building during the day. A tank containing Phase Change Material (PCM) is cooled overnight and produces chilled water during the day to cool the building.

### Approx Capital Operating Cost

Dependant on technology and scale.

### References

http://www.engr.psu.edu/ae/faculty/bahnfleth/chilled_water_storage_western_australia.pdf

http://www.melbourne.vic.gov.au/Sustainability/CH2/aboutch2/Pages/CoolingSystem.aspx

## Small-scale waste to energy (WtE)

### Purpose

To convert mixed waste to energy at the precinct level.

### Inputs and outputs

Inputs – mixed waste

Outputs – energy, residual

### Potential application scale

By its nature this technology is small scale. Capacity per precinct would be no more than 20,000 tonnes per year. This could mean one 20,000 t facility or two 10,000 t facilities. Scaling facilities beyond this would reduce the number required and defeat the purpose of having local precinct-based plants.

### History of application

Waste to energy falls into two areas; thermal and biological. Thermal treatment encompasses a wide range of technology types from mass burn incineration to plasma arc. Biological generally means anaerobic digestion which produces a biogas that is burnt to produce electricity.

Some thermal technologies, such as mass burn incineration at large scale facilities are a very mature WtE technologies. This technology in particular has been widely used in Europe for decades for energy and heat generation.

More recent technologies such as gasification, pyrolysis and plasma arc have been used successful for converting particular individual waste materials to energy, such as wood waste. Their application to mixed waste processing is only a recent development and mostly applied at a larger scale.

Micro scale anaerobic digesters are commonly used on farms for in China and India. There are more than 40 million small scale anaerobic digesters operating world-wide. Small scale AD systems also have as their primary feedstock animal manure and food waste and produce gas for cooking, heating, lighting and electricity production, as well as liquid fertiliser and compost. AD facilities of the scale that might be required for Canning Bridge are available. Although most new AD systems in the US and Europe are for processing agricultural waste, AD systems can also process food waste. When the technology was first developed AD system processed mixed waste but with the development of source separation programs and sophisticated separation systems most new AD facilities designed for municipal and commercial waste only process separated organics.

### Costs

Full turnkey AD plants capable of handling between 3,000 and 5,000 tonnes of food waste per year are available in the UK for between £850,000 and £2 million (A$1.3-$3 million).

Four AD plants in Europe with capacity of up to 25,000 tonnes per year have capital costs of between A$316 and A$799 per tonne. Another has an operational cost of A$34.80 per tonne.

### References


Lunstrøm, Petter (no date) Energos Gasification Technology – Proven Small-scale, Energy from Waste http://www.ieatask33.org/app/webroot/files/file/2011/Norway.pdf

Themelis, Nickolas J. (2007) Thermal Treatment Review Waste Management World 8 (4) http://www.waste-management-world.com/articles/print/volume-8/issue-4/features/thermal-treatment-review.html

Ellyin, Claudine (2012) Small Scale Waste-To-Energy Technologies Department of Earth and Environmental Engineering, Columbia University. Submitted in partial fulfilment of the requirements for M.S. degree in Earth Resources Engineering

GEM - http://www.gemcanadawaste.com, http://www.gem-ltd.co.uk, http://www.mswpower.com/Waste-to-Energy.aspx, http://cogentech-inc.com/id19.html

Marty, E. (2002) Case study - Production of Fuels from Waste & Biomass by the EDDITh Thermolysis Process Recent Industrial Developments http://www.ienica.net/usefulreports/pyrolysiscs2.pdf

Compact Power - http://gasifiers.bioenergylists.org/files/Compact_power.pdf

Naanovo - http://www.naanovo.com/wte

WasteGen - http://www.wastegen.com

GGI Energy - http://www.ggienergy.com/

Novo Energy - http://wte.novoenergyllc.com/

Ellyin, Claudine and Themelis, Nickolas J. (2011) Small Scale Waste-To-Energy Technologies NAWTEC 19, Lancaster PA, May 16-18 http://www.nawtec.org/Portals/2/2011/Ellyin_Claudine.pdf

Envikraft - http://www.envikraft.com, http://www.envikraft.dk/

UK Department of Energy and Climate Change and Department for Environment Food and Rural Affairs - http://www.biogas-info.co.uk/index.php/feedstocks.html and http://www.biogas-info.co.uk/index.php/ad-map.html

De Baere, Luc and Mattheeuws (2010) Anaerobic Digestion of MSW in Europe BioCycle 51(2): 24 http://www.biocycle.net/2010/02/anaerobic-digestion-of-msw-in-europe/


## Large scale centralised separation, composting and WtE facility

### Purpose

Separate mixed waste into several streams for direct sale to markets or recovery by composting or conversion to energy.

### Inputs and outputs

Inputs – mixed waste

Outputs – recyclable materials (glass, cardboard, plastics, metals), compost, digestate, biogas and energy (depending on the technology), residual.

### Potential application scale

All the proposed technologies can be expanded. Some are designed to be modular so scaling up is easily done by adding another module. In this case, the final facility design would be developed for the maximum waste capacity and then modules added or elements upgraded for the individual components, separation, composting, digestion and WtE as the development progressed and large quantities required processing.

### History of application

The technology for mechanical separation of waste streams was developed in the US in the 1970s. For many years these materials recovery facilities (MRFs) were used to further separate source-separated recyclables. The first MRF was built in Australia in the early 1990s. In time MRF concepts and separation technologies were applied to other waste streams including construction and demolition, commercial and industrial and mixed waste.

Most MRFs use similar technologies including, rotating trommels, disc and other screens, magnets and eddy currents, vibrating and bouncing conveyors and air blowers as well as manual separation. More recently, more sophisticated technologies such as optical recognition has reduced the need for direct human involvement in sorting and has also reduced the size of materials particles that can be separated and therefore increasing the range of materials that can be sorted.

Waste to energy falls into two areas; thermal and biological. Thermal treatment encompasses a wide range of technology types from mass burn incineration to plasma arc. Biological generally means anaerobic digestion which produces a biogas that is burnt for energy.

Some thermal technologies, such as mass burn incineration at large scale facilities are very mature WtE technologies. This technology in particular has been widely used in Europe for decades for energy and heat generation.

More recent technologies such as gasification, pyrolysis and plasma arc have been used successful for converting particular individual waste materials to energy, such as wood waste. Their application to mixed waste processing is only a recent development. There are no thermal treatment plants currently operating in Australia.

### Costs

A number of composting facilities have been operating in Australia. Published capital costs for these range between $10 million for a 21,000 t per year facility to $100 million for a 195,000 t per year facility.

Several anaerobic digestion facilities are also operating in Australia. Published capital costs range between $35 million and $50 million for 75,000 t and 100,000 t per year facilities.

Estimates have been published of the costs of a range of AWT facility for the ACT. To process 50,000 tonnes per year, capital costs range between $15 million for in-vessel composting, $24 million for AD, $39 million for gasification and around $50 million for pyrolysis or incineration. Processing costs range from $67 per tonne for in-vessel composting up to $133 per tonne for gasification.

Capital costs to establish a MRF are in the order of $10-$15 million and around $30-$35 per tonne operating costs.

### References


http://www.ben-global.com/

http://www.epem.gr/waste-c-control/database/html/costdata-00.htm

URS (2010) Final Report – Supplementary Report – Economic modelling of Options for Waste Infrastructure in the ACT for ACT Department of the Environment, Climate Change, Energy and Water

http://www.alpheco.co.uk/

http://www.civicenvironmental.com/

http://www.bekon.eu/

http://oaktech-environmental.com/

http://www.epem.gr/waste-c-control/database/html/costdata-00.htm

http://www.horstmann.pl/_uk/kompostownie-technologia.shtml

http://www.entsorga.it/

# Water

## Demand management

### Water efficient fixtures and appliances

#### Purpose

The purpose of water efficient appliances is to minimise in-house potable and non-potable water demands by substituting appliances and fittings that require less water.

#### Potential Application Scale

Water efficient fixtures and appliances can be applied at the building scale within the development area.

#### History of Application

Water efficient appliances have been and continue to be used across Australia. The Water Efficiency Labelling and Standards (WELS) Scheme is Australia's water efficiency labelling scheme that rates certain products with their water efficiency in accordance with the standard set under the national Water Efficiency Labelling and Standards Act 2005. The WELS scheme uses a star rating to label the water efficiency of an appliance, where the more stars the more water efficient the appliance. Products that are included in the scheme include showers, tap equipment, flow controllers, toilet equipment, urinal equipment, clothes washing machines and dishwashers.

#### Costs

The cost of water efficient appliances varies depending on the product. However, installing water efficient appliances becomes more cost effective in new buildings compared with substituting existing appliances when retrofitting. The cost to retrofit water efficient appliances within existing properties in regional WA has been assessed in studies completed for the Water Corporation (Marsden Jacobs, 2012), and unit costs so calculated have ranged from approximately 5c/kL (water efficient shower heads in commercial properties) to $2/kL (toilets in residential properties). The "extra-over" cost of installing water efficient devices in new properties will be significantly lower

#### References


http://www.watercorporation.com.au/_files/Business/Water_Efficiency_Office_Short_Report.pdf

Marsden Jacobs, 2012. *Water Corporation Regional Integrated Water Efficiency Program – Final Progress Report* , A report prepared for the Water Corporation. http://www.watercorporation.com.au/_files/Integrated_Regional_Water_Efficiency_Programs_Report_Sept_2012.pdf

*Perth Water Use Study 2008/09,* http://www.watercorporation.com.au/_files/PublicationsRegister/12/Perth_Residential_Water_Use_Study_2008_09_FINAL.PDF


### Smart meters

#### Purpose

A smart water meter is a normal water meter connected to a data logger that allows for continuous monitoring of water consumption. The purpose of smart meters is to collect water consumption data in a timely manner and allow for the analysis of the data by water managers to assist with water demand management and water efficiency. In addition, the timely relaying of this data to the water user can result in significant changes in water use behaviour (see consumer education). Other benefits of smart metering include immediate leak detection and remedial action that can save quantities of water.

Typically, smart metering has features such as real time monitoring, high resolution interval metering, automated data transfer and access to the data via the internet.

### Potential Application Scale

Smart meters can be applied at the building scale across the development area. The data collected by smart meters can be aggregated across the precinct or development area as part of water consumption analysis.

### History of Application

Smart water meters are a proven technology. The Water Corporation have retrofitted smart meters to all properties in a number of townsites in Western Australia served by the Water Corporation, including Kalgoorlie-Boulder (2 year trial commencing July 2010) and a number of townsites in the Pilbara (Pilbara Smart Metering Program, commenced October 2012 and still in progress).

### Costs

The cost to retrofit smart meters in regional WA has been assessed in studies completed for the Water Corporation (Marsden Jacobs, 2012), and unit costs so calculated have ranged from approximately 30 to 40 c/kL. The “extra-over” cost of installing smart meters to new properties will be significantly lower

### References


1.http://www.watercorporation.com.au/_files/PublicationsRegister/12/Kalgoorlie_SMT_FAQs.pdf

2. http://www.watercorporation.com.au/P/pilbara_smart_metering.cfm/

3. Marsden Jacobs, 2012. Water Corporation Regional Integrated Water Efficiency Program – Final Progress Report , A report prepared for the Water Corporation. http://www.watercorporation.com.au/_files/Integrated_Regional_Water_Efficiency_Programs_Report_Sept_2012.pdf


## Sub-Surface Irrigation Systems

### Purpose

Sub-surface irrigation systems, which rely on irrigation of plants via relatively closely spaced small bore subsurface pipework that incorporates in-line drippers, are an alternative to conventional surface spray systems. If coupled with appropriate soil improvement where required (e.g. areas with sandy soil having poor water retention capacity) , losses associated with sub-surface irrigation systems are significantly lower than those with surface spray systems due to its superior uniformity of application, and because spray drift and evaporation losses are reduced.

### Potential Application Scale

Whilst this technology can be used at any scale, there is an argument that sub-surface irrigation is more appropriate for POS areas managed by local authority’s rather than residential irrigation areas, on the grounds that some residents may not undertake the routine maintenance required to prevent blockage or other problems.

### History of Application

Sub-surface irrigation systems are a proven technology, and are used in many parts of the world. Locally, a good example of irrigation turf using a sub-surface irrigation system is at the Shire of Mundaring's Harry Riseborough Oval. Approximately 1.6 ha of this oval is irrigated in this manner, with treated wastewater from the Water Corporation's Mundaring WWTP. Use of this technology for irrigation of turf in residential settings does however remain uncommon, possibly stemming from the lower cost of conventional spray irrigation systems, or due to other factors (e.g. ongoing maintenance needs, greater difficulty in establishing turf with these systems).

### Costs

If labour costs are included, irrigation of turf sub-surface irrigation systems are more costly than conventional spray irrigation systems. An additional consideration is that newly laid turf requires spray irrigation for the establishment period, which can add to the overall cost of using sub-surface systems for irrigation of turf in new developments.

### References


1. http://www.recycledwater.com.au/uploads/File/newsletters/reWater%20Spring%2008.pdf


## Consumer education

### Purpose

The purpose of this management initiative is to educate consumers on what they can do to minimise potable and non-potable water use. The aim is to communicate water use to consumers via water meters and online devices. For example, metered water use could be displaying within the house or be accessed easily via the web on computers or handheld devices such as smart phones. This initiative enables consumers to readily access their water consumption so that behaviour can be adjusted to meet water targets.

### Potential Application Scale

Consumer education of the water consumption can be applied at the building scale across the development area. The results of water use can be aggregated across precincts to communicate larger scale water targets.

### History of Application

"Waterwise" consumer education is widely practices by water utilities and local government authorities in Australia. The Water Corporation have extensive consumer education campaigns designed to minimise potable water consumption and reduce per-capita water demands. One example is their Waterwise Schools Program.

### Costs

The cost of consumer education is less expensive than other water demand reduction options. Consumer education can potentially achieve the greatest cost and water efficiency benefits.

### References


1. http://www.watercorpeducation.com.au/page/23/Waterwise-garden-quiz

### Water loss control

#### Purpose

This “management initiative” involves implementing a systematic method of reducing water loss by the detection of unreported leaks followed up by the prompt repair of the identified leaks. Non-visible leaks can be detected by examining consumption data or by analysing night time flow data. Once the existence of a leak is confirmed, the specific location can be pinpointed by using electronic listening devices prior to excavation and repair.

#### Potential Application Scale

This initiative can be employed at all scales.

#### History of Application

Water loss control has long been a key element of water utility demand management programs, and these losses (“unaccounted for water”) are monitored closely by utilities.

#### Costs

The cost of leak detection and repair (within the Water Corporation’s supply system) in regional WA has been assessed in studies completed for the Water Corporation (Marsden Jacobs, 2012), and unit costs so calculated have ranged from approximately 40c to $1.50/kL. Whilst the level of leakage within new water supply infrastructure should be lower than that from infrastructure that has been in service for some time, this demonstrates the potential value of this initiative as part of an integrated demand management strategy for Canning Bridge.

#### References

1. Marsden Jacobs, 2012. Water Corporation Regional Integrated Water Efficiency Program – Final Progress Report, A report prepared for the Water Corporation. http://www.watercorporation.com.au/_files/Integrated_Regional_Water_Efficiency_Programs_Report_Sept_2012.pdf

## Water supply

### Rainwater tanks, connected to non-potable water supply

#### Purpose

Collection of rainwater from the available roof area to supply an alternative water source for non drinking water purposes (e.g. irrigation of gardens, internal non drinking water uses or both).

#### Potential Application Scale

Rainwater tanks can be applied at the building scale within the development area (single dwelling, multi- dwelling or commercial)

#### History of Application

Rainwater tanks have been used in Western Australia for many years. In metropolitan areas where scheme drinking water is available, rainwater tanks can provide a valuable alternate water source.

#### Costs

The 2007 report by Marsden Jacobs *The cost-effectiveness of rainwater tanks in Urban Australia* (for the National Water Commission) indicated the following costs:

- a rainwater tank for indoor/outdoor use ranges from $3.25/kL - $8.85/kL
- a rainwater tank for outdoor use only ranges from $2.87/kL - $5.74/kL

The report indicated that the cost efficiency and yield from rainwater tanks varies considerably between individual properties and is influenced significantly by the connected roof area as well as end use.

### References

1. Marsden Jacobs Associates 2007 The cost effectiveness of rainwater tanks in urban Australia. Prepared for the National Water Commission.

2. http://www.public.health.wa.gov.au/3/659/2/rainwater_collection.pm

## Rainwater tanks, connected to potable water supply

### Purpose

Collection of rainwater from the available roof area to supply an alternative water source for all water sources (eg drinking water).

### Inputs and Outputs

Pumps will be required to supply the water. A level of treatment will be required for the water to be reliably safe to drink.

### Potential Application Scale

Rainwater tanks can be applied at the building scale within the development area (single dwelling, multi- dwelling or commercial)

### History of Application

Rainwater tanks have been used in Western Australia for many years. In metropolitan areas where scheme drinking water is available, rainwater tanks can provide a valuable alternate water source. Where a dedicated reticulated drinking water supply is not available, rainwater tanks are often used as the primary source of water (eg country and rural areas).

### Costs

The cost of supplying a rainwater tank for drinking water purposes is expected to be greater than if a rainwater tank is supplied for non potable purposes only. This increase in costs can be attributed to the increased size of the tank required to guarantee reliability of the supply as well as any treatment costs required.

### References

1. http://www.public.health.wa.gov.au/3/659/2/rainwater_collection.pm

## Treated wastewater recycling for non-drinking water supply purposes

### Purpose

Subject to being treated to a quality adequate to protect human health and the environment, treated effluent from wastewater treatment plants can be used for irrigation purposes and to meet a range of other non-drinking water demands including toilet flushing, car washing, clothes washing (typically cold supply only), etc. It can also be used by industry, for instance in cooling towers and to meet some process water demands.

Significant potable water consumption savings can be achieved where the treated wastewater is used to meet water demands that would otherwise be met with potable water. If the area of public open space (POS) able to be irrigated would otherwise be constrained by the availability of irrigation water, or treated wastewater is supplied to householders at a lower cost than potable water (of note there are negatives of such a pricing approach), treated wastewater recycling can also increase the area of POS and private land that is irrigated.

### Inputs and Outputs

Inputs - Aside from the wastewater sources from residential and commercial premises, energy, chemicals (e.g. chlorine, lime, flocculants and/or coagulants) and other consumables are required to treat wastewater to the level where it can be reused for non-drinking water supply purposes.

Outputs – No additional outputs to those generated by a normal wastewater treatment plant.

### Potential Application Scale

Treated wastewater can be recycled at a range of scales, from on-premises (for the case of on-lot wastewater treatment), to community-scale (where a community scale WWTP and associated “third-pipe” scheme supplies the treated wastewater), to a regional scale (where treated wastewater is supplied by a major centralised plant and associated treated wastewater distribution and reticulation infrastructure).

### History of Application

Treated wastewater recycling for non-drinking water supply purposes is widely practiced in many parts of the world. Many such recycling schemes are in operation in Western Australia, though these schemes are primarily used to meet irrigation demands at parks, sporting fields, golf courses and the like. Treated wastewater is also used for irrigation of numerous woodlots in regional areas (e.g. Albany, Manjimup, Margaret River). Highly treated wastewater from the Water Corporation’s Kwinana Water Recycling Plant, used to meet industrial water demands in the Kwinana Industrial area, is another notable local treated wastewater recycling example.

Whilst no such residential schemes of any notable scale exist in Western Australia at this time, there are a number of significant “third-pipe” treated wastewater recycling schemes elsewhere in Australia where treated wastewater is used to meet POS and domestic irrigation demands as well as a range of in-house non-drinking water demands. Examples include the Rouse Hill scheme in Sydney, and the Pimpama-Coomera Scheme in the Gold Coast.

### Costs

The cost of treated wastewater recycling is a function of the application scale. For a major third-pipe recycling scheme to serve the Canning Bridge precinct, the unit cost of recycled water is likely to be at least $3/kL, with a significant portion of the cost associated with the recycled water distribution and reticulation infrastructure.

### References

1.
http://www.watercorporation.com.au/_files/PublicationsRegister/22/Water_Forever_Options_Report.pdf

### Treated wastewater recycling for potable water supply purposes

#### Purpose

Treated wastewater can also be used for potable water supply purposes, either directly or indirectly via supply into drinking water storages or aquifers using for potable water supply purposes, though the level of treatment necessary to protect human health is very high. Whilst technically feasible, the degree to which this practice would be accepted by the Australian public at the present time is questionable.

Whilst the cost of the required water recycling plants is high, one benefit of this option is that a separate “third pipe” network is not required.

#### Inputs and Outputs

As above.

#### Potential Application Scale

Realistically, given the complexity of the water recycling plant and level of management required to consistently meet stringent water quality requirements, potable reuse of treated wastewater is only practical at a “regional” scale.

#### History of Application

Treated wastewater is used for potable water supply purposes at a number of locations around the world, including Singapore (NEWater, indirect potable reuse) and Namibia (Windhoek, world’s first direct potable reuse scheme). In Australia, a major indirect potable reuse scheme was constructed to help drought-proof SE Queensland, to enable highly treated wastewater from a number of wastewater treatment plants to be pumped into Wivenhoe Dam, Brisbane’s main drinking water source. And locally, subject to attainment of the necessary regulatory approvals and financial considerations, the Water Corporation plans to construct a major indirect potable reuse scheme in the northern suburbs, with highly treated wastewater from the Water Corporation’s Beenyup WWTP injected into aquifers used for potable water supply purposes.

#### Costs

The cost of the advanced water recycling plant required to produce water suitable for potable water supply purposes is very high, though (as noted above) this is offset by obviating the need for a third-pipe network.

#### References

Western Corridor Recycled Water Project

http://www.watersecure.com.au/pub/images/stories/annual_reports/wcrw_annual_report_07-08.pdf

http://www.environment.gov.au/water/publications/urban/western-corridor-recycled-water.html

## Water storage

### Aquifer storage and recovery (ASR)

#### Purpose

The purpose of aquifer storage and recovery is to provide a means of storing stormwater and/or excess treated wastewater to recover and reuse at a later time. Stormwater or treated wastewater can be directed to a local aquifer via infiltration galleries, infiltration ponds or an injection bore for storage in the aquifer. When water is required, a bore can abstract the water which is then treated before being delivered to the water demand.

#### Inputs and Outputs

The inputs for ASR could include stormwater collected from across the Structure Plan area or excess treated wastewater that requires storage prior to reuse. Stormwater often requires treatment prior to injection or infiltration into the aquifer. The output from ASR is recycled water abstracted from the aquifer for reuse for non-potable applications such as irrigation, garden watering, toilet flushing and cold laundry washing. The abstracted water may also require treatment depending on the groundwater quality and the final use of the recycled water.

It should be noted that water required as an input for ASR may compete with the water required as an input for the urban stream. Stormwater and/or treated wastewater may be required for the urban stream in the SP area and therefore there may not be sufficient water available for ASR.

#### Potential Application Scale

The application scale will be on a regional or structure plan level.

#### History of Application

ASR is successfully used in Australia to provide recycled water for non-potable sources, such as irrigation. South Australia has several schemes in place such as Grange golf course. The Beenyup Groundwater Replenishment trial has also recently finished and has been deemed successful.

#### Costs

A recent cost estimation in 2010 for an aquifer storage and recovery scheme in the Perth area, using stormwater as the source water, indicated that the annualised water cost would be in the order of $1.20/kL.

#### References

1. GHD 2010. Stormwater Managed Aquifer Recharge Concept – Feasbility and Conceptual Design, A report prepared for the City of Canning, August 2010. .

### Rainwater tanks

See above.

## Wastewater treatment

### Membrane bioreactor (MBR) – sewer mining configuration

#### Purpose

An MBR plant could be installed in the area to enable wastewater "mined" from the local wastewater collection system to be treated to a high level where it could be reused for a variety of non-drinking water supply purposes. To minimise the cost and footprint of the treatment plant, in this situation waste activated sludge from the plant and possibly other treatment residuals (e.g. macerates screenings) are returned to the sewerage system. Alternatively the remaining organic fraction could be co-processed with the organic stream of municipal solid waste.

### Inputs and Outputs

Refer to “treated wastewater recycling for non-drinking water supply purposes”, above.

### Potential Application Scale

Refer to “treated wastewater recycling for non-drinking water supply purposes”, above.

### History of Application

MBR’s are proven technology widely used in many parts of the world. As the membrane filtration technology improves over time, the plants are becoming more energy efficient, and the relative cost of MBR plants (cost relative to more traditional activated sludge treatment with tertiary filtration, to achieve an equivalent quality) is reducing.

### Costs

The capital cost of a “large scale” MBR plant configured in this manner, i.e. not including any sludge treatment or dewatering facilities, is in the order of $3M per ML/d of capacity. As a plant designed to treat wastewater from the Canning Bridge precinct would not be “large scale”, the unit cost of such a plant would be higher due to economy of scale considerations.

### References

1. GHD, 2010. Report for Wungong Urban Water Project, Refinement of Sewer Mining and NDW Distribution Concepts and Cost Estimates, unpublished report prepared for the Armadale Redevelopment Authority, April 2010

## Advanced Wastewater Treatment Plants Incorporating Sludge Treatment and Energy Recovery

### Purpose

In recent years there has been a growing interest in improving the sustainability performance of wastewater treatment, i.e.:

- Maximising beneficial reuse of biosolids and recycled water;
- Minimising energy consumption;
- Maximising energy and nutrient recovery; and
- Improving cost sustainability.

To achieve these sustainability objectives a different approach to organics removal is required. This can be achieved in high rate anaerobic reactors or novel anaerobic membrane bioreactors, or very high rate aerobic activated sludge process technologies. With the latter processes, the aerated process mainly functions to convert the soluble organics into biomass, while minimising the oxidation of organics as is typically the case in ‘normal’ activated sludge processes. With this process the sludge has high digestibility, resulting in the majority of the incoming organics being converted to biogas in anaerobic digestion processes, with concurrent low energy input and high energy recovery potential.

### Inputs and Outputs

Refer to “treated wastewater recycling for non-drinking water supply purposes”, above. In relation to outputs, an advanced wastewater treatment plant with sludge treatment and energy recovery would produce biosolids and electricity (via combustion of biogas in gas engines) that can be used to meet treatment energy demands, with any excess exported to the grid.

- % of renewable energy production

- % reduction in peak power demand

### Potential Application Scale

Due to cost considerations this initiative would only be practical for a regional scale plant.

### History of Application

Whilst this is still an emerging field, several municipal wastewater treatment plants designed with these objectives in mind are now operational. One such plant is the nominal 200,000 person capacity Strauss treatment plant near Innusbrook, Austria. This plant has been operating with an overall net energy generation (from biogas) since 2005, as well as incorporating energy minimising processes and decreased chemical consumption.

### Costs

No costing information is available for these plants, but for a plant of the scale required to serve the Canning Bridge precinct the cost would be significantly higher than a conventional WWTP.

### References


1. WERF, 2010. Sustainable treatment: Best Practices from the Strauss in Zillertal Wastewater Treatment Plant – A Case Study. March 2010. Sourced from www.werf.org


## Trickling filter type plant with tertiary treatment – sewer mining configuration

### Purpose

In this initiative wastewater would be 'mined' from the local wastewater network, and conveyed to a proprietary wastewater treatment system that uses multi-stage aerobic tricking filters in a compact plant configuration, to produce a relatively high quality secondary effluent with a low energy demand relative to conventional activated sludge processes. These proprietary plants are typically housed within what looks like a 'normal' 2-storey residential dwelling. With appropriate tertiary treatment (e.g. membrane filtration plus disinfection), recycled water from these plants can be used to meet a wide range of non -drinking water demands. As for the MBR initiative, return of waste sludge (and possibly other treatment residuals) from the plant to the sewerage scheme would be the most cost effective sludge management strategy. Alternatively the remaining organic fraction could be co-processed with the organic stream of municipal solid waste.

### Inputs and Outputs

Refer to "treated wastewater recycling for non-drinking water supply purposes", above.

### Potential Application Scale

Refer to "treated wastewater recycling for non-drinking water supply purposes", above.

### History of Application

Tricking filters are one of the earlier types of secondary wastewater treatment plant. The specific proprietary systems this initiative is based on around have been in operation in the United States for many years.

### Costs

The capital cost of relatively small plants of this type having a capacity in the order of 200 kL/d and designed to achieve a very high effluent quality cost in the order of $10M per ML/d capacity (based on budget price provided to GHD for purpose of study completed in 2007). The unit cost will reduce as capacity increases due to economy of scale benefits.

### Natural Systems

#### Purpose

Natural systems including sub-surface flow and surface flow wetlands can be used to treat wastewater. Tertiary treatment would be required if it is proposed to use treated wastewater from these systems. Typically these systems have a relatively high area requirement.

#### Inputs and Outputs

Refer to “treated wastewater recycling for non-drinking water supply purposes”, above.

#### Potential Application Scale

Refer to “treated wastewater recycling for non-drinking water supply purposes”, above.

#### History of Application

Natural systems are used to treat wastewater in many parts of the world. We are however not aware of natural systems being used to treat wastewater in a situation similar to the Canning Bridge precinct (limited area required for plant, limited buffer to built-up areas, stringent effluent quality requirements).

#### Costs

Uncertain.

#### Concluding Remarks

It is unlikely that natural systems would be a viable option for this project given their relatively high area requirement and the need to produce high quality effluent to safeguard human health and the environment.

#### References

http://www.switchurbanwater.eu/outputs/pdfs/w3-2_5-3_gen_prs_natural_treatment_systems_in_uwm.pdf

### Greywater diversion or treatment

#### Purpose

The purpose of all greywater technologies is to ‘treat’ water collected from baths, showers and washing machines to deliver to non-potable uses. For single residential lots, basic greywater diversion devices (GDDs) can be used, whereby greywater only requires basic screening and can be reused on-lot for sub-surface irrigation of turf or garden beds. In other situations, for instance multi-residential and commercial developments, more advanced greywater treatment systems (GTSs) are required to produce higher quality water able to be used for irrigation or other non-drinking water supply purposes. GDDs cannot be used for these developments.

#### Inputs and Outputs

GDDs require no power (aside from that used to pump the greywater into the sub-surface irrigation system) or chemicals. The only output aside from screened greywater is the hair, lint and other matter captured by the lint filter, and the sludge that must periodically be removed from the greywater collection tank.

Depending on the type of treatment process used, GTSs can require power, chemicals and other consumables to level the greywater to the level where it can be reused for non-drinking water supply purposes.  The outputs from a GTS are similar to those for a GDD.

### Potential Application Scale

GDD type systems (with on-lot reuse for irrigation purposes) could be implemented for all single residential dwelling.  GTSs could be implemented at the building scale, or at the precint scale (e.g. via a number of community scale greywater treatment plants and associated third-pipe distribution systems).  GDDs are however unlikely to be viable for smaller lots (R30 or smaller).

### History of Application

Whilst there are many GDD type greywater systems in operation in Western Australia, there are very few GTS currently in operation, presumably because of their high cost.  There are some examples where GDDs have been installed at a relatively large scale, for instance at the Bridgewater Lifestyle Village in Mandurah (380 homes).

### Costs

The typical capital cost of a GDD type system for a residential house, including installation and associated “extra-over” plumbing costs, is in the order of $4,000-5,000.  The typical capital cost of a greywater treatment system for a single residential house is in the order of approximately $13,000-15,000.

### References


1. DoH, 2010.  Code of Practice for the Reuse of Greywater in Western Austrralia, April 2010

2. GHD, 2012.  Greywater Reuse Feasibility Study, Final Report, unpublished report prepared for the Water Corporation, September 2012.

3. http://www.water.wa.gov.au/PWF_03404_ETC_Murdoch.pdf?id=235


## On-Site Wastewater Treatment

### Purpose

The purpose of on-site wastewater treatment technologies is to treat all of the wastewater and associated waste, and allow treated wastewater to be reused on-site to meet non-drinking water demands.

Three technologies, the Envirocycle Model 10NR, Earth Safe ES10PC and NovaClear 10EP AWTS, are three all waste on-site wastewater treatment technologies and are compared below.

- The Envirocycle Model 10NR has the lowest operating cost and lowest energy consumption. It requires 3 service calls per year.  Management of the activated sludge system is required however anaerobic digestion reduces biomass and therefore the volume of sludge to be pumped out is reduced.  There are potential odour issues from the primary anaerobic processes.

- The Earth Safe ES10PC is the least expensive system, however has a lower effluent quality and larger footprint.  There are chemical requirements for chlorine disinfection and the associated risks with chemical handling.  It requires 4 service calls per year.  It has the largest footprint.  Management of the activated sludge system is required and there are potential odour issues from the primary anaerobic process.

• NovaClear 10EP AWTS has the highest effluent quality and smallest footprint. Filtration is via flat plate membranes. It requires 4 service calls per year. There are chemical requirements for chlorine disinfection and the associated risks with chemical handling.

#### Inputs and Outputs

Similar to greywater treatment systems.

#### Potential Application Scale

Application of on-site wastewater treatment technologies would be at the building scale. As the SP area is within the Perth Metropolitan area, it is likely that this initiative would NOT obviate the need for a reticulated sewerage scheme throughout the area.

#### History of Application

On-lot wastewater systems are widely used around the world, though typically only in situations where there is no access to a reticulated sewerage scheme.

#### Costs

A recent cost estimation in 2011 for the Envirocycle Model 10NR indicated the cost would be in order of $7000 for the treatment system, excluding water to commission, plumbing from the dwelling and electrical connections. An annual servicing fee for the system was estimated at approximately $300.

#### References

2. GHD, 2011. Warrandyte Backlog Sewerage – Alternative Options Assessment. A report for Yarra Valley Water. March 2011.

## Stormwater management

### Stormwater treatment

#### Purpose

To detain and treat the stormwater generated from impervious areas on site using wetlands or underground tanks to store the stormwater for later use. Uses may include irrigation or other non-potable uses.

#### Inputs and Outputs

The inputs will include stormwater runoff and potentially a treatment option (ie UV, chlorination or iron removal), depending on final use.

The outputs may include sludge removal from wetlands or tanks as sediment settles out of the stormwater. If treatment is required, other outputs may include backwash or sludge.

#### Potential Application Scale

Stormwater treatment is applicable at the structure plan or local precinct scale.

#### History of Application

Stormwater harvesting schemes are in operation in the eastern states of Australia, particularly Victoria and New South Wales. Some examples of stormwater harvesting projects include:

- Blackmans Swamp Creek Stormwater Harvesting Scheme in Orange which is capable of providing 1300ML – 2100ML/year of additional water. This scheme cost of $5m (which included extensive consultation)

- Afton Street Stormwater Project in Melbourne

### Costs

The cost of harvesting and storing stormwater will be more expensive than the business as usual approach of infiltrating stormwater to the ground. The additional costs will be in the infrastructure (i.e. wetland or tanks) as well as in any treatment necessary.

### References

1. http://www.orange.nsw.gov.au/site/index.cfm?display=147115

2.
http://www.melbournewater.com.au/content/water_recycling/what_is_recycled_water/other_water_supplies/stormwater_harvesting.asp

# Appendix C – Discounted cash flow analysis

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Emissions | kg CO2-e/MWh | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| SWIS | 631 | | | | | | | Build | 25 years | | | | | | | | | | | | | | | | | | | | | | |
| Gas turbines | 515 | | | | | | | DR | 7% | | 1.00 | 0.93 | 0.87 | 0.82 | 0.76 | 0.71 | 0.67 | 0.62 | 0.58 | 0.54 | 0.51 | 0.48 | 0.44 | 0.41 | 0.39 | 0.36 | 0.34 | 0.32 | 0.30 | 0.28 | 0.26 |
| | | | | | | | | ER | 3% | | 1.00 | 1.03 | 1.06 | 1.09 | 1.13 | 1.16 | 1.19 | 1.23 | 1.27 | 1.30 | 1.34 | 1.38 | 1.43 | 1.47 | 1.51 | 1.56 | 1.60 | 1.65 | 1.70 | 1.75 | 1.81 |
| | | | | | | | | ER fuels | 5% | | 1.00 | 1.05 | 1.10 | 1.16 | 1.22 | 1.28 | 1.34 | 1.41 | 1.48 | 1.55 | 1.63 | 1.71 | 1.80 | 1.89 | 1.98 | 2.08 | 2.18 | 2.29 | 2.41 | 2.53 | 2.65 |
| | | | | | | | | ER solar | -3% | | 1.00 | 0.97 | 0.94 | 0.91 | 0.89 | 0.86 | 0.83 | 0.81 | 0.78 | 0.76 | 0.74 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 |
| | | | | | | | | | | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| Canning Bridge | | Power | Annual | NPC | Emissions | Capex | Opex | Fuel | Carbon | | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 |
| | | MVA | GWh pa | $m | mtCO2 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 star | incl H&C | 44 | 164 | 354.6 | 3.88 | 99.359 | | | | 65.300534 | 3.9744 | 3.8258 | 3.6828 | 3.5451 | 3.4126 | 3.285 | 3.1622 | 3.044 | 2.9302 | 2.8206 | 2.7152 | 2.6137 | 2.516 | 2.4219 | 2.3314 | 2.2442 | 2.1603 | 2.0796 | 2.0018 | 1.927 | 1.855 |
| | | | | 491.8 | | | 2.135 | | | 27.956032 | 0 | 0.0822 | 0.1583 | 0.2286 | 0.2934 | 0.353 | 0.4078 | 0.458 | 0.5038 | 0.5456 | 0.5836 | 0.6179 | 0.6489 | 0.6767 | 0.7015 | 0.7235 | 0.7429 | 0.7598 | 0.7744 | 0.7869 | 0.7974 |
| | | | | | | | | 11.98 | | 261.3683 | 0 | 0.4703 | 0.9231 | 1.3587 | 1.7778 | 2.1807 | 2.5679 | 2.9399 | 3.2971 | 3.6399 | 3.9687 | 4.284 | 4.5861 | 4.8754 | 5.1523 | 5.4171 | 5.6702 | 5.912 | 6.1428 | 6.3628 | 6.5725 |
| | | | | | | | | | | 137.17681 | 0 | 0.1002 | 0.2029 | 0.308 | 0.4155 | 0.5256 | 0.6383 | 0.7536 | 0.8716 | 0.9923 | 1.1157 | 1.242 | 1.3711 | 1.5032 | 1.6382 | 1.7762 | 1.9173 | 2.0615 | 2.2089 | 2.3595 | 2.5135 |
| | excl H&C | 31 | 108 | 236.5 | 2.56 | 70.003 | | | | 46.007194 | 2.8001 | 2.6954 | 2.5947 | 2.4977 | 2.4043 | 2.3144 | 2.2279 | 2.1446 | 2.0644 | 1.9873 | 1.913 | 1.8415 | 1.7726 | 1.7064 | 1.6426 | 1.5812 | 1.5221 | 1.4652 | 1.4104 | 1.3577 | 1.3069 |
| | | | | 326.9 | | | 1.41 | | | 18.41007 | 0 | 0.0541 | 0.1042 | 0.1505 | 0.1932 | 0.2325 | 0.2685 | 0.3016 | 0.3318 | 0.3593 | 0.3843 | 0.4069 | 0.4273 | 0.4456 | 0.462 | 0.4765 | 0.4892 | 0.5004 | 0.51 | 0.5182 | 0.5251 |
| | | | | | | | | 7.89 | | 172.12059 | 0 | 0.3097 | 0.6079 | 0.8948 | 1.1707 | 1.4361 | 1.6911 | 1.936 | 2.1712 | 2.397 | 2.6135 | 2.8211 | 3.0201 | 3.2106 | 3.393 | 3.5674 | 3.7341 | 3.8933 | 4.0452 | 4.1902 | 4.3283 |
| | | | | | | | | | | 90.335947 | 0 | 0.066 | 0.1336 | 0.2028 | 0.2736 | 0.3462 | 0.4204 | 0.4963 | 0.574 | 0.6535 | 0.7347 | 0.8179 | 0.9029 | 0.9899 | 1.0788 | 1.1697 | 1.2626 | 1.3576 | 1.4546 | 1.5538 | 1.6552 |
| 5 star | incl H&C | 33 | 122 | 264.2 | 2.89 | 74.519 | | | | 48.9754 | 2.9808 | 2.8693 | 2.7621 | 2.6588 | 2.5594 | 2.4637 | 2.3716 | 2.283 | 2.1976 | 2.1155 | 2.0364 | 1.9603 | 1.887 | 1.8164 | 1.7485 | 1.6832 | 1.6203 | 1.5597 | 1.5014 | 1.4453 | 1.3912 |
| | | | | 366.3 | | | 1.59 | | | 20.79656 | 0 | 0.0612 | 0.1178 | 0.17 | 0.2182 | 0.2626 | 0.3034 | 0.3407 | 0.3748 | 0.4059 | 0.4341 | 0.4597 | 0.4827 | 0.5034 | 0.5219 | 0.5382 | 0.5526 | 0.5652 | 0.5761 | 0.5854 | 0.5932 |
| | | | | | | | | 8.91 | | 194.43252 | 0 | 0.3499 | 0.6867 | 1.0108 | 1.3225 | 1.6222 | 1.9103 | 2.187 | 2.4527 | 2.7077 | 2.9523 | 3.1869 | 3.4116 | 3.6268 | 3.8328 | 4.0298 | 4.2181 | 4.398 | 4.5696 | 4.7333 | 4.8893 |
| | | | | | | | | | | 102.04616 | 0 | 0.0746 | 0.1509 | 0.2291 | 0.3091 | 0.391 | 0.4748 | 0.5606 | 0.6484 | 0.7382 | 0.83 | 0.9239 | 1.02 | 1.1182 | 1.2186 | 1.3213 | 1.4263 | 1.5336 | 1.6432 | 1.7553 | 1.8698 |
| | excl H&C | 23 | 80 | 175.3 | 1.89 | 51.938 | | | | 34.13437 | 2.0775 | 1.9998 | 1.9251 | 1.8531 | 1.7838 | 1.7172 | 1.653 | 1.5912 | 1.5317 | 1.4744 | 1.4193 | 1.3662 | 1.3152 | 1.266 | 1.2187 | 1.1731 | 1.1293 | 1.0871 | 1.0464 | 1.0073 | 0.9696 |
| | | | | 242.2 | | | 1.04 | | | 13.637089 | 0 | 0.0401 | 0.0772 | 0.1115 | 0.1431 | 0.1722 | 0.1989 | 0.2234 | 0.2458 | 0.2662 | 0.2847 | 0.3014 | 0.3165 | 0.3301 | 0.3422 | 0.3529 | 0.3624 | 0.3706 | 0.3778 | 0.3839 | 0.389 |
| | | | | | | | | 5.84 | | 127.49673 | 0 | 0.2294 | 0.4503 | 0.6628 | 0.8672 | 1.0637 | 1.2526 | 1.4341 | 1.6083 | 1.7755 | 1.9359 | 2.0897 | 2.2371 | 2.3782 | 2.5133 | 2.6425 | 2.766 | 2.8839 | 2.9965 | 3.1038 | 3.2061 |
| | | | | | | | | | | 66.915516 | 0 | 0.0489 | 0.099 | 0.1502 | 0.2027 | 0.2564 | 0.3114 | 0.3676 | 0.4252 | 0.484 | 0.5443 | 0.6059 | 0.6688 | 0.7333 | 0.7991 | 0.8664 | 0.9353 | 1.0056 | 1.0775 | 1.151 | 1.2261 |
| 6 star | incl H&C | 21 | 75 | 163.5 | 1.77 | 47.421 | | | | 31.166164 | 1.8969 | 1.8259 | 1.7577 | 1.692 | 1.6287 | 1.5678 | 1.5092 | 1.4528 | 1.3985 | 1.3462 | 1.2959 | 1.2474 | 1.2008 | 1.1559 | 1.1127 | 1.0711 | 1.0311 | 0.9925 | 0.9554 | 0.9197 | 0.8853 |
| | | | | 226.2 | | | 0.98 | | | 12.784771 | 0 | 0.0376 | 0.0724 | 0.1045 | 0.1342 | 0.1614 | 0.1865 | 0.2094 | 0.2304 | 0.2495 | 0.2669 | 0.2826 | 0.2968 | 0.3095 | 0.3208 | 0.3309 | 0.3397 | 0.3475 | 0.3542 | 0.3599 | 0.3646 |
| | | | | | | | | 5.48 | | 119.52819 | 0 | 0.2151 | 0.4221 | 0.6214 | 0.813 | 0.9973 | 1.1743 | 1.3445 | 1.5078 | 1.6646 | 1.815 | 1.9591 | 2.0973 | 2.2296 | 2.3562 | 2.4773 | 2.5931 | 2.7037 | 2.8092 | 2.9098 | 3.0057 |
| | | | | | | | | | | 62.733296 | 0 | 0.0458 | 0.0928 | 0.1408 | 0.19 | 0.2404 | 0.2919 | 0.3446 | 0.3986 | 0.4538 | 0.5102 | 0.568 | 0.627 | 0.6874 | 0.7492 | 0.8123 | 0.8768 | 0.9428 | 1.0102 | 1.0791 | 1.1494 |
| | excl H&C | 14 | 50 | 109.0 | 1.18 | 31.614 | | | | 20.777443 | 1.2646 | 1.2173 | 1.1718 | 1.128 | 1.0858 | 1.0452 | 1.0062 | 0.9685 | 0.9323 | 0.8975 | 0.8639 | 0.8316 | 0.8005 | 0.7706 | 0.7418 | 0.7141 | 0.6874 | 0.6617 | 0.6369 | 0.6131 | 0.5902 |
| | | | | 150.8 | | | 0.65 | | | 8.5231805 | 0 | 0.0251 | 0.0483 | 0.0697 | 0.0894 | 0.1076 | 0.1243 | 0.1396 | 0.1536 | 0.1663 | 0.1779 | 0.1884 | 0.1978 | 0.2063 | 0.2139 | 0.2206 | 0.2265 | 0.2317 | 0.2361 | 0.2399 | 0.2431 |
| | | | | | | | | 3.65 | | 79.685459 | 0 | 0.1434 | 0.2814 | 0.4142 | 0.542 | 0.6648 | 0.7829 | 0.8963 | 1.0052 | 1.1097 | 1.21 | 1.3061 | 1.3982 | 1.4864 | 1.5708 | 1.6516 | 1.7287 | 1.8024 | 1.8728 | 1.9399 | 2.0038 |
| | | | | | | | | | | 41.822198 | 0 | 0.0306 | 0.0619 | 0.0939 | 0.1267 | 0.1603 | 0.1946 | 0.2298 | 0.2657 | 0.3025 | 0.3402 | 0.3787 | 0.418 | 0.4583 | 0.4994 | 0.5415 | 0.5845 | 0.6285 | 0.6734 | 0.7194 | 0.7663 |
| 6 star + | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 34 MW solar | incl H&C | 10 | 34 | 74.8 | 0.80 | 22.582 | | | | 14.84103 | 0.9033 | 0.8695 | 0.837 | 0.8057 | 0.7756 | 0.7466 | 0.7187 | 0.6918 | 0.666 | 0.6411 | 0.6171 | 0.594 | 0.5718 | 0.5504 | 0.5299 | 0.5101 | 0.491 | 0.4726 | 0.455 | 0.438 | 0.4216 |
| | | | | 103.3 | | | 0.44 | | | 5.7957627 | 0 | 0.017 | 0.0328 | 0.0474 | 0.0608 | 0.0732 | 0.0845 | 0.0949 | 0.1045 | 0.1131 | 0.121 | 0.1281 | 0.1345 | 0.1403 | 0.1454 | 0.15 | 0.154 | 0.1575 | 0.1606 | 0.1631 | 0.1653 |
| | | | | | | | | 2.48 | | 54.186112 | 0 | 0.0975 | 0.1914 | 0.2817 | 0.3686 | 0.4521 | 0.5324 | 0.6095 | 0.6835 | 0.7546 | 0.8228 | 0.8881 | 0.9508 | 1.0107 | 1.0682 | 1.1231 | 1.1755 | 1.2257 | 1.2735 | 1.3191 | 1.3626 |
| | | | | | | | | | | 28.439094 | 0 | 0.0208 | 0.0421 | 0.0638 | 0.0861 | 0.109 | 0.1323 | 0.1562 | 0.1807 | 0.2057 | 0.2313 | 0.2575 | 0.2843 | 0.3116 | 0.3396 | 0.3682 | 0.3975 | 0.4274 | 0.4579 | 0.4892 | 0.5211 |
| | excl H&C | 5 | 26 | 53.3 | 0.62 | 11.291 | | | | 7.4205152 | 0.4516 | 0.4347 | 0.4185 | 0.4029 | 0.3878 | 0.3733 | 0.3593 | 0.3459 | 0.333 | 0.3205 | 0.3085 | 0.297 | 0.2859 | 0.2752 | 0.2649 | 0.255 | 0.2455 | 0.2363 | 0.2275 | 0.219 | 0.2108 |
| | | | | 75.0 | | | 0.34 | | | 4.4320538 | 0 | 0.013 | 0.0251 | 0.0362 | 0.0465 | 0.056 | 0.0646 | 0.0726 | 0.0799 | 0.0865 | 0.0925 | 0.098 | 0.1029 | 0.1073 | 0.1112 | 0.1147 | 0.1178 | 0.1205 | 0.1228 | 0.1248 | 0.1264 |
| | | | | | | | | 1.90 | | 41.436439 | 0 | 0.0746 | 0.1463 | 0.2154 | 0.2818 | 0.3457 | 0.4071 | 0.4661 | 0.5227 | 0.5771 | 0.6292 | 0.6792 | 0.7271 | 0.7729 | 0.8168 | 0.8588 | 0.8989 | 0.9373 | 0.9739 | 1.0087 | 1.042 |
| | | | | | | | | | | 21.747543 | 0 | 0.0159 | 0.0322 | 0.0488 | 0.0659 | 0.0833 | 0.1012 | 0.1195 | 0.1382 | 0.1573 | 0.1769 | 0.1969 | 0.2174 | 0.2383 | 0.2597 | 0.2816 | 0.304 | 0.3268 | 0.3502 | 0.3741 | 0.3985 |
| | Solar | 34 | 41 | 47.0 | | 77.577205 | | | | 31.787487 | 3.1031 | 2.8131 | 2.5502 | 2.3118 | 2.0958 | 1.8999 | 1.7224 | 1.5614 | 1.4155 | 1.2832 | 1.1633 | 1.0545 | 0.9855 | 0.9211 | 0.8608 | 0.8045 | 0.7519 | 0.7027 | 0.6567 | 0.6137 | 0.5736 |
| | | | | | | | 1.163658 | | | 15.233646 | 0 | 0.0448 | 0.0863 | 0.1246 | 0.1599 | 0.1924 | 0.2222 | 0.2495 | 0.2745 | 0.2973 | 0.318 | 0.3367 | 0.3536 | 0.3687 | 0.3823 | 0.3943 | 0.4048 | 0.414 | 0.422 | 0.4288 | 0.4345 |
| | Solar | 19.5 | 24 | 27.0 | | 44.49280875 | | | | 18.231059 | 1.7797 | 1.6134 | 1.4626 | 1.3259 | 1.202 | 1.0897 | 0.9878 | 0.8955 | 0.8118 | 0.7359 | 0.6672 | 0.6048 | 0.5652 | 0.5283 | 0.4937 | 0.4614 | 0.4312 | 0.403 | 0.3766 | 0.352 | 0.329 |
| | | | | | | | 0.667392 | | | 8.7369442 | 0 | 0.0257 | 0.0495 | 0.0714 | 0.0917 | 0.1103 | 0.1274 | 0.1431 | 0.1575 | 0.1705 | 0.1824 | 0.1931 | 0.2028 | 0.2115 | 0.2192 | 0.2261 | 0.2322 | 0.2375 | 0.242 | 0.2459 | 0.2492 |
| 100 | MWh Storage | | | 79.2 | | 91.2673 | | | | 37.397044 | 3.6507 | 3.3095 | 3.0002 | 2.7198 | 2.4656 | 2.2352 | 2.0263 | 1.8369 | 1.6652 | 1.5096 | 1.3685 | 1.2406 | 1.1595 | 1.0836 | 1.0127 | 0.9465 | 0.8846 | 0.8267 | 0.7726 | 0.7221 | 0.6748 |
| | | | | | | | 3.194356 | | | 41.817853 | 0 | 0.123 | 0.2368 | 0.3419 | 0.4389 | 0.5281 | 0.61 | 0.685 | 0.7536 | 0.8161 | 0.8729 | 0.9243 | 0.9707 | 1.0122 | 1.0493 | 1.0823 | 1.1113 | 1.1366 | 1.1585 | 1.1771 | 1.1927 |
| 65 | | | | 51.5 | | 59.3 | | | | 24.308079 | 2.3729 | 2.1512 | 1.9501 | 1.7679 | 1.6027 | 1.4529 | 1.3171 | 1.194 | 1.0824 | 0.9813 | 0.8895 | 0.8064 | 0.7537 | 0.7043 | 0.6583 | 0.6152 | 0.575 | 0.5373 | 0.5022 | 0.4693 | 0.4386 |
| | | | | | | | 2.076331 | | | 27.181604 | 0 | 0.0799 | 0.1539 | 0.2222 | 0.2853 | 0.3432 | 0.3965 | 0.4453 | 0.4899 | 0.5305 | 0.5674 | 0.6008 | 0.6309 | 0.658 | 0.6821 | 0.7035 | 0.7223 | 0.7388 | 0.753 | 0.7651 | 0.7753 |
| Trigen | | 21 | 135 | 194.7 | 2.61 | 57.6592 | | | | 37.894691 | 2.3064 | 2.2201 | 2.1372 | 2.0573 | 1.9804 | 1.9063 | 1.8351 | 1.7665 | 1.7004 | 1.6369 | 1.5757 | 1.5168 | 1.4601 | 1.4055 | 1.3529 | 1.3024 | 1.2537 | 1.2068 | 1.1617 | 1.1183 | 1.0765 |
| | | | | 307.56858 | | | 2.018071 | | | 26.418913 | 0 | 0.0777 | 0.1496 | 0.216 | 0.2772 | 0.3336 | 0.3854 | 0.4328 | 0.4761 | 0.5156 | 0.5515 | 0.584 | 0.6132 | 0.6395 | 0.6629 | 0.6837 | 0.7021 | 0.718 | 0.7319 | 0.7436 | 0.7535 |
| | | | | | | | | 5.9763198 | | 130.363 | 0 | 0.2346 | 0.4604 | 0.6777 | 0.8867 | 1.0877 | 1.2808 | 1.4663 | 1.6445 | 1.8155 | 1.9795 | 2.1367 | 2.2874 | 2.4317 | 2.5698 | 2.7019 | 2.8281 | 2.9487 | 3.0638 | 3.1736 | 3.2782 |
| | | | | | | | | | | 112.89197 | 0 | 0.0825 | 0.167 | 0.2534 | 0.342 | 0.4326 | 0.5253 | 0.6202 | 0.7173 | 0.8166 | 0.9182 | 1.0221 | 1.1284 | 1.2371 | 1.3482 | 1.4618 | 1.5779 | 1.6966 | 1.8179 | 1.9418 | 2.0685 |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.24 | 0.23 | 0.21 | 0.20 | 0.18 | 0.17 | 0.16 | 0.15 | 0.14 | 0.13 | 0.12 | 0.11 | 0.11 | 0.10 | 0.09 | 0.09 | 0.08 | 0.08 | 0.07 | 0.07 | 0.06 | 0.06 | 0.05 | 0.05 | 0.05 | 0.04 | 0.04 | 0.04 | 0.04 | 0.03 |
| 1.86 | 1.92 | 1.97 | 2.03 | 2.09 | 2.16 | 2.22 | 2.29 | 2.36 | 2.43 | 2.50 | 2.58 | 2.65 | 2.73 | 2.81 | 2.90 | 2.99 | 3.07 | 3.17 | 3.26 | 3.36 | 3.46 | 3.56 | 3.67 | 3.78 | 3.90 | 4.01 | 4.13 | 4.26 | 4.38 |
| 2.79 | 2.93 | 3.07 | 3.23 | 3.39 | 3.56 | 3.73 | 3.92 | 4.12 | 4.32 | 4.54 | 4.76 | 5.00 | 5.25 | 5.52 | 5.79 | 6.08 | 6.39 | 6.70 | 7.04 | 7.39 | 7.76 | 8.15 | 8.56 | 8.99 | 9.43 | 9.91 | 10.40 | 10.92 | 11.47 |
| 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 |
| 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 |
| 2037 | 2038 | 2039 | 2040 | 2041 | 2042 | 2043 | 2044 | 2045 | 2046 | 2047 | 2048 | 2049 | 2050 | 2051 | 2052 | 2053 | 2054 | 2055 | 2056 | 2057 | 2058 | 2059 | 2060 | 2061 | 2062 | 2063 | 2064 | 2065 | 2066 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1.7856 | 1.7189 | 1.6546 | 1.5928 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0.8059 | 0.8127 | 0.8179 | 0.8216 | 0.8238 | 0.793 | 0.7634 | 0.7348 | 0.7074 | 0.6809 | 0.6555 | 0.631 | 0.6074 | 0.5847 | 0.5628 | 0.5418 | 0.5215 | 0.502 | 0.4833 | 0.4652 | 0.4478 | 0.4311 | 0.4149 | 0.3994 | 0.3845 | 0.3701 | 0.3563 | 0.343 | 0.3302 | 0.3178 |
| 6.7722 | 6.962 | 7.1425 | 7.3137 | 7.476 | 7.3363 | 7.1992 | 7.0646 | 6.9325 | 6.803 | 6.6758 | 6.551 | 6.4286 | 6.3084 | 6.1905 | 6.0748 | 5.9612 | 5.8498 | 5.7405 | 5.6332 | 5.5279 | 5.4246 | 5.3232 | 5.2237 | 5.126 | 5.0302 | 4.9362 | 4.8439 | 4.7534 | 4.6645 |
| 2.6707 | 2.8314 | 2.9955 | 3.1632 | 3.3344 | 3.3743 | 3.4147 | 3.4556 | 3.497 | 3.5388 | 3.5812 | 3.6241 | 3.6675 | 3.7114 | 3.7558 | 3.8008 | 3.8463 | 3.8923 | 3.9389 | 3.9861 | 4.0338 | 4.0821 | 4.1309 | 4.1804 | 4.2304 | 4.2811 | 4.3323 | 4.3842 | 4.4367 | 4.4898 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1.2581 | 1.211 | 1.1657 | 1.1222 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0.5307 | 0.5352 | 0.5386 | 0.541 | 0.5425 | 0.5222 | 0.5027 | 0.4839 | 0.4658 | 0.4484 | 0.4317 | 0.4155 | 0.4 | 0.385 | 0.3706 | 0.3568 | 0.3434 | 0.3306 | 0.3182 | 0.3063 | 0.2949 | 0.2839 | 0.2733 | 0.263 | 0.2532 | 0.2437 | 0.2346 | 0.2259 | 0.2174 | 0.2093 |
| 4.4597 | 4.5848 | 4.7036 | 4.8163 | 4.9232 | 4.8312 | 4.7409 | 4.6523 | 4.5653 | 4.48 | 4.3963 | 4.3141 | 4.2335 | 4.1543 | 4.0767 | 4.0005 | 3.9257 | 3.8523 | 3.7803 | 3.7097 | 3.6403 | 3.5723 | 3.5055 | 3.44 | 3.3757 | 3.3126 | 3.2507 | 3.1899 | 3.1303 | 3.0718 |
| 1.7588 | 1.8646 | 1.9727 | 2.0831 | 2.1958 | 2.2221 | 2.2487 | 2.2757 | 2.3029 | 2.3305 | 2.3584 | 2.3866 | 2.4152 | 2.4441 | 2.4733 | 2.5029 | 2.5329 | 2.5632 | 2.5939 | 2.625 | 2.6564 | 2.6882 | 2.7204 | 2.7529 | 2.7859 | 2.8192 | 2.853 | 2.8871 | 2.9217 | 2.9567 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1.3392 | 1.2892 | 1.241 | 1.1946 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0.5995 | 0.6046 | 0.6085 | 0.6112 | 0.6128 | 0.5899 | 0.5679 | 0.5467 | 0.5262 | 0.5065 | 0.4876 | 0.4694 | 0.4518 | 0.4349 | 0.4187 | 0.403 | 0.388 | 0.3735 | 0.3595 | 0.3461 | 0.3331 | 0.3207 | 0.3087 | 0.2971 | 0.286 | 0.2753 | 0.265 | 0.2551 | 0.2456 | 0.2364 |
| 5.0378 | 5.1791 | 5.3133 | 5.4407 | 5.5614 | 5.4575 | 5.3555 | 5.2554 | 5.1571 | 5.0607 | 4.9661 | 4.8733 | 4.7822 | 4.6928 | 4.6051 | 4.5191 | 4.4346 | 4.3517 | 4.2704 | 4.1905 | 4.1122 | 4.0353 | 3.9599 | 3.8859 | 3.8133 | 3.742 | 3.672 | 3.6034 | 3.5361 | 3.47 |
| 1.9868 | 2.1063 | 2.2284 | 2.3531 | 2.4805 | 2.5102 | 2.5402 | 2.5706 | 2.6014 | 2.6326 | 2.6641 | 2.696 | 2.7282 | 2.7609 | 2.794 | 2.8274 | 2.8612 | 2.8955 | 2.9302 | 2.9652 | 3.0007 | 3.0367 | 3.073 | 3.1098 | 3.147 | 3.1847 | 3.2228 | 3.2614 | 3.3005 | 3.34 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0.9334 | 0.8985 | 0.8649 | 0.8326 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0.3931 | 0.3965 | 0.399 | 0.4008 | 0.4019 | 0.3868 | 0.3724 | 0.3585 | 0.3451 | 0.3322 | 0.3197 | 0.3078 | 0.2963 | 0.2852 | 0.2745 | 0.2643 | 0.2544 | 0.2449 | 0.2357 | 0.2269 | 0.2184 | 0.2103 | 0.2024 | 0.1948 | 0.1876 | 0.1806 | 0.1738 | 0.1673 | 0.1611 | 0.155 |
| 3.3035 | 3.3961 | 3.4841 | 3.5677 | 3.6468 | 3.5787 | 3.5118 | 3.4461 | 3.3817 | 3.3185 | 3.2565 | 3.1956 | 3.1359 | 3.0773 | 3.0198 | 2.9633 | 2.9079 | 2.8536 | 2.8002 | 2.7479 | 2.6965 | 2.6461 | 2.5967 | 2.5481 | 2.5005 | 2.4538 | 2.4079 | 2.3629 | 2.3187 | 2.2754 |
| 1.3028 | 1.3812 | 1.4612 | 1.543 | 1.6265 | 1.646 | 1.6657 | 1.6857 | 1.7058 | 1.7263 | 1.7469 | 1.7678 | 1.789 | 1.8104 | 1.8321 | 1.854 | 1.8762 | 1.8987 | 1.9214 | 1.9444 | 1.9677 | 1.9913 | 2.0151 | 2.0392 | 2.0636 | 2.0883 | 2.1133 | 2.1386 | 2.1642 | 2.1901 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0.8522 | 0.8204 | 0.7897 | 0.7602 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0.3686 | 0.3717 | 0.3741 | 0.3757 | 0.3767 | 0.3627 | 0.3491 | 0.3361 | 0.3235 | 0.3114 | 0.2998 | 0.2886 | 0.2778 | 0.2674 | 0.2574 | 0.2478 | 0.2385 | 0.2296 | 0.221 | 0.2127 | 0.2048 | 0.1971 | 0.1898 | 0.1827 | 0.1758 | 0.1693 | 0.1629 | 0.1568 | 0.151 | 0.1453 |
| 3.097 | 3.1839 | 3.2664 | 3.3447 | 3.4189 | 3.355 | 3.2923 | 3.2308 | 3.1704 | 3.1111 | 3.053 | 2.9959 | 2.9399 | 2.8849 | 2.831 | 2.7781 | 2.7262 | 2.6752 | 2.6252 | 2.5761 | 2.528 | 2.4807 | 2.4344 | 2.3889 | 2.3442 | 2.3004 | 2.2574 | 2.2152 | 2.1738 | 2.1332 |
| 1.2214 | 1.2948 | 1.3699 | 1.4466 | 1.5249 | 1.5431 | 1.5616 | 1.5803 | 1.5992 | 1.6184 | 1.6378 | 1.6574 | 1.6772 | 1.6973 | 1.7176 | 1.7382 | 1.759 | 1.78 | 1.8013 | 1.8229 | 1.8447 | 1.8668 | 1.8891 | 1.9118 | 1.9346 | 1.9578 | 1.9812 | 2.005 | 2.029 | 2.0533 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0.5682 | 0.5469 | 0.5265 | 0.5068 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0.2457 | 0.2478 | 0.2494 | 0.2505 | 0.2512 | 0.2418 | 0.2327 | 0.224 | 0.2157 | 0.2076 | 0.1998 | 0.1924 | 0.1852 | 0.1783 | 0.1716 | 0.1652 | 0.159 | 0.1531 | 0.1473 | 0.1418 | 0.1365 | 0.1314 | 0.1265 | 0.1218 | 0.1172 | 0.1128 | 0.1086 | 0.1046 | 0.1007 | 0.0969 |
| 2.0647 | 2.1226 | 2.1776 | 2.2298 | 2.2793 | 2.2367 | 2.1949 | 2.1538 | 2.1136 | 2.0741 | 2.0353 | 1.9973 | 1.9599 | 1.9233 | 1.8873 | 1.8521 | 1.8175 | 1.7835 | 1.7501 | 1.7174 | 1.6853 | 1.6538 | 1.6229 | 1.5926 | 1.5628 | 1.5336 | 1.5049 | 1.4768 | 1.4492 | 1.4221 |
| 0.8142 | 0.8632 | 0.9133 | 0.9644 | 1.0166 | 1.0288 | 1.0411 | 1.0535 | 1.0662 | 1.0789 | 1.0918 | 1.1049 | 1.1181 | 1.1315 | 1.1451 | 1.1588 | 1.1726 | 1.1867 | 1.2009 | 1.2153 | 1.2298 | 1.2445 | 1.2594 | 1.2745 | 1.2898 | 1.3052 | 1.3208 | 1.3366 | 1.3526 | 1.3688 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0.4058 | 0.3907 | 0.376 | 0.362 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0.1671 | 0.1685 | 0.1696 | 0.1703 | 0.1708 | 0.1644 | 0.1583 | 0.1523 | 0.1467 | 0.1412 | 0.1359 | 0.1308 | 0.1259 | 0.1212 | 0.1167 | 0.1123 | 0.1081 | 0.1041 | 0.1002 | 0.0964 | 0.0928 | 0.0894 | 0.086 | 0.0828 | 0.0797 | 0.0767 | 0.0739 | 0.0711 | 0.0684 | 0.0659 |
| 1.404 | 1.4433 | 1.4808 | 1.5163 | 1.5499 | 1.5209 | 1.4925 | 1.4646 | 1.4372 | 1.4104 | 1.384 | 1.3581 | 1.3328 | 1.3078 | 1.2834 | 1.2594 | 1.2359 | 1.2128 | 1.1901 | 1.1679 | 1.146 | 1.1246 | 1.1036 | 1.083 | 1.0627 | 1.0428 | 1.0234 | 1.0042 | 0.9855 | 0.967 |
| 0.5537 | 0.587 | 0.621 | 0.6558 | 0.6913 | 0.6996 | 0.7079 | 0.7164 | 0.725 | 0.7337 | 0.7424 | 0.7513 | 0.7603 | 0.7694 | 0.7786 | 0.788 | 0.7974 | 0.8069 | 0.8166 | 0.8264 | 0.8363 | 0.8463 | 0.8564 | 0.8667 | 0.877 | 0.8875 | 0.8982 | 0.9089 | 0.9198 | 0.9308 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0.2029 | 0.1953 | 0.188 | 0.181 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0.1278 | 0.1289 | 0.1297 | 0.1303 | 0.1306 | 0.1257 | 0.121 | 0.1165 | 0.1121 | 0.108 | 0.1039 | 0.1 | 0.0963 | 0.0927 | 0.0892 | 0.0859 | 0.0827 | 0.0796 | 0.0766 | 0.0738 | 0.071 | 0.0683 | 0.0658 | 0.0633 | 0.061 | 0.0587 | 0.0565 | 0.0544 | 0.0523 | 0.0504 |
| 1.0736 | 1.1037 | 1.1323 | 1.1595 | 1.1852 | 1.1631 | 1.1413 | 1.12 | 1.0991 | 1.0785 | 1.0584 | 1.0386 | 1.0192 | 1.0001 | 0.9814 | 0.9631 | 0.9451 | 0.9274 | 0.9101 | 0.8931 | 0.8764 | 0.86 | 0.8439 | 0.8281 | 0.8127 | 0.7975 | 0.7826 | 0.7679 | 0.7536 | 0.7395 |
| 0.4234 | 0.4489 | 0.4749 | 0.5015 | 0.5286 | 0.535 | 0.5414 | 0.5478 | 0.5544 | 0.561 | 0.5678 | 0.5746 | 0.5814 | 0.5884 | 0.5954 | 0.6026 | 0.6098 | 0.6171 | 0.6245 | 0.6319 | 0.6395 | 0.6472 | 0.6549 | 0.6627 | 0.6707 | 0.6787 | 0.6868 | 0.6951 | 0.7034 | 0.7118 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0.5361 | 0.501 | 0.4682 | 0.4376 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0.4392 | 0.4429 | 0.4457 | 0.4477 | 0.4489 | 0.4321 | 0.416 | 0.4004 | 0.3855 | 0.371 | 0.3572 | 0.3438 | 0.331 | 0.3186 | 0.3067 | 0.2952 | 0.2842 | 0.2736 | 0.2633 | 0.2535 | 0.244 | 0.2349 | 0.2261 | 0.2177 | 0.2095 | 0.2017 | 0.1942 | 0.1869 | 0.1799 | 0.1732 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0.3075 | 0.2873 | 0.2685 | 0.251 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0.2519 | 0.254 | 0.2556 | 0.2568 | 0.2575 | 0.2478 | 0.2386 | 0.2297 | 0.2211 | 0.2128 | 0.2049 | 0.1972 | 0.1898 | 0.1827 | 0.1759 | 0.1693 | 0.163 | 0.1569 | 0.151 | 0.1454 | 0.1399 | 0.1347 | 0.1297 | 0.1248 | 0.1202 | 0.1157 | 0.1114 | 0.1072 | 0.1032 | 0.0993 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0.6307 | 0.5894 | 0.5509 | 0.5148 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1.2055 | 1.2157 | 1.2235 | 1.229 | 1.2323 | 1.1862 | 1.1419 | 1.0992 | 1.0581 | 1.0186 | 0.9805 | 0.9438 | 0.9085 | 0.8746 | 0.8419 | 0.8104 | 0.7801 | 0.751 | 0.7229 | 0.6959 | 0.6698 | 0.6448 | 0.6207 | 0.5975 | 0.5752 | 0.5537 | 0.533 | 0.513 | 0.4939 | 0.4754 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0.4099 | 0.3831 | 0.3581 | 0.3346 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0.7836 | 0.7902 | 0.7953 | 0.7988 | 0.801 | 0.7711 | 0.7422 | 0.7145 | 0.6878 | 0.6621 | 0.6373 | 0.6135 | 0.5906 | 0.5685 | 0.5472 | 0.5268 | 0.5071 | 0.4881 | 0.4699 | 0.4523 | 0.4354 | 0.4191 | 0.4035 | 0.3884 | 0.3739 | 0.3599 | 0.3464 | 0.3335 | 0.321 | 0.309 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1.0362 | 0.9975 | 0.9602 | 0.9243 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0.7616 | 0.7681 | 0.773 | 0.7764 | 0.7785 | 0.7494 | 0.7214 | 0.6944 | 0.6685 | 0.6435 | 0.6194 | 0.5963 | 0.574 | 0.5525 | 0.5319 | 0.512 | 0.4928 | 0.4744 | 0.4567 | 0.4396 | 0.4232 | 0.4074 | 0.3921 | 0.3775 | 0.3634 | 0.3498 | 0.3367 | 0.3241 | 0.312 | 0.3003 |
| 3.3778 | 3.4725 | 3.5624 | 3.6479 | 3.7288 | 3.6591 | 3.5907 | 3.5236 | 3.4578 | 3.3931 | 3.3297 | 3.2675 | 3.2064 | 3.1465 | 3.0876 | 3.0299 | 2.9733 | 2.9177 | 2.8632 | 2.8097 | 2.7571 | 2.7056 | 2.655 | 2.6054 | 2.5567 | 2.5089 | 2.462 | 2.416 | 2.3709 | 2.3265 |
| 2.1979 | 2.3301 | 2.4652 | 2.6032 | 2.7441 | 2.777 | 2.8102 | 2.8439 | 2.8779 | 2.9124 | 2.9472 | 2.9825 | 3.0182 | 3.0543 | 3.0909 | 3.1279 | 3.1653 | 3.2032 | 3.2416 | 3.2804 | 3.3197 | 3.3594 | 3.3996 | 3.4403 | 3.4815 | 3.5232 | 3.5654 | 3.608 | 3.6512 | 3.6949 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Development multiplier | | 0 | 0.04 | 0.08 | 0.12 | 0.16 | 0.2 | 0.24 | 0.28 | 0.32 | 0.36 |
| Build | 25 years | | | | | | | | | | |
| DR | 7% | 1.00 | 0.93 | 0.87 | 0.82 | 0.76 | 0.71 | 0.67 | 0.62 | 0.58 | 0.54 |
| ER | 3% | 1.00 | 1.03 | 1.06 | 1.09 | 1.13 | 1.16 | 1.19 | 1.23 | 1.27 | 1.30 |
| ER fuels | 5% | 1.00 | 1.05 | 1.10 | 1.16 | 1.22 | 1.28 | 1.34 | 1.41 | 1.48 | 1.55 |
| ER solar | -3% | 1.00 | 0.97 | 0.94 | 0.91 | 0.89 | 0.86 | 0.83 | 0.81 | 0.78 | 0.76 |
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

| Emissions | kg CO2-e/MWh |
|---|---|
| SWIS | 631 |
| Gas turbines | 515 |

| | | Capex | NPC | NPC with carbon price | CO2 | | | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BaU | Grid costs | 99 | 355 | 492 | 3.88 | | 354.62487 | 3.9744 | 4.3783 | 4.7641 | 5.1324 | 5.4837 | 5.8187 | 6.1379 | 6.4418 | 6.7311 | 7.0061 |
| | | | | | | | | 3.9744 | 8.3527 | 13.117 | 18.249 | 23.733 | 29.552 | 35.689 | 42.131 | 48.862 | 55.868 |
| BaU - 5 stars | Grid costs | 75 | 264 | | | | 264.20448 | 2.9808 | 3.2804 | 3.5665 | 3.8396 | 4.1002 | 4.3486 | 4.5853 | 4.8106 | 5.0251 | 5.2291 |
| | Addtl building costs | 245 | 161 | | | | | 9.8 | 9.4336 | 9.081 | 8.7415 | 8.4147 | 8.1002 | 7.7973 | 7.5059 | 7.2253 | 6.9552 |
| | | 320 | 425 | 527 | 2.89 | 26% | 425.22308 | 12.781 | 12.714 | 12.647 | 12.581 | 12.515 | 12.449 | 12.383 | 12.316 | 12.25 | 12.184 |
| | | | | | | | | 12.781 | 25.495 | 38.142 | 50.723 | 63.238 | 75.687 | 88.07 | 100.39 | 112.64 | 124.82 |
| BaU - 6 stars | Grid costs | 47 | 163 | | | | 163.47912 | 1.8969 | 2.0786 | 2.2522 | 2.4179 | 2.5759 | 2.7265 | 2.8701 | 3.0067 | 3.1367 | 3.2603 |
| | Addtl building costs | 735 | 483 | | | | | 29.4 | 28.301 | 27.243 | 26.225 | 25.244 | 24.3 | 23.392 | 22.518 | 21.676 | 20.865 |
| | | 782 | 647 | 709 | 1.77 | 54% | 646.53491 | 31.297 | 30.38 | 29.495 | 28.642 | 27.82 | 27.027 | 26.262 | 25.524 | 24.812 | 24.126 |
| | | | | | | | | 31.297 | 61.676 | 91.172 | 119.81 | 147.63 | 174.66 | 200.92 | 226.45 | 251.26 | 275.39 |
| 6 stars + solar + storage | | | | | | | | | | | | | | | | | |
| | Grid costs | 23 | 75 | | | | 74.822905 | 0.9033 | 0.984 | 1.0612 | 1.1348 | 1.205 | 1.2719 | 1.3356 | 1.3962 | 1.4539 | 1.5088 |
| | Solar | 78 | 47 | | | | | 3.1031 | 2.8579 | 2.6364 | 2.4364 | 2.2556 | 2.0923 | 1.9446 | 1.8109 | 1.69 | 1.5805 |
| | Storage | 91 | 79 | | | | | 3.6507 | 3.4325 | 3.237 | 3.0617 | 2.9045 | 2.7632 | 2.6363 | 2.522 | 2.4189 | 2.3258 |
| | Addtl building costs | 735 | 483 | | | | | 29.4 | 28.301 | 27.243 | 26.225 | 25.244 | 24.3 | 23.392 | 22.518 | 21.676 | 20.865 |
| | | 926 | 684 | 713 | 0.80 | 79% | 684.11472 | 37.057 | 35.575 | 34.178 | 32.857 | 31.609 | 30.428 | 29.308 | 28.247 | 27.239 | 26.28 |
| | | | | | | | | 37.057 | 72.632 | 106.81 | 139.67 | 171.28 | 201.7 | 231.01 | 259.26 | 286.5 | 312.78 |
| 6 stars + trigen | Grid costs | 0 | 0 | | | | | | | | | | | | | | |
| | Trigen | 58 | 195 | | | | 194.6766 | 2.3064 | 2.5324 | 2.7472 | 2.951 | 3.1443 | 3.3276 | 3.5012 | 3.6656 | 3.821 | 3.9679 |
| | Thermal network | 150 | 225 | | | | | 77.625 | 2.5269 | 2.4324 | 2.3415 | 2.2539 | 34.062 | 2.9517 | 2.8414 | 2.7352 | 2.6329 |
| | Addtl building costs | 735 | 483 | | | | | 29.4 | 28.301 | 27.243 | 26.225 | 25.244 | 24.3 | 23.392 | 22.518 | 21.676 | 20.865 |
| | Building savings | -549 | -540 | | | | | -21.95 | -21.66 | -21.36 | -21.05 | -20.73 | -20.41 | -20.09 | -19.76 | -19.42 | -19.08 |
| | | 394 | 362 | 475 | 2.61 | 33% | 361.99289 | 87.379 | 11.701 | 11.064 | 10.467 | 9.9085 | 41.278 | 9.759 | 9.2691 | 8.8105 | 8.3814 |
| | | | | | | | | 87.379 | 99.08 | 110.14 | 120.61 | 130.52 | 171.8 | 181.56 | 190.83 | 199.64 | 208.02 |
| 6 stars + solar + storage + geothermal | | | | | | | | | | | | | | | | | |
| | Grid costs | 11 | 53 | | | | 53.289008 | 0.4516 | 0.5223 | 0.5899 | 0.6545 | 0.7161 | 0.775 | 0.8311 | 0.8846 | 0.9356 | 0.9841 |
| | Solar | 44 | 27 | | | | | 1.7797 | 1.6391 | 1.5121 | 1.3973 | 1.2937 | 1.2 | 1.1153 | 1.0386 | 0.9693 | 0.9065 |
| | Storage | 59 | 51 | | | | | 2.3729 | 2.2311 | 2.1041 | 1.9901 | 1.8879 | 1.7961 | 1.7136 | 1.6393 | 1.5723 | 1.5117 |
| | Geothermal | 74 | 83 | | | | | 31.76 | 1.7643 | 1.7658 | 1.7647 | 1.7613 | 1.7556 | 1.7479 | 1.7383 | 1.727 | 1.7141 |
| | Thermal network | 150 | 225 | | | | | 77.625 | 2.5269 | 2.4324 | 2.3415 | 2.2539 | 34.062 | 2.9517 | 2.8414 | 2.7352 | 2.6329 |
| | Addtl building costs | 735 | 483 | | | | | 29.4 | 28.301 | 27.243 | 26.225 | 25.244 | 24.3 | 23.392 | 22.518 | 21.676 | 20.865 |
| | Building savings | -549 | -540 | | | | | -21.95 | -21.66 | -21.36 | -21.05 | -20.73 | -20.41 | -20.09 | -19.76 | -19.42 | -19.08 |
| | | 525 | 382 | 404 | 0.62 | 84% | 381.80654 | 121.44 | 15.325 | 14.289 | 13.323 | 12.423 | 43.477 | 11.666 | 10.904 | 10.194 | 9.5298 |
| | | | | | | | | 121.44 | 136.76 | 151.05 | 164.37 | 176.8 | 220.27 | 231.94 | 242.84 | 253.04 | 262.57 |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.4 | 0.44 | 0.48 | 0.52 | 0.56 | 0.6 | 0.64 | 0.68 | 0.72 | 0.76 | 0.8 | 0.84 | 0.88 | 0.92 | 0.96 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 0.51 | 0.48 | 0.44 | 0.41 | 0.39 | 0.36 | 0.34 | 0.32 | 0.30 | 0.28 | 0.26 | 0.24 | 0.23 | 0.21 | 0.20 | 0.18 | 0.17 | 0.16 | 0.15 | 0.14 | 0.13 | 0.12 | 0.11 | 0.11 | 0.10 | 0.09 | 0.09 | 0.08 | 0.08 | 0.07 |
| 1.34 | 1.38 | 1.43 | 1.47 | 1.51 | 1.56 | 1.60 | 1.65 | 1.70 | 1.75 | 1.81 | 1.86 | 1.92 | 1.97 | 2.03 | 2.09 | 2.16 | 2.22 | 2.29 | 2.36 | 2.43 | 2.50 | 2.58 | 2.65 | 2.73 | 2.81 | 2.90 | 2.99 | 3.07 | 3.17 |
| 1.63 | 1.71 | 1.80 | 1.89 | 1.98 | 2.08 | 2.18 | 2.29 | 2.41 | 2.53 | 2.65 | 2.79 | 2.93 | 3.07 | 3.23 | 3.39 | 3.56 | 3.73 | 3.92 | 4.12 | 4.32 | 4.54 | 4.76 | 5.00 | 5.25 | 5.52 | 5.79 | 6.08 | 6.39 | 6.70 |
| 0.74 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 |
| 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 |
| 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 | 2041 | 2042 | 2043 | 2044 | 2045 | 2046 | 2047 | 2048 | 2049 | 2050 | 2051 | 2052 | 2053 | 2054 | 2055 |
| 7.2675 | 7.5156 | 7.751 | 7.974 | 8.1852 | 8.3849 | 8.5735 | 8.7514 | 8.9191 | 9.0768 | 9.2249 | 9.3637 | 9.4937 | 9.615 | 9.728 | 8.2998 | 8.1293 | 7.9625 | 7.7994 | 7.6399 | 7.4839 | 7.3313 | 7.182 | 7.036 | 6.8931 | 6.7533 | 6.6166 | 6.4828 | 6.3518 | 6.2237 |
| 63.136 | 70.651 | 78.402 | 86.376 | 94.562 | 102.95 | 111.52 | 120.27 | 129.19 | 138.27 | 147.49 | 156.86 | 166.35 | 175.96 | 185.69 | 193.99 | 202.12 | 210.08 | 217.88 | 225.52 | 233.01 | 240.34 | 247.52 | 254.56 | 261.45 | 268.2 | 274.82 | 281.3 | 287.65 | 293.88 |
| 5.4228 | 5.6068 | 5.7813 | 5.9466 | 6.1032 | 6.2512 | 6.391 | 6.5229 | 6.6471 | 6.764 | 6.8737 | 6.9766 | 7.0728 | 7.1627 | 7.2464 | 6.1743 | 6.0474 | 5.9233 | 5.802 | 5.6833 | 5.5673 | 5.4538 | 5.3427 | 5.2341 | 5.1278 | 5.0238 | 4.9221 | 4.8225 | 4.7252 | 4.6299 |
| 6.6952 | 6.4449 | 6.2039 | 5.972 | 5.7488 | 5.5339 | 5.327 | 5.1278 | 4.9361 | 4.7516 | 4.574 | 4.403 | 4.2384 | 4.08 | 3.9274 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12.118 | 12.052 | 11.985 | 11.919 | 11.852 | 11.785 | 11.718 | 11.651 | 11.583 | 11.516 | 11.448 | 11.38 | 11.311 | 11.243 | 11.174 | 6.1743 | 6.0474 | 5.9233 | 5.802 | 5.6833 | 5.5673 | 5.4538 | 5.3427 | 5.2341 | 5.1278 | 5.0238 | 4.9221 | 4.8225 | 4.7252 | 4.6299 |
| 136.94 | 148.99 | 160.98 | 172.89 | 184.75 | 196.53 | 208.25 | 219.9 | 231.48 | 243 | 254.45 | 265.83 | 277.14 | 288.38 | 299.55 | 305.73 | 311.78 | 317.7 | 323.5 | 329.18 | 334.75 | 340.21 | 345.55 | 350.78 | 355.91 | 360.93 | 365.86 | 370.68 | 375.4 | 380.03 |
| 3.3777 | 3.4892 | 3.5948 | 3.695 | 3.7897 | 3.8793 | 3.9639 | 4.0437 | 4.1188 | 4.1894 | 4.2557 | 4.3178 | 4.3759 | 4.4301 | 4.4806 | 3.7957 | 3.7177 | 3.6414 | 3.5668 | 3.4939 | 3.4225 | 3.3527 | 3.2844 | 3.2177 | 3.1523 | 3.0884 | 3.0259 | 2.9647 | 2.9048 | 2.8462 |
| 20.085 | 19.335 | 18.612 | 17.916 | 17.246 | 16.602 | 15.981 | 15.384 | 14.808 | 14.255 | 13.722 | 13.209 | 12.715 | 12.24 | 11.782 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23.463 | 22.824 | 22.207 | 21.611 | 21.036 | 20.481 | 19.945 | 19.427 | 18.927 | 18.444 | 17.978 | 17.527 | 17.091 | 16.67 | 16.263 | 3.7957 | 3.7177 | 3.6414 | 3.5668 | 3.4939 | 3.4225 | 3.3527 | 3.2844 | 3.2177 | 3.1523 | 3.0884 | 3.0259 | 2.9647 | 2.9048 | 2.8462 |
| 298.85 | 321.67 | 343.88 | 365.49 | 386.53 | 407.01 | 426.95 | 446.38 | 465.31 | 483.75 | 501.73 | 519.26 | 536.35 | 553.02 | 569.28 | 573.07 | 576.79 | 580.43 | 584 | 587.49 | 590.92 | 594.27 | 597.55 | 600.77 | 603.92 | 607.01 | 610.04 | 613 | 615.91 | 618.75 |
| 1.5609 | 1.6103 | 1.6571 | 1.7015 | 1.7434 | 1.7831 | 1.8205 | 1.8558 | 1.889 | 1.9202 | 1.9495 | 1.9769 | 2.0025 | 2.0264 | 2.0486 | 1.7207 | 1.6853 | 1.6508 | 1.617 | 1.5839 | 1.5515 | 1.5199 | 1.4889 | 1.4587 | 1.4291 | 1.4001 | 1.3717 | 1.344 | 1.3168 | 1.2903 |
| 1.4812 | 1.3913 | 1.3391 | 1.2898 | 1.2431 | 1.1988 | 1.1567 | 1.1167 | 1.0787 | 1.0425 | 1.0081 | 0.9752 | 0.9439 | 0.9139 | 0.8853 | 0.4489 | 0.4321 | 0.416 | 0.4004 | 0.3855 | 0.371 | 0.3572 | 0.3438 | 0.331 | 0.3186 | 0.3067 | 0.2952 | 0.2842 | 0.2736 | 0.2633 |
| 2.2415 | 2.165 | 2.1301 | 2.0959 | 2.0621 | 2.0287 | 1.9958 | 1.9633 | 1.9311 | 1.8992 | 1.8676 | 1.8362 | 1.8052 | 1.7743 | 1.7438 | 1.2323 | 1.1862 | 1.1419 | 1.0992 | 1.0581 | 1.0186 | 0.9805 | 0.9438 | 0.9085 | 0.8746 | 0.8419 | 0.8104 | 0.7801 | 0.751 | 0.7229 |
| 20.085 | 19.335 | 18.612 | 17.916 | 17.246 | 16.602 | 15.981 | 15.384 | 14.808 | 14.255 | 13.722 | 13.209 | 12.715 | 12.24 | 11.782 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 25.369 | 24.501 | 23.738 | 23.003 | 22.295 | 21.612 | 20.954 | 20.319 | 19.707 | 19.117 | 18.547 | 17.997 | 17.467 | 16.955 | 16.46 | 3.4019 | 3.3037 | 3.2086 | 3.1166 | 3.0275 | 2.9411 | 2.8576 | 2.7766 | 2.6982 | 2.6222 | 2.5487 | 2.4774 | 2.4083 | 2.3414 | 2.2765 |
| 338.15 | 362.65 | 386.39 | 409.39 | 431.69 | 453.3 | 474.25 | 494.57 | 514.28 | 533.39 | 551.94 | 569.94 | 587.41 | 604.36 | 620.82 | 624.22 | 627.53 | 630.73 | 633.85 | 636.88 | 639.82 | 642.68 | 645.45 | 648.15 | 650.77 | 653.32 | 655.8 | 658.21 | 660.55 | 662.83 |
| 4.1066 | 4.2374 | 4.3607 | 4.4767 | 4.5857 | 4.688 | 4.7839 | 4.8736 | 4.9574 | 5.0355 | 5.1082 | 5.1756 | 5.238 | 5.2956 | 5.3486 | 4.5073 | 4.4085 | 4.3121 | 4.2181 | 4.1262 | 4.0366 | 3.9491 | 3.8637 | 3.7804 | 3.699 | 3.6195 | 3.5419 | 3.4661 | 3.3921 | 3.3199 |
| 28.766 | 3.0294 | 2.9162 | 2.8072 | 2.7022 | 2.6012 | 2.504 | 2.4104 | 2.3202 | 2.2335 | 2.15 | 2.0696 | 1.9923 | 1.9178 | 1.8461 | 1.7771 | 1.7107 | 1.6467 | 1.5851 | 1.5259 | 1.4688 | 1.4139 | 1.3611 | 1.3102 | 1.2612 | 1.2141 | 1.1687 | 1.125 | 1.0829 | 1.0425 |
| 20.085 | 19.335 | 18.612 | 17.916 | 17.246 | 16.602 | 15.981 | 15.384 | 14.808 | 14.255 | 13.722 | 13.209 | 12.715 | 12.24 | 11.782 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| -18.75 | -18.41 | -18.07 | -17.72 | -17.38 | -17.04 | -16.71 | -16.37 | -16.03 | -15.7 | -15.37 | -15.04 | -14.72 | -14.39 | -14.08 | -5.293 | -5.095 | -4.905 | -4.721 | -4.545 | -4.375 | -4.211 | -4.054 | -3.902 | -3.756 | -3.616 | -3.481 | -3.351 | -3.225 | -3.105 |
| 34.212 | 8.1949 | 7.8228 | 7.4749 | 7.1499 | 6.8465 | 6.5634 | 6.2994 | 6.0535 | 5.8245 | 5.6115 | 5.4136 | 5.2298 | 5.0592 | 4.901 | 0.9916 | 1.0242 | 1.0543 | 1.082 | 1.1074 | 1.1307 | 1.1518 | 1.171 | 1.1883 | 1.2038 | 1.2176 | 1.2298 | 1.2405 | 1.2497 | 1.2575 |
| 242.23 | 250.42 | 258.25 | 265.72 | 272.87 | 279.72 | 286.28 | 292.58 | 298.63 | 304.46 | 310.07 | 315.48 | 320.71 | 325.77 | 330.67 | 331.67 | 332.69 | 333.74 | 334.83 | 335.93 | 337.06 | 338.22 | 339.39 | 340.58 | 341.78 | 343 | 344.23 | 345.47 | 346.72 | 347.97 |
| 1.0302 | 1.0741 | 1.1158 | 1.1554 | 1.193 | 1.2285 | 1.2622 | 1.294 | 1.3241 | 1.3525 | 1.3792 | 1.4043 | 1.4279 | 1.45 | 1.4707 | 1.3158 | 1.2888 | 1.2624 | 1.2365 | 1.2112 | 1.1865 | 1.1623 | 1.1386 | 1.1155 | 1.0928 | 1.0706 | 1.049 | 1.0278 | 1.007 | 0.9867 |
| 0.8495 | 0.7979 | 0.768 | 0.7397 | 0.7129 | 0.6875 | 0.6634 | 0.6405 | 0.6187 | 0.5979 | 0.5782 | 0.5593 | 0.5413 | 0.5242 | 0.5077 | 0.2575 | 0.2478 | 0.2386 | 0.2297 | 0.2211 | 0.2128 | 0.2049 | 0.1972 | 0.1898 | 0.1827 | 0.1759 | 0.1693 | 0.163 | 0.1569 | 0.151 |
| 1.4569 | 1.4072 | 1.3846 | 1.3623 | 1.3403 | 1.3187 | 1.2973 | 1.2761 | 1.2552 | 1.2345 | 1.2139 | 1.1935 | 1.1734 | 1.1533 | 1.1335 | 0.801 | 0.7711 | 0.7422 | 0.7145 | 0.6878 | 0.6621 | 0.6373 | 0.6135 | 0.5906 | 0.5685 | 0.5472 | 0.5268 | 0.5071 | 0.4881 | 0.4699 |
| 1.6997 | 1.6841 | 1.6672 | 1.6493 | 1.6303 | 1.6105 | 1.5898 | 1.5685 | 1.5465 | 1.524 | 1.501 | 1.4776 | 1.4539 | 1.4298 | 1.4055 | 0.7021 | 0.6759 | 0.6506 | 0.6263 | 0.6029 | 0.5803 | 0.5586 | 0.5378 | 0.5176 | 0.4983 | 0.4797 | 0.4617 | 0.4445 | 0.4279 | 0.4119 |
| 28.766 | 3.0294 | 2.9162 | 2.8072 | 2.7022 | 2.6012 | 2.504 | 2.4104 | 2.3202 | 2.2335 | 2.15 | 2.0696 | 1.9923 | 1.9178 | 1.8461 | 1.7771 | 1.7107 | 1.6467 | 1.5851 | 1.5259 | 1.4688 | 1.4139 | 1.3611 | 1.3102 | 1.2612 | 1.2141 | 1.1687 | 1.125 | 1.0829 | 1.0425 |
| 20.085 | 19.335 | 18.612 | 17.916 | 17.246 | 16.602 | 15.981 | 15.384 | 14.808 | 14.255 | 13.722 | 13.209 | 12.715 | 12.24 | 11.782 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| -18.75 | -18.41 | -18.07 | -17.72 | -17.38 | -17.04 | -16.71 | -16.37 | -16.03 | -15.7 | -15.37 | -15.04 | -14.72 | -14.39 | -14.08 | -5.293 | -5.095 | -4.905 | -4.721 | -4.545 | -4.375 | -4.211 | -4.054 | -3.902 | -3.756 | -3.616 | -3.481 | -3.351 | -3.225 | -3.105 |
| 35.142 | 8.9209 | 8.3978 | 7.905 | 7.4408 | 7.0037 | 6.5922 | 6.2049 | 5.8406 | 5.4979 | 5.1757 | 4.8728 | 4.5882 | 4.3209 | 4.0699 | -0.439 | -0.401 | -0.364 | -0.329 | -0.296 | -0.264 | -0.234 | -0.206 | -0.179 | -0.153 | -0.128 | -0.105 | -0.083 | -0.063 | -0.043 |
| 297.71 | 306.63 | 315.03 | 322.93 | 330.37 | 337.38 | 343.97 | 350.17 | 356.01 | 361.51 | 366.69 | 371.56 | 376.15 | 380.47 | 384.54 | 384.1 | 383.7 | 383.34 | 383.01 | 382.71 | 382.45 | 382.21 | 382.01 | 381.83 | 381.68 | 381.55 | 381.44 | 381.36 | 381.3 | 381.25 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | | | | | | | | | | |
| 0.07 | 0.06 | 0.06 | 0.05 | 0.05 | 0.05 | 0.04 | 0.04 | 0.04 | 0.04 | 0.03 |
| 3.26 | 3.36 | 3.46 | 3.56 | 3.67 | 3.78 | 3.90 | 4.01 | 4.13 | 4.26 | 4.38 |
| 7.04 | 7.39 | 7.76 | 8.15 | 8.56 | 8.99 | 9.43 | 9.91 | 10.40 | 10.92 | 11.47 |
| 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 |
| 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 |
| 2056 | 2057 | 2058 | 2059 | 2060 | 2061 | 2062 | 2063 | 2064 | 2065 | 2066 |
| | | | | | | | | | | |
| 6.0984 | 5.9757 | 5.8556 | 5.7381 | 5.6231 | 5.5105 | 5.4003 | 5.2925 | 5.1869 | 5.0835 | 4.9823 |
| 299.98 | 305.95 | 311.81 | 317.55 | 323.17 | 328.68 | 334.08 | 339.37 | 344.56 | 349.64 | 354.62 |
| | | | | | | | | | | |
| 4.5366 | 4.4453 | 4.356 | 4.2686 | 4.183 | 4.0993 | 4.0173 | 3.9371 | 3.8585 | 3.7817 | 3.7064 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4.5366 | 4.4453 | 4.356 | 4.2686 | 4.183 | 4.0993 | 4.0173 | 3.9371 | 3.8585 | 3.7817 | 3.7064 |
| 384.57 | 389.02 | 393.37 | 397.64 | 401.82 | 405.92 | 409.94 | 413.88 | 417.74 | 421.52 | 425.22 |
| | | | | | | | | | | |
| 2.7889 | 2.7328 | 2.6779 | 2.6241 | 2.5715 | 2.5201 | 2.4697 | 2.4203 | 2.3721 | 2.3248 | 2.2785 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.7889 | 2.7328 | 2.6779 | 2.6241 | 2.5715 | 2.5201 | 2.4697 | 2.4203 | 2.3721 | 2.3248 | 2.2785 |
| 621.54 | 624.28 | 626.95 | 629.58 | 632.15 | 634.67 | 637.14 | 639.56 | 641.93 | 644.26 | 646.53 |
| | | | | | | | | | | |
| 1.2643 | 1.2389 | 1.214 | 1.1896 | 1.1658 | 1.1424 | 1.1196 | 1.0972 | 1.0753 | 1.0539 | 1.0329 |
| 0.2535 | 0.244 | 0.2349 | 0.2261 | 0.2177 | 0.2095 | 0.2017 | 0.1942 | 0.1869 | 0.1799 | 0.1732 |
| 0.6959 | 0.6698 | 0.6448 | 0.6207 | 0.5975 | 0.5752 | 0.5537 | 0.533 | 0.513 | 0.4939 | 0.4754 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.2136 | 2.1527 | 2.0937 | 2.0364 | 1.9809 | 1.9271 | 1.8749 | 1.8243 | 1.7753 | 1.7277 | 1.6815 |
| 665.04 | 667.19 | 669.29 | 671.32 | 673.3 | 675.23 | 677.11 | 678.93 | 680.71 | 682.43 | 684.11 |
| | | | | | | | | | | |
| 3.2493 | 3.1803 | 3.113 | 3.0472 | 2.9829 | 2.9201 | 2.8587 | 2.7987 | 2.7401 | 2.6829 | 2.6269 |
| 1.0035 | 0.966 | 0.9299 | 0.8951 | 0.8616 | 0.8294 | 0.7984 | 0.7686 | 0.7398 | 0.7122 | 0.6856 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| -2.989 | -2.877 | -2.769 | -2.666 | -2.566 | -2.47 | -2.378 | -2.289 | -2.204 | -2.121 | -2.042 |
| 1.264 | 1.2693 | 1.2734 | 1.2763 | 1.2782 | 1.2792 | 1.2791 | 1.2782 | 1.2764 | 1.2739 | 1.2706 |
| 349.24 | 350.51 | 351.78 | 353.06 | 354.34 | 355.61 | 356.89 | 358.17 | 359.45 | 360.72 | 361.99 |
| | | | | | | | | | | |
| 0.9668 | 0.9474 | 0.9283 | 0.9097 | 0.8915 | 0.8736 | 0.8562 | 0.8391 | 0.8223 | 0.8059 | 0.7899 |
| 0.1454 | 0.1399 | 0.1347 | 0.1297 | 0.1248 | 0.1202 | 0.1157 | 0.1114 | 0.1072 | 0.1032 | 0.0993 |
| 0.4523 | 0.4354 | 0.4191 | 0.4035 | 0.3884 | 0.3739 | 0.3599 | 0.3464 | 0.3335 | 0.321 | 0.309 |
| 0.3965 | 0.3816 | 0.3674 | 0.3536 | 0.3404 | 0.3277 | 0.3154 | 0.3037 | 0.2923 | 0.2814 | 0.2709 |
| 1.0035 | 0.966 | 0.9299 | 0.8951 | 0.8616 | 0.8294 | 0.7984 | 0.7686 | 0.7398 | 0.7122 | 0.6856 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| -2.989 | -2.877 | -2.769 | -2.666 | -2.566 | -2.47 | -2.378 | -2.289 | -2.204 | -2.121 | -2.042 |
| -0.024 | -0.007 | 0.0099 | 0.0256 | 0.0404 | 0.0544 | 0.0676 | 0.0799 | 0.0916 | 0.1025 | 0.1128 |
| 381.23 | 381.22 | 381.23 | 381.26 | 381.3 | 381.35 | 381.42 | 381.5 | 381.59 | 381.69 | 381.81 |

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