# Climate Change Mitigation through Strategic Planning in Local Government

## *A Technology Approach*


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*All emissions that have resulted from conducting this research and preparing this thesis have been offset by means of a contribution towards a certified carbon offsetting scheme (Appendix M).*

***This has been a carbon neutral research project!***

# Declarations

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# Abstract

By strategically assessing the technology options that are available for the purpose of mitigating climate change, it is hypothesised that solutions may be found that not only provide good net emission reductions, but also reasonable economic returns.

There are two primary objectives of the study. The first objective aims to assess the validity of the hypothesis that climate change mitigation can effectively be approached on the local or municipal level. The second aims to assess the technology options for climate change mitigation, with the intention of developing mitigation strategy for Brighton Council, exploring in detail a single cost-effective engineering solution that could result in significant greenhouse gas emission reductions.

The adopted methodology is designed to follow a logical progression. First, a base line data set is established; second, an assessment of the options is undertaken in relation to that data set; third, the most cost effective option is identified and considered in more detail.

Using the Brighton municipality as a case study, a comprehensive inventory of greenhouse gas emissions is established for both the community and the council as a corporate entity. The inventory outputs are considered against the range of technology options and a triple bottom line assessment is made in order to identify opportunities for the council and its community.

The main contribution of the thesis is the identification of green waste gasification as the most justified technology approach to climate change mitigation, for Brighton Council. Modeling of a system is undertaken to confirm the result. A preliminary look at the business case for such an initiative is provided.

The modeled system is a circulating, fluidized bed arrangement that gasifies the chipped green waste for the production of electricity. It is noted that biochar can be produced through a similar process and therefore longer term strategy should be incorporated into the initiative to help the establishment of a new biochar market, thus leading to additional net emission reduction and revenue. Not only could this result provide real savings in emissions, as well as revenue for the council and its community, it would demonstrate to the wider community that through strategic consideration of the options, economic opportunity can be found in climate change mitigation.

The results of the study demonstrate that climate change mitigation can effectively be approached on the local level. Additional questions are raised as to applicability of the study results for other councils and the wider community.

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# Nomenclature

## List of Acronyms and other Definitions

***ABARE* -** The Australian Bureau of Agricultural and Resource Economics

***ANZSIC* -** The Australian and New Zealand Standard Industrial Classification

***CCP* -** Cities for Climate Protection

$CO_2e$ **-** Carbon dioxide equivalent

***CRF* -** Common Reporting Format, referring to the a series of standardized data tables within the UNFCCC inventory reporting guidelines

***ESAA* -** Energy Supply Association of Australia

***Green Energy* -** Purchased electricity with an emission factor of zero

***Greenhouse Gas Protocol Initiative* -** A partnership between the World Resources Institute (WRI) and the World Business Council for Sustainable Development

***ICLEI* -** International Council for Local Environmental Initiatives

***NEM* -** National Electricity Market

***NEMMCO* -** The National Electricity Market Management Company is the market operator of the NEM and the system operator of the national grid

***NGA* -** National Greenhouse Accounts Factors

***PID Controller* -** Proportional Integral Derivative Controller

***PURPA* -** The Public Utility Regulatory Policies Act

***REC* -** Renewable Energy Certificate

***Scope 1* -** Emissions at the point of source e.g. fuel combustion

***Scope 2* -** Emissions as a result of indirect processes e.g. fuel extraction

***Scope 3* -** Other indirect emissions not considered under 'scope 2'

***UNFCCC* -** United Nations Framework Convention on Climate Change

## List of Parameters

| ***Parameter*** | ***Unit*** |
|---|---|
| Calorific Value | $kJ/kg$ |
| Density ($\rho$) | $kg/m^3$ |
| Drag Coefficient ($C_d$) | |
| Enthalpy ($h$) | $kJ/kg$ |
| Heat Flow Rate ($\dot{Q}$) | $kW$ |
| Heat of Combustion | $kJ/mol$ |
| Heat of Formation | $kJ/mol$ |
| Heat of Reaction | $kJ/mol$ |
| Mass Flow Rate ($\mathring{m}$) | $kg/sec$ |
| Molar Mass | $g/mol$ |
| Polytropic Compressor Power ($P$) | $kW$ |
| Pressure | $Pa$ |
| Specific Heat ($c_p$) | $kJ/kg \cdot K$ |
| Specific Volume ($c_v$) | $m^3/kg$ |
| Superficial Velocity ($v_s$) | $m/sec$ |
| Surface Area of Boiler Pipe ($A_s$) | $m^2$ |
| Temperature ($T$) | °C |
| Terminal Velocity ($V_t$) | $m/sec$ |
| Thermal Conductivity | $W/m \cdot K$ |
| Velocity due to Momentum($v_m$) | $m/sec$ |
| Viscosity | $kg/m \cdot s$ |
| Volumetric Flow Rate ($Q_a$) | $m^3/sec$ |

Note, bracketed abbreviation is as used in thesis. Where no bracketed parameter abbreviation is provided, the unabbreviated parameter is used.

# Chapter 1

# Introduction

## 1.1 Objectives

The present study has two primary objectives. Firstly, it aims to assess the validity of the hypothesis that climate change mitigation can effectively be approached on the local or municipal level. Secondly, it aims to assess the technology options for climate change mitigation, from the local government perspective. It is intended that mitigation strategy be developed, exploring in detail a single cost-effective engineering solution that could result in significant greenhouse gas emission reductions.

In achieving the second objective, Brighton Council has been adopted as a case study. A methodology is developed and applied to Brighton Council from which localised strategies are identified using local resources and initiatives. The methodology employs a triple bottom line approach to the assessment of options, for the case study specific scenario. Here, taking the 'triple bottom line' approach is defined as focusing attention not only on the economic value generated but also the expected social and environmental value created by the project [ICLEI-A/NZ Sustainability Services, 2007].

## 1.2 Background

Brighton Council is situated approximately 25 kilometres to the northwest of Hobart, bounded to the south by the Derwent Estuary and traversed by the Midland Highway, the major corridor linkage between the north and the south of Tasmania. It is a municipality of approximately 17,090 hectares, consisting of approximately 5800 properties and a population of around 14,125 people. In the past, Brighton was primarily a rural municipality, however following the establishment of public housing estates in Bridgewater and Gagebrook, together with a boom in private developments in the late 1980's and 1990's, the municipality is now recognised as being predominantly urban and peri-urban based.

Brighton Council made formal recognition of the potential significance of climate change for the first time in 2002, with commencement of the Cities for Climate Protection program [ICLEI, n.d. - b]. The council then resolved to target greenhouse gas emission reductions of 20% by 2010 for both the community and the corporate sectors. The final report for this program however revealed significant divergence from this emission reduction trajectory for a number of reasons [Heyward, 2008].

Brighton Council recognised that local governments have substantial influence within the community, as both leaders and authorities, to effect change and realise greenhouse gas emission reductions. It was also recognised that there may be real opportunities for councils, as corporate entities, to realise growth and progress, in parallel with climate change mitigation.

Brighton Council then committed to supporting the present study as a means to more strategically approach the issue of climate change mitigation and therefore maximise these potentials.

## 1.3 Methodology and Thesis Structure

A preliminary literature review describes the context of the present research. It discusses local government's role in climate change mitigation and provides an initial look at the tools that are available to local government in addressing climate change mitigation and therefore this research project.

The fundamental approach adopted by the present study then adheres to the following general procedure:

1. Development and application of an inventory model for the Council's community and corporate greenhouse gas emission profiles.

2. Desktop, triple bottom line assessment of the various technology options, based on available literature and the baseline inventory data sets.

3. Identification of an initiative that demonstrates particularly good potential in the desktop assessment. Development of a system model for that initiative, for the purpose of providing input to a preliminary business case assessment.

Each of the initial stages is necessary to provide input to the proceeding stage, the final stage then provides resolution to the research objectives.

It is noted that the study does not attempt to achieve or advance the state of the art in local government emission inventory methods, but simply to provide a basis for identifying technical approaches for local government to reduce its greenhouse gas emissions.

The present follows a similar structure to the project methodology outlined above. Following from the literature review, it is divided into three distinct, self contained parts that may be read as individual documents or consecutively in the context of the broader research objectives, each part logically following from the preceding one to provide the complete picture of the research project.

A final part is then provided to conclude the thesis and discuss the findings of the research.

# Chapter 2

# Literature Review

## 2.1 Local Government's Role in Dealing with Climate Change

It is recognised by the Intergovernmental Panel on Climate Change that policy makers need to respond to the issue of climate change from two perspectives: mitigation and adaptation [IPCC, 1988]. Moreover, the Australian Federal Government has endorsed this dual approach for the case of local government:

Local Government's response to climate change requires a dual approach:

- Management and reduction of greenhouse gas emissions (mitigation)
- Making adjustments to existing activities and practices so that vulnerability to potential impacts associated with climate change can be reduced or opportunities realised (adaptation)

[SMEC, 2007]

The present study aims to look at climate change from the perspective of mitigation, considering the options on the local or municipal level.

History shows that the development of the climate change issue in local government has been primarily driven by the larger spheres of government. Moreover, the international community has instigated change by means of intergovernmental negotiations, leading to action on the national level and thus, in the case of Australia, the state and local levels. Internationally, 1997 was a very important year for the adoption of climate change onto the local government agenda. This was the year that saw completion of Kyoto protocol negotiations, bringing the climate change issue into the spotlight.

Betsill and Bulkeley [2007] note that prior to such international initiatives, there had been an increasing number of sub-national governments and communities working to raise the profile of climate change on the local agenda. Primarily, three transnational networks acted to facilitate these efforts. Climate Alliance; Cities for Climate Protection (CCP) and Energie Cites.

The ICLEI, founded in 1990 as the International Council for Local Environmental Initiatives, is an international association of local governments and national and regional local government organisations that have made a commitment to sustainable development [ICLEI, n.d. - a]. ICLEI began its CCP campaign in 1993. The Cities for Climate Protection (CCP) Campaign assists cities to adopt policies and implement quantifiable measures to reduce local greenhouse gas emissions, improve air quality, and enhance urban livability and sustainability [ICLEI, n.d. - b]. The CCP campaign is now recognised as being the most significant framework available for facilitating local government initiatives in combating climate change.

Historically, the issue of climate change has more often than not, been framed in global terms. As a result, many local decision makers have not seen it as something with which they should be concerned [Betsill, 2001]. Much of the success of the CCP campaign can be attributed to the reframing of the issue, thus providing a mechanism for concerned local communities to take action without having to leave the issue in the hands of the upper echelons of government. Betsill [2001] notes that the CCP experience suggests that climate change is most likely going to be 'reframed' as a local issue.

Further to this, CCP have successfully promoted the connection between controlling greenhouse gas emissions and other issues (such as air quality) that are already on the local government agenda. Local government is increasingly discovering that there are co-benefits to climate change mitigation which include both economic savings and other environmental benefits [Betsill, 2001]. Moreover, this approach to encouraging local government in the implementation of climate change mitigation initiative is recognised by Allman et al. [2004], in their paper on the progress of English and Welsh authorities in addressing climate change. In this paper it is stated that successful authorities have recognised the secondary benefits of tackling climate change, for example, potential employment, improved quality of life and reduction in fuel poverty [Allman et al., 2004]. This justification for climate change mitigation within local government is also strongly emphasised by the ICLEI [ICLEI, n.d. - b]. Similar sentiment was expressed in the Stern Review in a discussion relating to macro-political policy choice and the transition to a low-carbon economy [Stern, 2007]. It is highlighted here that effective policy choice on climate change could help to achieve other objectives and as a result, could negate the overall cost to the economy from reducing greenhouse gas emissions. Co-benefits discussed include reducing ill-health and mortality from air pollution and the preservation of bio-diversity in forests.

Despite the clear recognition of such co-benefits, progress in local government continues to be slow in the push to integrate the climate change issue into core local government activity.

Traditionally, strategy development in climate change response has been the responsibility of the economists, as is evident in the Stern Review [Stern, 2007] and the draft Garnaut Climate Change Review [Garnaut, 2008]. Increasingly however, climate change response in terms of strategy development and then strategy implementation is being handed over to those with technical expertise. [Betsill, 2001] notes that a critical barrier to municipal action on climate change exists because there may not be the human resources available in local government to facilitate the cities climate protection program. Moreover, a significant level of technical expertise is required for monitoring and analysis of local greenhouse gas emissions which municipal officers may lack. It is also emphasised that controlling greenhouse gas emissions requires coordinated collaboration between officials working in all areas of local government. Such areas may include waste management; transportation; public works; utilities; health; land use planning; air quality management and so on. It is apparent however that local government need to dedicate personnel with the appropriate technical knowledge to the tasks rather than attempting to delegate the tasks to existing officials in each of these areas and thus further over working them. It is recognised however that in general, local government is unable and often unwilling to commit resources to the creation of such positions. This is particularly the case since often there are issues on the agenda that are perceived as being much more pressing. Based on these observations, it seems evident that combating climate change in local government is to be most effectively achieved by means of a coordinated approach that is directed and managed from a technical perspective. The present study aims to consider climate change in local government from a technical standpoint, so as to develop and implement justifiable strategy, as Betsill suggests.

The necessity for a coordinated approach is further recognised by Allman et al. [2004], with reference to the English and Welsh situation. In their paper, they use the term 'coordinated approach' with respect to resource and funding availability, as opposed to what is expressed in the discussion above concerning the coordinated collaboration of municipal officers. Their discussion makes the point that there has been a lack of clear and long-term funding available to local authorities and as such, local government has often taken an opportunistic, ad hoc approach to sourcing climate change mitigation funding. Furthermore, it is explained that the result of such an approach has led to many somewhat tokenistic pilot or demonstration projects aimed at achieving short term goals. What is more, without a coordinated approach to funding regimes, gaps can be created between different initiatives [Allman et al., 2004]. Here it is evident that a strategic, coordinated approach to climate change is essential.

A further difficulty is again recognised by Betsill [2001], where he makes the comment that it is difficult for municipalities to move from political rhetoric to policy action. Later, this issue is again recognised by Betsill and Bulkeley [2007] in a discussion on the debate over the link between cities and the climate change. The growing push by local communities to see the climate change issue placed on the local agenda may well act to negate this hurdle.

It is clear that controlling local emissions will do little to protect a particular community from the potential adverse effects of climate change. From that perspective it is thus difficult to justify a significant contribution of local government resources to the cause. From a national perspective however, combined local action is clearly a very effective mechanism for achieving greenhouse gas reduction obligations. Allman et al. [2004] discuss the point that there is an extremely important role for government in providing advice and guidance to all of the other sectors of the community, despite the fact that the public sector is responsible for less than 3% of total emissions. It is evident that much of the top down political response to climate change can be attributed to this fact.

It is now generally recognised that local government will play a significant role in climate change mitigation. This sentiment was expressed precisely by Betsill and Bulkeley [2007]. 'While the framework of international negotiations remains important, cities are now acknowledged as a critical arena in which the governance of climate change is taking place'.

Betsill [2001] acknowledges that the primary international response to global warming has been through negotiations of the United Nations Framework Convention and the Kyoto Protocol. He stresses however that countries will not be able to meet the commitments contained within these agreements without the assistance of local governments. It seems clear that now we are seeing a top down, bottom up, combined approach to combating climate change, driven both by international responsibility and a local, moral obligation. Furthermore, much of the efforts instigated by government are and will continue to be played out in the local government arena.

The recent release of Australia's Garnaut Climate Change Review, aimed at examining the impacts of climate change on Australia's economy, has further contributed to the argument that only global cooperation has any prospect of mitigating climate change and that any national strategy must be brought in line with such international agreements [Garnaut, 2008]. This sentiment can be considered equally valid for the development of local mitigation strategy within the context of state or national mitigation strategy.

It is clear that the issues surrounding climate change mitigation in local government are most effectively addressed by not focusing on global climate change, rather, to 'think locally, act locally'. In this way, obligations on the national and international level can be justified and met on the local level.

## 2.2 Tools Available to Local Government in Addressing Climate Change

'Transnational networks have invested heavily in creating tools through which local authorities can create emissions inventories and forecasts, in order to determine where policy interventions are likely to have the most success' [Betsill and Bulkeley, 2007].

### 2.2.1 Inventory Establishment Methods

A true greenhouse gas emission inventory, by definition, requires comprehensive measurement of the flux of all emission sources and sinks. This process is clearly not practical for most purposes and in particular the summation of emission sources and sinks across a large and complex area, as is the case for Brighton Council. By convention however, the analysis and estimation of greenhouse gas emission fluxes is now commonly termed a greenhouse gas emission inventory. As such, a number of emission inventory modeling methods have been developed, with varying degrees of complexity.

Greenhouse gas emission inventories are used as a first step in developing strategy for mitigating climate change. They effectively provide a baseline from which emission targets can be set and from which effective emission reduction or avoidance methods can be identified.

Various models have been developed, appropriate in application to a number of varying scenarios. Of particular interest to local government and in the case of Brighton Council are those models developed by ICLEI through its CCP campaign. In 2006, Brighton Council completed a CCP inventory which is in the present study, considered a first approximation. This model involved what would appropriately be called an emission inventory for Brighton Council's corporate activities. This is because corporate activity emissions can be directly measured by means of known parameters such as electricity usage and vehicle fuel expenditure. In addition to this there was an emission inventory developed for the community, in which a number of assumptions are made, based on the various sectors, the location of the area and the type of development common to the area [Heyward, 2008].

An alternative method is to employ the use of data and software developed through the United States Environmental Protection Agency (EPA). This technique was discussed by means of a case study in which a comprehensive emission inventory is developed for the Pennsylvania State University [Knuth et al., 2007]. In it's application, a list of emission generating activities are established, to which correlating greenhouse gas emission coefficients are applied. The output of this method is thus a distributed greenhouse gas emission model. For the case of Pennsylvania State University, a spreadsheet based inventory tool was then developed to allow for continued maintenance of the inventory and to measure the effectiveness of mitigation efforts. This model was later developed further to accommodate the needs of Montgomery County's inventory requirements.

The Australian Government's Department of Climate Change recognise that greenhouse gas emissions are generated from a large number of processes and as such, it is generally not possible to monitor emissions directly. Their methodology for establishing greenhouse gas emission inventories promotes the use of data that is obtained from observable activities which can then be applied to other comparable scenarios [Department of Environment Water Heritage & Arts, 2006b]. This model estimates greenhouse gas emissions and sinks using a combination of country specific and IPCC methodologies and emission factors. By using the National Greenhouse Accounts (NGA) Factors workbook [Department of Climate Change, 2008a], activities from any sector can be measured in terms of a multitude of parameters such as production rates, fuel usage and population and then multiplied by given coefficients to provide values of carbon dioxide equivalence that are then summed. This is the basis for the Australian national greenhouse gas inventory. Supporting this model, the Australian Government's Department of the Environment notes that the above methodology is consistent with the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories; IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories and IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry. The department also notes that it is comparable with international best practice.

Australia's Garnaut Climate Change review suggested that an emissions trading scheme will become the central instrument of Australia's greenhouse gas reduction and climate change mitigation strategy [Garnaut, 2008]. An emission trading scheme is a market based mechanism that requires emitters to buy and sell permits that allow them to emit greenhouse gasses. Such a system essentially adds monetary value to the environment, resulting in a regulated net reduction in emissions. The fundamental basis to such a system is an accurate and efficient means of reporting on greenhouse gas emissions on a firm by firm basis. For example, any business that emits greenhouse gasses will be required to report on the amount of greenhouse gas, or conduct an inventory at regular intervals of time so that they can then purchase the appropriate amount of permits to meet their obligations under the scheme. Since the greenhouse gas inventory is such an integral part of such a scheme and professor Garnaut has defined such a scheme as being integral to Australia's climate change mitigation strategy, it is likely that this industry will become highly developed and essential to Australia's economy.

### 2.2.2 Action Plan or Strategy

Ribon and Scott [2007] conclude that a comprehensive carbon strategy will include a $CO_2$ emission assessment (a greenhouse gas emission inventory), avoidance, reduction and offsetting. It is implied in their report that the term 'comprehensive strategy' means a strategy to become carbon neutral. Therefore, if the organisation proposes an emission target that is carbon neutral, then an appropriate action plan or strategy should be categorised as such. Furthermore, it would be appropriate to consider the options available in the order of categories stated. That is, once a greenhouse gas emission inventory has been established, first the avoidance options should be defined, followed by reduction options and finally, assuming there is an amount of unavoidable emissions, carbon offsetting should be sourced. Given a less than neutral carbon emission target, it may be possible for an organisation to neglect carbon offsetting, carbon reductions or otherwise alter the approach to achieve the most economic outcome.

Clearly, as a baseline, and justification for an action plan or strategy, it is necessary to establish a greenhouse gas emission inventory. This should be done in the most comprehensive manner possible, given the resources available. From this, the options for avoidance and reduction become apparent. Once the obvious options have been clearly defined, there should be a process of prioritisation in order to establish the most effective and appropriate strategies to achieve the set target for greenhouse gas emission reduction. As discussed by Knuth et al. [2007], criteria should be developed to evaluate the effectiveness of various mitigation options. Criteria employed at the University of Pennsylvania include feasibility to the university; cost effectiveness and possible emission reductions. Further criteria discussed by Knuth et al. [2007] include longer term cost savings and other ancillary benefits. Such criteria were defined by the University of Pennsylvania as being most significant to the situation. These may differ in different scenarios. For the case of local government, it is likely that similar criteria be adopted, possibly with the addition of politically focused criteria. That is, there may be options available that are preferable to elected members for various reasons. There may also be options available that are preferable due to larger 'umbrella' strategies or policies, either from within local government or the higher echelons of government.

Actions appropriate to local government differ greatly depending a number of variables including locality; extent of authority; financial ability and political will. It is clear that a comprehensive assessment of the options must be undertaken prior to the adoption of an action plan.

### 2.2.3 Carbon Offsetting

Ribon and Scott [2007] noted that since a typical business requires some amount of greenhouse gas emission to function, a comprehensive greenhouse gas strategy should involve offsetting those emissions that cannot be reduced further by investing in emission reduction projects which have prevented or removed an equivalent amount of carbon dioxide elsewhere. As stated earlier, it is implied here that the term 'comprehensive strategy' means a strategy to become carbon neutral. Such an approach maybe considered equally valid for the case of local government since for any council wishing to become carbon neutral, some amount of greenhouse gas emission may not practically be avoidable and hence, some amount of carbon offsetting maybe necessary.

It is made apparent however in the Ribon and Scott [2007] report that the business of choosing a provider of carbon offsetting is complicated due to the lack of regulation and the large variety of quality standards emerging internationally. It is also noted that issues arise in the lack of transparency with regards to offset quality.

It appears evident that carbon offsetting is an important element, but not the only element of an organisation's greenhouse gas strategy. The carbon offsetting industry is inherently opportunistic as it enables carbon offset service providers to capitalise on climate change and the shift towards climate change mitigation. As a result, quality standards can become ambiguous and selection of a provider can become difficult. As the present study aims to develop strategy for local government to mitigate climate change, it is necessary to critically consider carbon offsetting and comprehensively review the options. Limited comparative research has been done into the validity of the options available to an organisation wishing to take up carbon offsetting within Australia and in particular, within local government in Australia. Furthermore, it is currently a dynamic and new industry with standards that are continuing to be developed and in which new providers are appearing regularly.

Whilst quality assurance in selection of an offset method is extremely important, a further issue discussed by Ribon and Scott [2007] is the differences in prices that are charged per tonne of carbon dioxide ($CO_2$). Furthermore, providers offering offsets from energy efficiency and renewable energy projects generally adhere to a recognised assurance scheme, where as providers with a bio-sequestration focus generally do not. Moreover, providers website's often fail to clearly convey information regarding their calculation models.

Australia's Garnaut Climate Change review has suggested that offset credits should generally be regarded as substitutes for permits under an Australian emissions trading scheme [Garnaut, 2008]. As a result, the carbon offsetting industry, as with the greenhouse gas inventory industry, is likely to become significantly more developed as industries discover its potential significance within the Australian economy.

## 2.3 Climate Change and the Brighton Municipality - Within the Context of Tasmania and Australia

Over the past few years in Australia, significant consideration has been given to local government's role in dealing with climate change from the perspective of adaptation. This may be because of the direct economic implications of climate change on local government and thus the community as a whole, if we fail to adapt. In 2007, the then Australian Minister for the Environment and Water Resources, Mr. Malcolm Turnbull commented that 'The projected impacts of climate change cut across all elements of local government responsibility' [SMEC, 2007]. As a result, much research has been done into climate change adaptation of local government in Australia, evident with the publication of government documents such as Australian Greenhouse Office, in the Department of the Environment and Heritage [2006] and SMEC [2007]. As well as Department of Climate Change [2007], established to provide funding for local government to conduct research into climate change adaptation strategy. While this aspect to climate change response is recognised as being extremely important, it is evident that a research emphasis is also required from the point of view of climate change mitigation (defined earlier as the management and reduction of greenhouse gas emissions).

Whilst research in this field has been conducted in industry and in other parts of the world, it is evident from the present literature review that the nature of the subject requires a local as well as a government perspective to be truly effective.

In early 2008, the state government of Tasmania adopted a framework for reducing government's greenhouse gas emissions [Crowley, 2007]. The framework is similar in principle to the framework of CCP in that it employs an ordered series of actions, namely, the establishment of a greenhouse gas inventory; defining of targets; monitoring and reporting; reducing emissions through action plans and evaluation and learning. Crowley's report indicates that the framework should be an impetus for cultural change towards greenhouse gas reductions within the community as a whole and specifically within local government. In April of 2008, the Premier's Local Government Council agreed to consider adopting the principles of the Crowley [2007] framework for local government. Furthermore, they agreed to share methodologies in assessing carbon footprints and share knowledge of any other successful climate change initiatives [Department of Premier & Cabinet, 2008].

In July of 2008, the state government of Tasmania then legislated to establish a greenhouse gas reduction target for Tasmania to at least 60% below 1990 levels by 2050 [Office of Parliamentary Council Tasmania, 2008]. This commitment brings Tasmania inline with common scientific opinion. That is, developed countries need to reduce their greenhouse gas emissions by 60 percent by 2050 against 2000 emission levels, if global greenhouse gas concentrations in the atmosphere are to be stabilised to between 450 and 550ppm by mid century [Garnaut, 2008]. It will be necessary for local government to play a significant role in achieving this goal as it is likely that many of the actions will be implemented on the local level.

A report produced by the local government association of Tasmania presented findings of a needs analysis survey in which councils in Tasmania were asked specific questions regarding their position on climate change response. 76% of all Tasmanian councils responded to the climate change needs analysis survey. As noted in the report, such a high response rate is indicative of a growing concern about climate change and its impacts on local communities [Local Government Association Tasmania, 2007]. It is evident from the report that further local research is required for the purpose of local capacity building and development of local resources.

Following the release of the Garnaut Climate Change Review, the Australian Government's Department of Climate Change released the Green Paper outlining a carbon pollution reduction scheme [Department of Climate Change, 2008b]. The Green Paper is fundamental to the federal government's climate change strategy and endorses much of the Garnaut Climate Change Review. It places a cap on the amount of greenhouse gasses industry can emit and introduces a model for emissions trading, as well as a timeline for implementation. The Green Paper has specified a number of industries that will be affected under the scheme including sewer and landfill waste streams. As such, local government will likely be directly affected. It is thus likely that greenhouse gas reduction strategy, on the local level, will become of much higher priority if and when the scheme is implemented, particularly within sewer and waste disposal processes.

It is evident from the present literature review that the issues surrounding climate change mitigation in this context, at the present time, are progressing at a particularly rapid rate both politically and in terms of our scientific understanding. As a result, it is unclear what developments will be made and thus what the political environment will consist of in the future. What is certain however is that there is a need for further research to be conducted so as to ensure that decision makers are appropriately informed and equipped to facilitate the most effective approach to climate change mitigation.

## 2.4 Preliminary Look at Options to Cut Emissions

As stated in section 2.2.1, it is the purpose of a greenhouse gas inventory to establish a baseline from which effective emission reduction or avoidance methods can be identified. As such, it will be necessary to conduct an inventory for the municipality of Brighton before the range of mitigation options come to light.

As noted by Garnaut [2008], Australia's per capita emissions are the highest in the OECD and among the highest in the world. Moreover, Australia's unusually high per capita emissions are primarily a result of Australia's dependence on coal based energy production. Tasmania's principle energy production technology is hydro which, when considered from the perspective of greenhouse gas emissions, is minimal. That being said, Tasmania has in recent times been linked to the national electricity grid via the Basslink interconnector, the world's longest undersea electricity cable [CitySpring, 2007]. As such, it can be assumed at this preliminary stage of the present investigation that the primary means for greenhouse gas emission cuts will be within the energy sector. Reductions maybe possible by effective use of renewable energy production, network efficiency improvements [CSIRO, 2006] as well as the deployment of new technologies such as distributed generation [Fri, 2003].

Distributed micro-generation technologies are recognised as being a significant potential direction for the power industry in the future low emission economy. Under a dynamic micro-generation electricity grid model, in which individual properties are contributing to demand and supply, significant reductions in greenhouse gas emissions can be made. Such a model lends itself well to renewable energy technologies such as photovoltaics, biomass gasification or micro wind. Furthermore, it provides greater efficiency than conventional centralised production technology due to minimised transmission losses [Greenpeace, 2005]. Distributed micro-generation has been shown to encourage load shifting or reduced energy consumption [Sauter and Watson, 2007]. Sauter and Watson [2007] argue that there is a significant social hurdle to overcome if a revolution towards a distributed power generation network was to occur. There are a number of plausible models available to us and it is critical that further research be undertaken to establish the most effective means for such a cultural change. From the perspective of local government, there is limited direct influence that can be utilised to drive such a transition. Strategic partnerships with the local energy authorities, combined with the adoption of appropriate council policy may however effectively help to facilitate such a transition.

Internationally, a very limited number of local authorities have adopted a strategic approach to climate change that goes beyond structured and easily implemented frameworks such as ICLEI's CCP. In terms of greenhouse gas emission inventory development, much of the present study adopts similar methodology to that of CCP however makes a considerable attempt to justify the methodology and where it is evident that a better approach exists, deviates accordingly. Further to this, a secondary approach is taken in which local data is obtained and used for validation purposes. Acclaimed for its early action and initiative on climate change [The Beacon Scheme, 2008], Woking Borough Council of south-west London England, published its original Climate Change Strategy in 2003. Woking Borough Council has approached the issue of climate change by considering key themes in which Council has either direct authority or significant influence. Namely, planning and regulation; energy; waste; transport; procurement (purchasing of goods or services by Council); education and promotion (increasing awareness of issues surrounding climate change); green spaces (strategic vegetation planting and implementation of water sensitive urban design); water; working with business; community and residents (leading by example but also encouraging the wider community by providing information and other help) [Woking Borough Council, 2008].

Fri [2003] makes the key point that climate change could well create a demand for innovation in this sector, far more persuasive and powerful than any environmental program so far.

## 2.5 Conclusion

Clearly there is a need for further research in the area of climate change mitigation strategy within the context of local government, and more specifically, within the context of Tasmania. While there are resources available to the wider international and national communities of local government, such as The Cities for Climate Protection (CCP) campaign, there is little available that deal with the specific local issues of Tasmania and the Brighton Council.

The present study aims to assess the validity of the hypothesis that climate change mitigation can effectively be approached on the local or municipal level. Using the Brighton Municipality as a case study, a comprehensive inventory of greenhouse gas emissions is to be established, the outputs of which enabling localised strategies to be developed using local and native resources and initiatives. Based on the literature that is available at this present time it is evident that there is much that local government can contribute to climate change mitigation that is outside of the scope of CCP.

With Australia's impending greenhouse gas emissions trading scheme, and the possibility of an international greenhouse gas emissions trading scheme, climate change mitigation strategy is to become significantly more important both within industry and government. It is thus timely that research of this variety be conducted, making a contribution to the ease of transition into the new economy.

Furthermore, from this literature study it has become evident that addressing the climate change issue from a technical perspective has strong merit due to the complexities of collecting and analysing data related to local greenhouse gas emission.

# Part I

# Greenhouse Gas Emission Inventory

# Chapter 3

# Background to Inventory Development

## 3.1 Philosophical Discussion

The greenhouse gas emission reporting industry is still very much in its infancy and thus lacks definitive methodology, procedural direction and a well understood approach. There are many issues surrounding the industry that at this present time, are still open to philosophical debate and are yet to find legal resolution. The future of the industry is however set to develop extensively as we see the combination of moral goodwill, commercial responsibility and political legislation driving obligatory greenhouse gas emission reductions and climate change mitigation within all sectors of the community. Whilst many of these issues may presently be beyond the scope of this study, it is necessary for completeness that they are examined in brief. Here they are discussed within the context of the present study and its objectives.

## 3.2 Inventory Scoping

The scope of a greenhouse gas emission inventory is often defined based on a geographical area. It is equally valid however to define the scope in terms of a certain demographic, organisation, association, economic sector, individual person, process, product or any other definitive collection of humans or human activities. It is therefore very important to be clear in the objectives of a greenhouse gas inventory prior to scoping it, so as to ensure that it is encapsulating relevant emission fluxes only and is not over or under estimating the outputs of the model.

The present study aims to establish a position on climate change mitigation for the municipality of Brighton and thus provide direction both for the community contained within the local government boundary and for the Brighton Council itself. There are thus two parallel greenhouse gas emission inventories that are possible, both distinct and dissimilar in scope. For the first greenhouse gas emission inventory, consideration is required for greenhouse gas emission fluxes occurring within the bounds of the municipality. It is thus in geographical terms that the scope should be defined. The second possible greenhouse gas emission inventory, unlike the first, considers greenhouse gas emissions that are distributed across a geographical area. The scope is thus better defined in terms of assets and associated activities for which the organisation is responsible. The proceeding chapters focus primarily on the first such possible greenhouse gas emission inventory, from the community perspective. Chapter 6 then summarises the second in the context of the Brighton Council as an organisation.

Further to this, since an emission inventory is established based on the flux, or rate of flow of greenhouse gas, there is inherent time dependence within any model. It is thus essential in scoping an inventory, to define the time frame which it is assessing. Moreover, the start and finish times are often set such that the inventory can be identified with a period of time within a greenhouse gas emission reduction trajectory towards a defined reduction target. Decisions here should also be based on the required outputs of the inventory; however, for most purposes it is conventional to scope greenhouse gas emission inventories over a twelve month period. This is due to the convenience of economic and social convention, that is, it is common practice within an organisation to base financial and activity records around the financial year. For the purpose of the present study, inventories will be based on the twelve month period just prior to commencement of study. That is, the full calendar year of 2007.

### 3.2.1 Perspective for Inventory Model Development

There are primarily two strategies, or perspectives, from which a greenhouse gas emission inventory model may be developed. That is, a top-down or a bottom-up approach. The decision as to which approach is most appropriate is generally based on its applicability to the predefined scope of the inventory. A combination approach is also available to some greenhouse gas emission inventory scenarios.

Taking the top-down perspective requires analysis of larger scale inventories and the disassembling of them into smaller subset components. The smaller scale inventories can then be further disbanded to reveal even higher resolution, provided that appropriate knowledge of the system is available such that the accuracy of the result is improved in doing so. In doing this, the result is known from the start, it is simply refined and further refined until further revisions are no longer possible or justified. Here the community inventory is scoped in terms of its geographical area. This area is a section of the greater land mass which is the state of Tasmania, which is of course an element Australia, an even larger geographical region. Given that greenhouse gas emission inventories have been conducted on these lower resolution scales, an approximation of Brighton's contribution to those inventories can be made. This can be done on a per capita basis, a per unit area basis or by any other measure of inventory magnitude that is justified.

Taking the bottom-up approach requires direct, initial consideration for the finer detail of a subject inventory scope. This would then be followed by a simple summation to establish the total flux of greenhouse gas. Similar to the top-down approach, it may be necessary in application to implement a multilayered model so as to achieve the required accuracy from its outputs. An inventory by definition follows this strategy and under most greenhouse gas emission inventory scenarios, this is likely to be the most applicable and least problematic in implementation.

Decisions regarding inventory perspective should be made purely on the validity of the model. For example, it is conceivable and in some instances probable, that a large scale inventory model may fail to acknowledge factors of considerable influence that exist within its small scale subsets, thus, in those instances the top-down approach would lack validity. However, in conducting bottom-up methodology, these discrepancies might become evident and thus application of the top-down approach would only be made applicable for validation of the bottom-up approach so long as such discrepancy is then factored in to the top-down approach. A combination approach thus becomes justified.

The debate then arises as to what degree of complexity is warranted and how many levels to either approach are appropriate. The answers to these questions are however only likely to become apparent in application of the model due to the practicalities associated with obtaining or refining data. That is to say, only by designing a model and then implementing it will its flaws become evident, thus enabling revision of the model.

### 3.2.2 Greenhouse Gas Responsibility

The global system of greenhouse gas emission flux is one that is complex, dynamic and ever changing. It is one that involves stationary as well as transient sources and sinks. It is greatly affected by ambient, environmental conditions that are beyond the influence of humanity but it is also greatly affected by society driven economics and culture. The debate over emission responsibility thus becomes appreciably complex, particularly with the economic and legal implications that are likely to develop as a result of society's move towards climate change realisation.

Should we attribute emissions to the end user of a product or at point of production of the product? Responsibility lies with whom? If the objective is to minimise emissions, given the supply and demand structure of our economy, responsibility should lie with the end user. This would then minimise the disposable nature of the market and encourage less production and thus fewer emissions. Such an approach is however particularly difficult to achieve since the point of use of a product is generally not the point of source of the emission. At the point of use, the product has already been distributed and thus accounting of associated greenhouse gas can only be achieved based on assumptions about the production method and materials used.

Greenhouse gas reporting clearly becomes less complex when responsibility is attributed to the point of production, often the point of the actual source of greenhouse gas. In this case, greenhouse gas associated with an item is counted along side that of many similar items, thus simplifying and ensuring accuracy in the inventory.

Consider for example a computer monitor. This is an item that is mass produced in a factory, it is built primarily of fossil fuels and minerals, all of which are produced and processed at mines, smelters and other types of processing plants around the world. Should the greenhouse gas associated with a computer monitor be attributed to the individual who purchases the item, in which case, how do you consider the thousands of sources of greenhouse gas emissions that were required for the production of the item? The item was produced because of a demand and thus it was the purchaser who is in reality responsible for the associated emissions. But if the emissions were accounted for at the point of source of the emission then they can be much more easily summed. The factory that produced the monitor, the point of production of the item, is of course part of the economy too. Should it be free of any responsibility since it is simply assembling processed materials and passing the product on to the consumer? But of course it wouldn't exist either if it were not generating profits, thus how do we attribute appropriate greenhouse gas responsibility to them?

Following from this debate is that of the emissions associated with an item post production but prior to acquisition by the consumer. This section of a product's life cycle may include delivery, storage and method of acquisition such as sales at a shop and thus all associated activities; marketing of the product, maintenance of the product and so on. Each of these activities may have considerable associated greenhouse gas, but to whom do we attribute them to? Hence the complexity of greenhouse gas emission reporting.

The philosophical debate discussed presently, regarding the rights and responsibilities over greenhouse gas sources and sinks, is likely to be resolved by considering the scope of the inventory and its required outputs. Thus it is of critical importance that such defining conditions are made clear and unambiguous prior to any attempt at developing the model. If for example a greenhouse gas emission inventory is scoped in terms of a geographical area, as is the case for the community inventory in the present study, consideration must be given to land use within the defined boundary as this will contribute to the combined total flux of emissions from within the scope. It maybe found however that much of the subject land is undeveloped and in fact contains natural processes that produce greenhouse gas, should this emission flux then be attributed to the current managers of that parcel of land despite the land manager having little to no influence over that specific emission flux? Similarly, if a natural land use is sequestering greenhouse gas, should it then be considered a greenhouse gas sink and attributed to the manager of that parcel of land. The answers to these questions may be found by considering the required outputs of the model. For the present study, an investigation into natural processes will likely do little to establish the primary anthropogenic greenhouse gas emission sources over which we have control and thus while it is considered an element of the inventory scope, it may be considered beyond the requirements of the study and thus should be neglected.

In order to assist greenhouse gas emission inventory developers and policy makers distribute greenhouse gas emission responsibility and to avoid double counting of emissions, the Greenhouse Gas Protocol Initiative introduced a method to delineate direct and indirect emission sources. By categorising emission sources as such, greenhouse gas emission inventory developers can be clear on where their responsibility lies with regards to their particular inventory requirements, as defined by their policy makers. The methodology defines three 'scopes' for emission accounting and reporting purposes. Namely, the following:

**Scope 1:** All direct greenhouse gas emissions.

**Scope 2:** Indirect greenhouse gas emissions from the consumption of purchased electricity, heat or steam.

**Scope 3:** Other indirect emissions, such as the extraction and production of purchased materials and fuels, transport-related activities in vehicles not owned or controlled by the reporting entity, electricity-related activities not covered in Scope 2, outsourced activities, waste disposal, etc.

[World Business Council for Sustainable Development, 2004]

Direction on the design of national greenhouse gas inventories is provided at the international level for the IPCC by Eggleston et al. [2006], and then domestically, on reporting greenhouse gas emissions to the federal government by the Department of Climate Change [2009b] and the Department of Climate Change [2008d]. A benchmark methodology is also provided for corporate or oganisational based inventories by Ranganathan et al. [2004]. Principles from these methodologies are drawn on throughout the present study as appropriate to suit the objectives of the present study.

As discussed in section 3.2.1, the development of a model to establish a greenhouse gas emission inventory should be conducted based on its validity with regards to the required outputs. For the purposes of the present study, a greenhouse gas emission inventory is required in order to provide a basis for further research into climate change mitigation measures. The required outputs are thus to establish the overarching sources of greenhouse gas, and to then categorise, prioritise and apply them to a mitigation technology comparison review. Furthermore, it is intended that this be done for the community's emission profile, a considerably more complex task than what would be the case for an individual organisation. With this in mind, the present study diverges from commonly applied methodology that would be applicable at the corporate level, while maintaining the accepted principles of greenhouse gas accounting.

### 3.2.3 Inventory Model Input and the Quality of Data

As is made evident in the preceding sections, inventory modeling is a complex science, subject to many case specific variables. Validity of the model outputs will always be dependant on the quality of data that is inputted and thus the quality and source of data that is used. Hence, the methodology in which data is sourced is critical to the success of an inventory.

In conducting an emission inventory, likely sources and sinks of greenhouse gas must be known. This is required in order to enable measurement or estimation of greenhouse gas flux. Sources of greenhouse gas are found in many aspects of human activity, an initial assessment of the defined inventory scope must thus be conducted. Such an assessment of greenhouse gas flux must try to consider all greenhouse gas flows and be limited only by the level of complexity that is required to achieve the purposes of the inventory.

The municipality of Brighton might expect for example greater commuting fuel use than the average Hobart citizen. Lower average income however may mean substantially lower indirect greenhouse gas emissions, such as air travel. People may be more likely to be at home through the day and thus have higher electricity costs. Certain industries may be more common than average in the area and thus will bring particular industry specific greenhouse gas emission profiles. Effective data collection methodology can thus be based on such an initial assessment, ensuring comprehensiveness and appropriate focus within the model.

The two principal avenues for data acquisition include directly measured data, as would be the primary option for a bottom-up methodology, and statistically obtained data, as would likely be more in line with a top-down approach. Either approach may be best suited to a given application.

### 3.2.4 Inventory Scoping Summary

Many of the issues discussed in this chapter are beyond the scope of the present study. As the political climate surrounding climate change develops, greenhouse gas emission reporting will become progressively more necessary and even obligatory. There will likely be legal negotiations around the issues discussed in section 3.2.2, leading to more clearly defined greenhouse gas responsibility and as such, a more prescriptive methodology.

# Chapter 4

# Community Inventory Strategic Approach

As discussed in the previous section of this thesis, there are various options available for the development of a greenhouse gas emission inventory. Careful consideration of these options has been undertaken in order to establish a model that effectively represents the Brighton community inventory objectives. The discussion presented here aims to examine the options selected, providing justification of the model within the wider context of the present study.

## 4.1 Inventory Objectives

Within the greater setting of this research, the community greenhouse gas emission inventory aims to establish an ordered list of greenhouse gas emission sources, structured both in terms of sectors (residential; industrial; agricultural etc) as well as primary, common emission sources (fuel use; electricity use; waste etc). The results of this, and the corporate Council inventory, then provide basis for comparison of the various technology options that are available for the purpose of reducing net emissions. The inventory will therefore justify emission reduction strategy.

## 4.2 Scope

A municipality within the context of Australia is essentially a political subdivision of a state or territory, defined in terms of its administrative authority and geographical boundaries. The Municipality of Brighton is thus defined in these terms, such that anything contained within its boundaries should be considered an element of the municipality and subject to the administration of the Brighton Council.

Following from the discussion provided in the previous chapter, in defining the scope of a municipality's greenhouse gas emission inventory consideration is given to everything that is encompassed within the municipal boundaries. Particular focus is given to anthropogenic emission flux since this is subject to influence by the Brighton Council and its community. Less emphasis is therefore given to the emission flux driven by natural processes.

The calendar year leading up to the commencement of this research is the subject time frame. That is, the full calendar year of 2007.

## 4.3 Perspective

Following from the discussion in section 3.2.1, the most appropriate perspective from which to base the Brighton community inventory is a combined top-down, bottom-up approach. In taking this approach the inventory may be established through a top-down approach and then subsequently validated by means of a bottom-up approach. The bottom-up approach would identify any significant localised greenhouse gas emission sources or sinks that would not be apparent through a simple top-down assessment.

The present study made a substantial effort to undertake the inventory in this way however the bottom-up approach was not successfully achieved.

From the bottom-up perspective, a survey was conducted in order to obtain a data set of real data that could then be compared to the top-down results.

In order to achieve this a sample group of each sector was surveyed. Of 5000 non-vacant residential properties, approximately 200 were surveyed. Of 110 agricultural properties, approximately 110 were surveyed. Of 47 industrial properties, approximately 47 were surveyed. Of 73 commercial properties, approximately 73 were surveyed. A very poor response rate to the surveys was achieved, not sufficient to provide a large enough sample base for the survey to be statistically valid.

The remainder of this chapter thus looks only at the top-down perspective.

## 4.4 Structure

As discussed previously, at the time of writing, the most relevant and applicable tool available to the Brighton municipality, exterior to the present study, for conducting a greenhouse gas emission inventory is that developed through the cities for climate protection (CCP) program. In terms of perspective, the CCP's community inventory methodology adopts a purely top-down approach, employing statistical techniques that are generally applicable to any local government within Australia. In this way, it is easily adopted to within the Australian local government framework, thus making it far reaching in its uptake. Furthermore, it is often easily structured within core Council activities, taking input data from systems that may already be in place.

Within the CCP milestone framework, development of an inventory is the first of five milestones. Its primary objective is to establish a baseline and thus a 'business as usual' from which forecasts and targets may be set. Such an approach could be considered 'achievement focused' since the focus of the program is to provide participants primarily with a mechanism for setting targets and reporting on achievements.

The approach taken by the present study differs from that of CCP. It is based on the objective of identifying the most strategic action plan for greenhouse gas reduction within the municipality of Brighton. It is thus the inventory's primary task to prioritise sources of greenhouse gas rather than to estimate the actual tonnages of greenhouse gas that is being emitted. It is recognised that there are vast amounts of assumption associated with any inventory that is not directly measuring emission flux. That is, it is probable that there will be substantial compounded error factored into the result with any top-down methodology. Whilst the present study adopts a numerical approach, providing estimations of greenhouse gas emission flux in a similar way to the CCP approach, the critical element here is not magnitude, rather, it is how each emission source compares relative to each of the other emission sources.

Considering the points outlined above, it is necessary to define a strategic approach in which the most critical of emission sources or associated human activities are compared. The following discusses the strategic approach that is adopted by the present study.

## 4.5 Community Sectors

The Brighton Planning Scheme, developed in 2000, specifies allowable land use according to a zoning scheme for all land contained within the municipality's boundaries. Furthermore, since the various sectors of the community contribute in sector specific ways to the magnitude of emission flux, measurement or estimation of the various emission sources is aided significantly by integrating such a sectoral breakdown into the inventory model. As such, it is convenient for an inventory of greenhouse gas emissions to adopt a similar scheme of community (or land use) sectors to that within the planning scheme.

For the purposes of this model, sectors are defined as follows:

- Residential
- Agricultural
- Commercial

- Industrial

In essence, each of these sectors is considered separately, as individual, sectoral inventories so as to enable a comparative study. Such an approach facilitates the ranking of community sectors in terms of their contribution toward greenhouse gas emission flux, thus meeting the requirement of the inventory objective.

It should be noted here that under the CCP methodology, agriculture is neglected as an individual sector and all associated emissions are considered as part of the industrial sector. Given the large amount of agricultural land within the municipality of Brighton, as defined by the planning scheme, it is considered here as a separate community sector in its own right. By varying the fundamental structure of the model away from the CCP approach, significant variation of the data collection and mathematical strategies is also required. Further to this, comparison between methodologies is not always achievable as will become evident in the later sections of this thesis.

## 4.6 Primary, Common Emission Sources

In order to conduct the individual, sectoral inventories mentioned above, it is necessary to consider from where within each sector emissions might be coming from. A classification mechanism is thus defined in which primary greenhouse gas emissions are categorised in terms of common emission sources. Here, the term 'primary' describes combined emission sources that are considered to be of highest significance or greatest magnitude. Such an approach leads to clear identification of the greatest emission sources within the community, thus enabling their prioritisation for strategic planning purposes, according to the objectives outlined in section 4.1.

Primary, common emission sources include the following:

- Electricity usage

- Fuel usage

- Fuel usage due to travel
- Waste

Further to these 'primary' emission sources, it is noted that there are a number of other sector specific emission sources that make a more minor contribution. These will be given less consideration within the present study. Moreover, the region in which Brighton Council exists has a water and sewer authority that manages the liquid waste stream. The council and its community therefore have little direct influence over this component of the waste stream and thus it is largely neglected in the analysis.

The approach to inventory development, as outlined presently, differs significantly from the national approach adopted by government, where the national approach does not define sectors and emission sources. For example, the national greenhouse gas emission inventory considers an inventory breakdown in terms of sectors but it does not put emphasis on emission sources. In some cases in fact it considers the emission source to be the sector. Further to this, the sectors that are considered are different from that of the present study. This is primarily due to differences in inventory scope and the requirement to meet international reporting standards, as defined by the IPCC and Kyoto.

The national inventory is divided into six IPCC defined sectors based on particular emissions processes [Department of Climate Change, 2008c]:

- Energy
- Industrial Processes
- Solvent and Other Product Use
- Agriculture
- Land Use Change and Forestry
- Waste

For the purpose of national reporting, it is imperative to stay within international reporting standards, however the present study has no such requirements and as discussed previously, develops a different approach to meet its own required outcomes.

Under the IPCC scheme, the energy sector includes both energy (electricity) industry as well as transport. Further to this, the energy industry and transport consistently rate as being among the highest of contributors to the summed total of greenhouse gas emissions within Australia, respectively contributing 40.8% and 15.1% to total national GHG emissions in 2006 [United Nations Framework Convention on Climate Change, 2007]. Given such a high contribution at the national level, they have been selected as primary, common emission sources for the present study.

The 'Industrial Processes' and 'Solvent and Other Product Use' sectors, as defined by the IPCC, have minimal relevance to the Brighton Council area and are therefore not considered as separate emission sources. Their effect is recognised as part of the 'fuel usage' primary, common emission source. Note however that as there is an industrial zoning within the Brighton municipal planning scheme, this has been considered within the present study as a community sector.

The agricultural sector is defined as a unique sector within the IPCC and is also defined as a community sector within the context of the present study.

Given the scope of the emission inventory in the present study, there is little use in considering land use change and forestry as an emission source. There is very little forestry activity within the scoped geographical area and Council's zoning ensures that land use change is limited, particularly within the scoped time period. This sector, as defined by the IPCC, is neglected within the context of the present study.

Waste is considered by the present study to be a primary and common emission source since it is significant (4.4%) in its contribution to total national greenhouse gas emissions [United Nations Framework Convention on Climate Change, 2007]. Further to this, it is common in that it is cross sectoral with contributions being made by all community sectors. Moreover, waste management is a core function of Council and as such, the potential for council to influence associated emissions is high.

## 4.7 Summary

Following the approach outlined above an ordered 'priority' list is obtained providing a list from greatest to least magnitudes of emission flux for each of the community sector to primary, common emission source combination.

Given that the primary objective of this inventory is to provide direction for emission reduction strategy decisions, an understanding of the amount to which each community sector and emission source contributes is particularly valuable.

# Chapter 5

# Community Inventory - Applied Methodology

This chapter presents a detailed description of the inventory methodology that is selected for application within the present study. Discussed here is the actual quantitative method as well as discussion on the practicalities that are associated with its application.

As defined in section 4.1, the objective of this methodology is to derive an approximation for greenhouse gas emissions, broken down into primary, common emission sources as well as community sectors. Also discussed previously is the perspective from which this methodology is to be approached. Accordingly, consideration is given here to the top-down approach.

Further to this, the present chapter attempts to add value to the methodology, as adopted by the study. That is, where possible, a comparative discussion is made on the options available for such an inventory within the context, thus providing justification and validity to the methodology employed.

## 5.1 Conversion to Carbon Dioxide Equivalent

Greenhouse gases are numerous and varied within our atmosphere, each possessing a different amount of global warming potential. In order to quantify emission flux it is necessary to derive a quantity for which each type of greenhouse gas can be made comparable. Carbon dioxide equivalent ($CO_2e$) is the conventional quantity used to achieve this. $CO_2e$ is the equivalent amount of $CO_2$ that would cause the same amount of global warming potential for a given amount of greenhouse gas, when measured over a specified timescale (generally, 100 years). Carbon dioxide equivalent ($CO_2e$) is calculated by multiplying the global warming potential of a gas in terms of $CO_2$, by the mass of the gas. The present study adopts carbon dioxide equivalence to define the greenhouse gas emission inventory and thus structure an assessment of the current state of emission flux within the municipality of Brighton.

The following is a list of the six major greenhouse gas species and their global warming potentials (GWP) in terms of $CO_2$:

- Carbon dioxide ($CO_2$)
- Methane ($CH_4$) - GWP is 21 times that of $CO_2$
- Nitrous oxide ($N_2O$) - GWP is about 310 times that of $CO_2$
- Hydrofluorocarbons ($HFCs$) - GWP is 100 to 3800 times that of $CO_2$
- Perfluorocarbons ($PFCs$) - GWP is 5000 to 10000 times that of $CO_2$
- Sulphur hexafluoride ($SF_6$) - GWP is 23900 times that of $CO_2$

Under the United Nations Framework Convention for Climate Change (UNFCCC) and its Kyoto Protocol, all parties including Australia are required to estimate fluxes for each of these six key greenhouse gases [UNFCCC, 2008]. Furthermore, emissions must be classified according to the six sectors identified by the IPCC, as discussed in section 4.6. This greenhouse gas inventory and reporting approach is in accordance with the Common Reporting Format (CRF) that is adopted by the federal government under these international agreements. The present study adopts an alternative approach that is considered here to be more appropriate for informing decision-making of mitigation measures on the local level, where by sectors and common emission sources are accounted for separately and then ordered by severity.

Each of the primary emission sources defined in the previous chapter produce significant amounts of greenhouse gas which must be converted to carbon dioxide equivalence. There are two methods of achieving this. That is, to apply the global warming potential factor to a given mass of the gas, as described above. Or alternatively, to apply a conversion factor to a given quantified activity or process.

In terms of the present study, for most cases it is much easier to quantify the activity or process causing the emission and apply accepted conversion factors to derive carbon dioxide equivalence. This is therefore the approach adopted.

Such conversion factors are in many cases dynamic, dependent on environmental and social conditions, varying in time for different locations. They are also open to a developing scientific knowledge base that leads to regular updates to standard factor derivation methods. The Australian authority on conversion factors is the Australian Government and its Department of Climate Change [Department of Climate Change, 2008a]. Much of what is accepted by them is directly obtained from the international authority, the International Panel for Climate Change [IPCC, 1988]. The present study therefore implements conversion factors as specified by Department of Climate Change [2008a], for the year as defined in the inventory scope.

The proceeding subsections show conversion methodology, as adopted by the present study.

### 5.1.1 Electricity usage

The following conversion factor is defined for Tasmania, for the financial year of 2007/2008:

$$kgCO_2e = 0.13P \tag{5.1}$$

Where: $P$ is the power used in the calendar year of 2007 ($kWh$)

[Department of Climate Change, 2008a]

### 5.1.2 Fuel usage (including both fuel usage and fuel usage due to travel)

The following procedure and conversion factors are defined for fuels:

| | $EC$ | $EF$ |
|---|---|---|
| Unleaded Petrol | 34.2 | 67.1 |
| Aviation Gasoline | 33.1 | 66.7 |
| Natural Gas | 46.5 | 60.7 |
| Diesel | 38.6 | 69.5 |
| LPG | 25.5 | 59.9 |
| Wood | 16.2 | 15.6 |

Table 5.1: Fuel Conversion Factors

Where: $EC$ is the energy content of the fuel ($GJ/tonne$)
$EF$ is the emission factor ($kgCO_2e/GJ$)

[Department of Climate Change, 2008a]

The carbon dioxide equivalent is thus:

$$kgCO_2e = EC \times EF \times M_F \tag{5.2}$$

Where: $M_F$ is the amount of fuel used in the calendar year of 2007 ($tonnes$)

### 5.1.3 Waste

For general co-mingled municipal waste, the following conversion factor is defined:

$$\text{Co-mingled volume to weight ratio} = 0.12 \tag{5.3}$$

$$kgCO_2e = 1.11M_W \tag{5.4}$$

Where: $M_W$ is the amount of waste ($kg$)

[Department of Climate Change, 2008a]

## 5.2 Working Population Profile

Prior to discussing the primary, common emission sources individually in detail, it is necessary to discuss a concept that is applied on numerous occasions for the disassembling of large data sets into smaller subsets. That is, the working population method.

In developing inventory methodology with top-down perspective a difficulty arises where broad scoped data that is already broken down into sectors must be disassembled into a smaller subset of data. Here the issue is primarily in disassembling state wide data into the smaller subset, representative of the Brighton municipality. This is particularly difficult since there is very little information available as to the breakdown of sectors on the municipal level. The Cities for

Climate Protection have developed a methodology that is based on a number of assumptions in order to overcome this complication. Namely, the working population profile method. The present section discusses implementation of this methodology.

Using Australian Bureau of Statistics census data, the number of people employed in each industry within the municipality is divided through by the number of people employed in each respective industry within Tasmania. Multiplying factors are thus derived that may be applied to various data sets in order to approximate the contribution to that data set made by the municipality.

The Australian Bureau of Statistics census employment data is presented in terms of ANZSIC which is the standard classification used in Australia and New Zealand for the collection, compilation and publication of statistics by industry [Australian Bureau of Statistics, 1993]. This classification scheme however differs from the sectors adopted by the present study. In application of the methodology within this study, it is thus necessary to restructure the scheme in terms of the sectors used here. That is, since there is a large number of ANZSIC sectors in comparison to the number of sectors employed in this study, ANZSIC sectors are simply allocated or distributed amongst the sectors adopted by the present study, refer to appendix A. Note here, as discussed previously, the agricultural sector is considered as an independent sector. Under the ANZSIC scheme it is already defined separately thus aiding this approach. This differs from the CCP approach in which all emissions associated with the agricultural sector are considered under the industrial sector.

It is recognised here that there is a significant assumption being made within this methodology and that is that the distribution of employed persons within an industry is representative of the distribution of other parameters such as fuel usage or electricity usage within the respective industry. Clearly, such an assumption would prove problematic where organisations within a given sector employ large amounts of clerical personnel within one municipality, but then conduct activities that produce an emission flux within a different municipality. In this case the emission flux would be attributed to the wrong municipality. Such an assumption is in many cases unavoidable and thus it must be accepted. Considering the inventory from a bottom-up perspective would likely identify such local issues.

## 5.3 Fuel Usage

Fuel usage, as a primary, common emission source, is less easily defined than the other primary, common emission sources, discussed in detail later in this chapter. This is due to the fact that it encompasses a number of fuel types, varying considerably between community sectors, depending on the nature of each sector. It has been included in the present study in an attempt to recognise those subtle emission sources that are apparent within society and that are not counted under the other primary, common emission sources, as adopted by the present study. Such emission sources may include for example emissions associated with the use of natural gas for cooking within the residential and commercial sectors.

The procedure adopted by the present study for deriving fuel usage and hence resultant emissions will now be discussed here. It is generally similar to the approach adopted by CCP within the CCP inventory reporting software with minor modifications applied in order to better suit the given application.

The approach employs the working population profile method as defined in section 5.2. Furthermore, it adopts 2006 census data as this is the closest census year preceding 2007 [Australian Bureau of Statistics, 2006].

Data provided by ABARE summarises the amount of energy consumed by each of the ANZSIC sectors for each fuel type within the state of Tasmania [Australian Bureau of Agricultural Resource Economics, 2008]. This information is then multiplied by the working population profile percentages giving the same sectoral information for the municipality of Brighton.

Conversion factors for both scope 1 and scope 2 are obtained from Department of Climate Change [2008a] from which values for kilograms of carbon equivalence are derived. The results are then summarised in terms of emissions from fuel usage per sector.

Refer to table B.1 for conversion factors. Scope 3 conversion factors have been presented in this table also to provide the reader with a complete view of the emission profile. Scope 3 emissions are however not used in this study for reasons discussed throughout part 1 of the thesis. Table B.2 for ABARE energy figures and resultant mass of $CO_2e$.

As discussed in section 4.4, there are fundamental differences to the methodology adopted within the present study for greenhouse gas emission inventory development, to that adopted by CCP. For fuel usage, CCP employs ABARE data in a similar way to the discussed above. It also distributes the resultant emission values according to the working population profile. The primary difference here however is the redistribution of this result in order to present values in terms of the community sectors that are adopted by the present study.

## 5.4 Fuel Usage due to Transport

Transportation of people and goods over both long and short distances is integral to modern society, making it fundamental to the way humans interact. Possibly the most realised greenhouse gas emission source within the community is thus that due to the fuel usage associated with transport. That is, the burning of fossil fuels, primarily through the internal combustion engine, for the purpose of powering vehicles, for a variety of transportation purposes.

Fossil fuels have in recent times been the cheapest, most reliable and most efficient power source for this element of society, thus leading to what could be considered an over use and a reliance on their existence. There is thus a large potential for reductions in emissions resulting from this societal trait, both by altering the culture surrounding transportation as well as the technology powering the industry.

The present study considers emissions associated with transportation in terms of the usage of fuel types within the inventory scope. The primary modes of transport considered are thus from road vehicles, using common fuels such as petrol, diesel and LPG.

Fuel usage due to transport is most easily quantifiable in terms of volume, for each type of fuel, over the specified period of time. Given approximate volume usages it is a simple matter of applying conversion factors to the respective fuel types in order to estimate the contribution of associated greenhouse gas to the atmosphere by the scoped geographical area. This is therefore the key strategy adopted by the present study for assessing this primary, common emission source.

Volumes for fuel usage maybe estimated by means of a number of different methodologies. The present study employs the use of two such approaches. Firstly, since the transportation sector is identified as an industry classification within ANZSIC, the methodology presented in section 5.3 is valid. This however neglects any fuel usage due to transport within the residential sector or within industry that is not specifically transport focused. It is thus likely to significantly under estimate the true values and hence another methodology is adopted as the primary methodology, with the ANZSIC methodology being employed for validation purposes only.

Data representing the transport industry is obtained directly from the Australian Bureau of Statistics [Australian Bureau of Statistics, 2007]. This data is presented in terms of a number of parameters including vehicle type, vehicle use, fuel consumption and average fuel efficiency.

The percentage of vehicle use within Tasmania, compared to that within Australia, is derived for each defined vehicle use, as defined by Australian Bureau of Statistics [2007]. This is based on total kilometres travelled within Tasmania and Australia for each vehicle use.

Tabulated data relating vehicle type to vehicle use, in terms of kilometres travelled within Australia, is then multiplied through by these percentages, thus providing an estimation of the number of kilometres travelled for each vehicle type and use. Refer to table C.1 for this data.

The fuel type to vehicle use data is then converted into percentages of the total fuel consumption for each vehicle type. As this data is obtained in terms of Australia as a whole, an assumption is made here that these percentages are the same for the case of Tasmania and then for the case of Brighton. Similarly for the fuel efficiency data, an assumption is made that this is equivalent throughout Australia for any given vehicle type. Refer to table C.2.

By multiplying the total kilometres travelled in Tasmania by the percentage of total fuel consumption and then by the average rate of fuel consumption for that fuel type for each vehicle type, values are obtained for the total fuel consumption in Tasmania, for each fuel, per vehicle use.

This is then multiplied through by the percentage of population in Brighton with respect to Tasmania. An assumption is made here that vehicle usage is equivalent throughout the state of Tasmania. Refer to table C.3.

Since this data is separated into vehicle usage, the summation of totals for each fuel type can be made for the residential sector and the business sector (including industrial, commercial and agricultural) separately. Applying the working population profile methodology to the business total provides a break down into the sectors as adopted by the present study. Refer to table C.4 for fuel usage due to transport results.

Conversion factors are then applied to obtain values for the associated mass of $CO_2e$.

There is a fundamental difference between the approach adopted here and that adopted by the CCP inventory methodology. That is, here fuel usage due to transportation is considered as a primary and common emission source and thus may be attributed to all community sectors. The CCP approach considers transportation as a sector of the community in itself and thus a total, summed value for each of the fuel types is all that is required. It is thus not possible to compare the methodologies in terms of numerical outcomes.

## 5.5 Electricity

The production of electricity as a primary, common emission source is recognised as being among the most significant contributors globally to greenhouse gas concentrations within our atmosphere. Moreover, this is primarily a result of the burning of fossil fuels in centralised electricity generation networks. As discussed in section 3.2.2, there is some debate over responsibility for these emissions. That is, should the associated emissions be attributed to the electricity generator or the end user of the electricity? For the purposes of this study, these emissions are attributed to the end user of the electricity and are thus scope 2 emissions as defined by the IPCC [1988]. This is because Council, and the Brighton community, have the largest influence over the associated emissions when considered from this perspective.

Since the state of Tasmania contains a reticulated electricity network known as Tasmania's 'electricity grid', it is possible to determine a factor for a given period of time for the state that converts electricity usage to the amount of associated scope 2 emissions, dependent on how the electricity is generated over the specified period. This is possible since the contributors of electricity to the Tasmanian electricity grid and the methods and amounts of generation over that period, are well recorded and reported by NEMMCO from which the Department of Climate Change [2008a] sources data and thus establishes an emission factor for that period.

Prior to the Basslink interconnector, commissioned in April 2006 [Basslink, n.d.], to connect Tasmania to the national electricity grid, scope 1 and 2 electricity emissions were close to negligible within Tasmania. This was due to the exceptionally large proportion of renewable energy within the network, produced primarily from hydro and wind technology. Since that point, Tasmania has had an increasing reliance on fossil fuel generated electricity, imported via Basslink to the Tasmanian electricity grid. As a result, emission factors for the state of Tasmania have also been increasing. For the scoped time period of 2007, Tasmania's combined scope 1 and scope 2 emission factor is 0.13 $kgCO_2e/kWh$. There is little option within the context of the present study but to adopt this figure for electricity conversion to carbon equivalence as further analysis into the issue would go beyond the necessary extent and objective of the study.

Since we have a mechanism for the conversion of electricity usage to associated carbon equivalence, it follows that we must derive a mechanism for establishing the electricity usage for within the scoped time period and geographical area. There are a number of methods available for achieving this.

As discussed in section 3.2.1, by definition the top-down approach to conducting an inventory requires an initial consideration for larger scale inventories or sets of data, followed by the disassembling of that data into smaller subsets such that the requirements of the inventory are met. This concept is directly applicable to electricity usage since we are able to obtain data both for Australia as a whole as well as for Tasmania. By the proportion of population living within the municipality of Brighton we can thus disassemble this data into a subset representative of Brighton and hence equate this to associated carbon dioxide equivalence.

Electricity usage and distribution data for Australia and Tasmania is available through two authorities, namely, The Australian Bureau of Agricultural and Resource Economics (ABARE) and Electricity Supply Association of Australia (ESAA). ABARE is an Australian federal government funded organisation that produces an annual publication called Australian Energy, [Syed et al., 2007], in which electricity data is presented in terms of state and industry usage. This data is obtained by ABARE via a series of surveys directed at energy users and producers. Statistical techniques are employed to extrapolate data from completed surveys in order to derive a complete data set. ESAA is the premier industry association, grouping electricity generation and gas supply companies. ESAA produces a publication called Energy Gas Australia [Energy Supply Association of Australia, 2008], the data for which is obtained directly from the electricity and gas distribution companies. Total electricity usage data from the ESAA is taken to be the most applicable for this study. Whilst the Cities for Climate Protection approach is to simply use the ABARE data, the present study takes data from ESAA and applies sectoral percentage breakdown information as provided by ABARE, thus providing a sectoral breakdown of energy usage within the state.

Figures for electricity consumption in Tasmania for the residential sector and the business sector as a whole are available from Energy Supply Association of Australia [2008]. A fraction of the residential figure is taken based on the proportion of population living in the municipality of Brighton to provide electricity consumption for the residential sector. Using electricity usage data from ABARE, the percentage contribution for each of the sectors may be defined neglecting the residential contribution. Applying these percentages to the ESAA figure for the business sector, an approximation for electricity usage is derived for each other sector. Application of the working population profile methodology generates values for the municipality of Brighton.

Below is a table presenting results from both the CCP methodology, as well as that derived by the present study:

| **Sector** | **Derived Methodology** **Tonnes $CO_2e$** | **CCP Methodology** **Tonnes $CO_2e$** | **Discrepancy** |
|---|---|---|---|
| Residential | 8377 | 8681 | 3% |
| Commercial | 1580 | 1709 | 8% |
| Agriculture | 48 | - | - |
| Industrial | 6836 | 4799 | 30% |

Table 5.2: Community Inventory - Derived & CCP

Note that agriculture is division A under the ANZSIC scheme and is considered part of the industrial sector within the CCP methodology.

As is evident in the table, minimal discrepancy is apparent between methodologies within the residential and commercial sectors. The agricultural sector has minimal influence despite being attributed to the industrial sector within the CCP methodology; refer to table D.1 for a breakdown of results under the ANZSIC scheme. There is significant discrepancy evident however for the industrial sector. This is primarily a result of the varying input source data. Refer to table D.2 for the redistribution of electricity consumption within the structure of the inventory adopted by the present study and D.3 for the calculated $CO_2e$.

Regardless of any discrepancy here, it is interesting to note that the order of magnitudes of the sectoral emission fluxes is similar. This reinforces the idea that the actual values are not the critical output of the model. There are a number of assumptions that are made and therefore the accuracy of the result is not necessarily great. We can however maintain a large degree of confidence in the relativity of sectors when compared to each other, thus meeting the objectives of the inventory.

## 5.6 Waste

Greenhouse gas emissions are generated from waste as the degradable organic materials breakdown. These organic materials constitute a major component of the waste stream and include such materials as paper, timber, food products, garden material etc. Emissions associated with waste are significant in volume and since waste management is part of Council's core business, there is a large potential for Council to make significant reductions in greenhouse gas emissions in this area. Furthermore, since all sectors of the community contribute to the waste stream, waste has been considered as a primary and common emission source as part of the present study.

As Council manages all waste within the community, actual data is available for this primary and common emission source, thus minimising any assumptions within the methodology.

There are two primary mechanisms for waste collection as managed by the Brighton Council, each of which results in final disposal of the waste at the Glenorchy landfill. Firstly, contracted kerb side collection of waste and recycling, transported directly to the Glenorchy landfill site. Secondly, a waste transfer station within the municipality of Brighton from which waste is collected and transported to the Glenorchy landfill as required.

As all waste finds itself eventually at the Glenorchy land fill site, accurate records are available to Brighton Council detailing waste tonnages for the scoped time period of the 2007 calendar year, as recorded by the Glenorchy City Council for accounting purposes. This data is presented in table E.1.

A sectoral breakdown of waste streams in Australia is obtained from the Australian Bureau of Statistics [2006]. This however does not correspond to the ANZSIC classification scheme and thus the breakdown is redistributed accordingly using the working population methodology. The assumption here is that the sectoral percentage break down of waste is equivalent on the local scale to that on the national scale.

The tonnage of waste, as recorded by Glenorchy City Council is thus accounted for on a sector basis and then sector specific emission factors are applied according to Department of Climate Change [2008a].

A capture rate of landfill gasses is assumed to be 55% based on an Australian average [Department of Environment Water Heritage & Arts, 2006a]. Figures are thus multiplied by 45% and converted to carbon dioxide equivalence.

It should be noted here that the captured gas is converted into electricity at the landfill site. This process results in an emission flux however since this electricity is fed into the reticulated electricity grid, all associated emissions are considered within the electricity emission factor for the specified year.

Refer to tables E.2 and E.3 for the waste emission calculations.

## 5.7 Summary of Results

Inventory results are presented in appendix F. They are presented in tablature format in table F.3. Also presented in table F.2 is a priority list, displayed such that results are ordered in terms of emission magnitude.

Results are then divided by the number of properties within the municipality for each of the sectors. This enables a clearer view of where the most potential for emission reductions lies. These results are presented in table F.4.

All results are displayed in graphical terms in figure F.1 and F.2.

## 5.8 Discussion of Community Inventory Results

A final priority list for climate change mitigation strategy should be a function of the degree of emission severity, as identified by the inventory, as well as the ease of implementation of emission reduction actions. The assessment discussed presently should thus be considered a preliminary look at the priority list only with further discussion provided later in this thesis.

Consider now that the initial objective of the community inventory process was to develop an ordered list of emission sources from which to base emission reduction strategy. Furthermore, inventory results must be presented in a manner that is conducive of emission reduction strategy development. The present section aims to discuss the results of the inventory process with these points in mind.

It is recognised that Council's influence may be better defined in terms of property numbers as opposed to the sector and primary, common emission source structure. As such a second set of results, defining the inventory on an individual property basis is provided. That is, the initial results have been divided through by the number of occupied properties for each respective sector. In doing this, fuel usage due to transport is still of particularly high priority within the commercial sector, however interestingly the industrial sector becomes significantly more prevalent as a result of the small numbers of occupied, industrial zoned properties.

Both sets of results indicate that the major emission source is a result of fuel usage due to travel. That is essentially the burning of petrol, diesel and minor amounts of LGP and CNG for transportation purposes on our roads. Further to this, it is evident that fuel usage due to travel within the commercial sector is the most major of emission sources. Considering the transportation industry, including the postal service and the many trucking companies, falls within this sector, such a result could be expected.

Both methods for displaying the results suggest that waste is a minor contributor within each of the sectors. This could be a result of the landfill gas capturing technology, now common place in landfill sites across Australia. That being said, it is recognised that Brighton Council is the waste manager within the Brighton Community. There is thus significant opportunity within Council's corporate emission abatement strategy to reduce community emissions through better management of waste.

Emissions as a result of electricity consumption are well dispersed for each of the sectors throughout the priority list. For the agricultural and residential sectors, emissions associated with electricity are not significant on a property by property basis. For the industrial and commercial sectors however, these emissions are of high priority and may be considered essential to an emission reduction strategy.

Interesting to note is that the summed total of emissions from the community inventory is 100 009 tonnes of carbon equivalent greenhouse gas. The present inventory disregards any consideration for non-anthropogenic greenhouse gas emission flux. That is, any emission flux that is a result of natural or non-human activity. As a result it should be noted that this summed figure neglects an amount of emission that could be considered integral to the scope of the inventory.

Inventory results are further discussed in relation to the various mitigation options in part II of this thesis.

## 5.9 National Inventory - The Alternative Top-Down Approach

An alternative and comparatively simplistic approach to greenhouse gas emission inventory model development in local government is to take national emission inventory data (or data from other larger scale emission inventories) and apply top-down methodology to determine the contribution of a specified municipality. As was discussed in section 3.2.1, such an approach has the potential to integrate error in the result. That is, when considering a large scale inventory model, factors present on the small scale will be averaged and if the large scale inventory data is broken down linearly through top-down methodology, such factors are neglected. The intention here however is to assess the applicability of all possible methodologies and thus derive the most effective approach to greenhouse gas emission reduction in local government for the case of the Brighton Council.

Australia's National Greenhouse Accounts are a comprehensive set of reports outlining Australia's greenhouse gas emissions as a nation, by state, and by industry [Department of Climate Change, 2008c]. Data is available for each census year in terms of the ANSZIC classification scheme, for each state. For the purposes of the present study it is thus possible to disassemble the data by means of the working population profile methodology as well as by direct proportion of population for the residential sector. Data can then be further broken down in terms of community sectors as adopted by the present study. Refer to appendix G for these calculations and results.

The result is not available in terms of the primary, common emission sources adopted by the inventory model developed by the present study. It is thus only useful for validation purposes within the present study. The summed total of each sector is in some respects comparable however maybe somewhat misleading in terms of the present study due to the way in which the model distributes emission sources between sectors, as will be discussed in the following section. Refer to table G.2 and figure G.1 for numerical and graphical representations of this comparison.

## 5.10 Comparative Discussion

Interestingly, the summed total of the national inventory methodology is within a couple of percent of the summed total of the top-down approach derived here, despite the considerable difference between sector totals. This indicates that emissions are potentially distributed differently between the sectors for each model.

Results for the agricultural sector are considerably less than that derived from the national inventory approach. Under the national inventory approach, the emission sources that are counted differ from those that are counted under the present study model. That is, under the national approach, the ANZSIC Agriculture, Forestry and Fishing sector adopts UNFCCC/CRF source categories that are associated with agricultural use machinery (not including road transport), as well as emissions directly associated with agriculture (enteric fermentation; manure management; soils, burning of agricultural wastes; use of pesticides etc) [Emission Inventories & Projections Task Force, 2003]. While agricultural use machinery corresponds to the fuel usage primary, common emission source, the agricultural specific emissions are not applicable to the model developed by the present study since they do not fit into any of the primary, common emission sources. Further to this, fuel usage due to transport emissions that are associated to the agricultural sector are counted under the present study model while they are not under the national model.

Division A of the ANZSIC code incorporates forestry and fishing as well as agriculture. While each of these industries are significant sources of emissions within Tasmania, neither exist within the municipality of Brighton. This is an example of where taking the linear top-down approach of breaking a larger scale emission inventory down to a smaller subset is not an effective representation of the inventory scope. The two methodologies are thus not directly comparable for the agricultural sector since they are accounting for different emission sources.

There is significant discrepancy also between models within the commercial sector. Here, both models consider emissions from each of the primary, common emission sources, the discrepancy is thus not a result of neglecting an emission source as is the case with the agricultural sector, rather, it is a result of the way in which the emission sources are defined. For the methodology adopted by the present study, the predominant emission source within the commercial sector is fuel usage due to transport making up 85% of the sector's emissions. As was discussed previously in section 5.4, there are two potential methods for considering fuel usage due to transport. Firstly, since the ANZSIC industrial classification scheme identifies transportation as a sector in itself (Division I), the energy associated with the fuel usage from that sector may be obtained from the ABARE data set and thus used to derive the resulting emissions. This is the approach employed by the national inventory methodology. It however neglects any fuel usage emissions due to transport within industries that are not specifically orientated towards transport. The model adopted by the present study avoids this issue by employing total fuel usage data obtained from the Australian Bureau of Statistics and then distributing it between the sectors as defined by the model. In taking this approach the model more comprehensively considers the combined fuel usage from all of the sectors. However, since the distribution between the sectors is achieved simplistically using the working population profile methodology, there exists a potential for error in the model that is unavoidable. Moreover, the discrepancy between models in the industrial sector may be evidence of this. That is, it is possible that some percentage of these emissions has been attributed to the industrial sector in the national inventory, but has been attributed to the commercial sector in the present study, simply due to the manner in which fuel usage is distributed in the models.

Interestingly, the CCP approach is similar to that adopted by the present study, it does not however attempt to distribute the emissions between sectors, rather it simply acknowledges the emissions within a sector of its own, the transportation sector. This is not possible here since the objective of the present study is to derive an inventory that prioritises emissions in terms of sectors as well as primary, common emission sources.

The residential sector is very close for both methodologies. This is possibly because it is a less ambiguous sector than the other sectors. The commercial, industrial and agricultural sectors are all economically based and as discussed above, it is possible that emissions are distributed differently between them.

# Chapter 6

# Corporate Inventory

As part of completing the CCP Plus milestone 'Planning and Review', Brighton Council conducted a comprehensive inventory of corporate emissions for 2007. Table 6.1 below summarises the inventory findings.

| **Sectors** | **Equiv** $CO_2$ **(Tonnes)** | **Equiv** $CO_2$ **(%)** | **Energy (GJ)** | **Cost** |
|---|---|---|---|---|
| Buildings | 43 | 6.4 | 1,150 | $51,114 |
| Vehicle Fleet | 258 | 39 | 3,796 | $122,352 |
| Employee Commute | 44 | 6.7 | 663 | $0 |
| Streetlights | 60 | 9.1 | 1,624 | $150,213 |
| Water/Sewage | 161 | 24.3 | 4,346 | $157,605 |
| Waste | 96 | 14.5 | 0 | $0 |
| **Total** | **662** | **100** | **11,579** | **481,284** |

Table 6.1: 2007 Corporate Inventory [Heyward, 2008]

The methodology adopted by the corporate inventory here is considered from the bottom-up perspective, since it is based on directly measured data. It therefore avoids many of the issues and methodology options that are evident in the top-down approach, discussed in the previous chapters with respect to the community inventory.

Here, corporate sectors are defined and associated values are provided for cost and energy. Values for all sectors are based on financial records for the 2007 calendar year except for the employee commute sector which was based on a survey of staff. Following from this, appropriate conversion factors have been applied in a similar way to the community sector inventory discussed previously in order to provide values for tonnage of $CO_2$ equivalent. A percentage break down is then given for emissions associated with each corporate sector.

Since 2007, a restructure of the management of public assets in Tasmania has led to a new authority taking responsibility for water and sewer. The following table therefore presents the results in table 6.1, neglecting emissions and costs associated with these assets.

| **Sectors** | **Equiv $CO_2$ (Tonnes)** | **Equiv $CO_2$ (%)** | **Energy (GJ)** | **Cost** |
|---|---|---|---|---|
| Buildings | 43 | 8.6 | 1,150 | 51,114 |
| Vehicle Fleet | 258 | 51.5 | 3,796 | 122,352 |
| Employee Commute | 44 | 8.8 | 663 | 0 |
| Streetlights | 60 | 12.0 | 1,624 | 150,213 |
| Waste | 96 | 19.2 | 0 | 0 |
| Total | 501 | 100 | 7,233 | 323,679 |

Table 6.2: 2007 Corporate Inventory - Neglecting Water and Sewer [Heyward, 2008]

# Part II

# Technology Options for Emission Reduction

# Chapter 7

# Overview of Options

Following from the investigation into Brighton Council's greenhouse gas emission inventory, covered in the previous chapters, it is necessary to consider the findings with respect to the various technological options available for achieving greenhouse gas emission reductions. This analysis is done from two perspectives, firstly to provide recommendations to Council on where investment in this area would be most effective. Secondly, to provide advice to the community on where they may invest money most effectively in order reduce community emissions. It may also provide advice to Council on where technology promotion would be most effective in the community.

In terms of Council's investment in its corporate emission profile, the general objective is to assess the options for reducing net emissions without affecting Council's ability to perform its function in anyway. Furthermore, this assessment is conducted primarily from a technological point of view. It is recognised that significant opportunity for achieving community emission reductions exists from the social awareness perspective as well as the Council planning perspective. This however is beyond the scope of the present study.

The reality of Council's decision making processes is that a triple bottom line approach is assumed best practice. While the outcome of this study will provide recommendations to Brighton Council's elected members for achieving greenhouse gas emission reductions, it will likely be from a triple bottom line perspective that they make their judgment. In that respect, the present assessment of greenhouse gas reducing technologies must give equal weight to the social and the economic impact, as is given to the environment. It is therefore not a simple case of identifying technologies that will enable Council to meet emission reduction targets and as such, this kind of target is not defined here. Rather, it is a case of identifying technologies that may have the potential to provide good net emission reductions as well as provide a sensible and justified investment option. Further to that, technologies with clear negative social impact are not considered.

From the community perspective, this analysis will add to the inventory information derived in the previous chapter in order to assess where people may be able to invest effectively for the purpose of reducing their emissions. In a similar way to Council's elected members, the community tends to make decisions based on a cost to benefit, triple bottom line assessment. In this respect the community will find the present study useful when considering their investment in greenhouse gas emission reductions.

This analysis has neglected technologies that are not sufficiently discussed in the literature, considering only technologies that are discussed enough to enable legitimate comparison against the other options. Detailed analysis of the more 'cutting edge' technologies is considered beyond the scope of the present study and it is assumed that their practical application would be less technically feasible and more costly since more research and development work would be required for their application.

# Chapter 8

# Fuel Usage and Transport

As discussed chapter 6, a comprehensive corporate greenhouse gas emission inventory was conducted by Brighton Council in 2007 [Heyward, 2008]. Results of the inventory (neglecting water and sewer emissions) are summarised in Table 6.2 and show that emissions associated with the corporate vehicle fleet constitute 51.5% of the total emission profile, with a further 8.8% attributed to staff commute. From the corporate perspective, the potential for quantifiable, transport associated emission savings, is only as great as the emissions that are currently generated by the vehicle fleet. That is, by employing the use of alternative technologies to directly reduce vehicle fleet emissions, there is only opportunity to reduce Council's net emissions by 51.5% or 60.3% if staff commute was included. While this is not insignificant, from an emission reduction, cost to benefit point of view this impacts on Council's justified investment limit in alternative fuel technologies. That is, by investing in alternative fuels, the most Council could reduce its emissions by is 60.3%. Council should therefore explore only the alternative fuel options that provide minimal impact on Council's vehicle fleet budget.

There are many well established alternatives to the conventional petroleum-fuel based vehicle that Council can consider for use in its vehicle fleet. Such technologies include bio-fuels such as biodiesel, biogas or bioalcohols; electric vehicles that are run on clean electricity or improved efficiency, cleaner burning fossil fuels such as compressed natural gas or liquefied petroleum gas. Many of these options however would require significant capital investment for the conversion of current fleet vehicles or the purchase of new and already converted vehicles. From the cost to benefit point of view, such an investment in technology would be very difficult to justify. Assuming fuel is still purchased, there would be little to no return on investment and it would simply be expenditure for the purpose of lessening Council's carbon footprint. Further to this, Council's turn over in fleet vehicles would impede the uptake of such technologies since there would likely be ongoing conversion and decommissioning costs. In order to rectify this issue, Council's fleet vehicle turn over policy would require reconsideration that could then potentially lead to additional depreciation costs due to the extended ownership of vehicles.

The alternative approach is therefore to consider technologies that do not require alteration to the existing vehicle fleet. Biodiesel is an example of where this is the case.

## 8.1 Biodiesel

In May 2008 Council's Environment and Heritage Committee resolved to express interest in the purchase of biodiesel for fleet vehicles [Brighton Council, 2008]. Since the production of biodiesel can be based purely on renewable resources, this would provide a mechanism to entirely remove fleet vehicle emissions. Furthermore, a local supplier demonstrated the capacity to supply high quality biodiesel that met current standards at the prevailing cost of petroleum diesel at the pump. There would therefore be no associated financial implication to its uptake. This decision led to biodiesel trials in two of Council's vehicles with the intention of validating the claim that its use would have nil impact on Council. While the trials demonstrated successful application of the technology, drivers of the vehicles reported significant power loss which impeded on their capacity to perform their duties. As a result the trials were abandoned and biodiesel as an alternative technology for reducing Council's net emissions was deemed to have impacted too greatly on Council's ability to perform its function. The investigation into biodiesel flagged to Council that the quality of fuel used in its vehicle fleet directly impacts on the organisation's ability to perform its function.

From Council's point of view, the uptake of an alternative fuel would need to demonstrate minimal financial impact and therefore minimal alteration to vehicles, as well as minimal reduction in efficiency, ruling out all other potential options.

## 8.2 Transport

From another perspective, 50% of vehicles purchased in Australia are for public and private fleets [Federal Chamber of Automotive Industries Pty Ltd, 2010]. On average, three years later these vehicles are sold for private use. The choice of vehicle that fleet managers make therefore impacts directly on the types of vehicles that the community use. A council policy to purchase only vehicles of high efficiency will thus ultimately contribute to an improved community transport carbon footprint. Such a policy would also provide direct cuts to Council's corporate emissions, Council's annual budget for fuel usage and new vehicles, as well as providing leadership by example to the community.

The derived methodology for the community greenhouse gas emission inventory suggests that emissions due to transport across the entire municipality are a major contributor to the area's emission profile. In fact the commercial and residential sectors rate as number one and number two respectively in the priority list presented in appendix F. There may therefore be significant opportunity within the community to make reductions in greenhouse gas emissions by changing the technology base for transport. The community may not be subjected to the financial barriers discussed above in the context of Council's vehicle fleet. Members of the community may also find that vehicle fuel usage constitutes a larger percentage of their emission profile, therefore justifying greater investment into alternative technologies in this area. Where vehicles are owned for much longer periods of time, ongoing conversion and decommissioning costs will not be a consideration, therefore increasing the viability of investment into alternative transport technology. There may also be community members that are not as dependant on vehicle performance that would therefore not be impeded by differing fuel energy density in the way that Council is. On a per property basis, the industrial sector's fuel usage that is not associated with transport rates as number two in the priority list, refer to table F.4. There is clearly significant opportunity for this sector to improve its emission profile by exploring more sustainable alternative fuels. Given the significant share of emissions that are attributed to vehicle usage in the community, it is very likely that some individuals and organisations will find investment into the area not only beneficial to their carbon footprint, but also financially.

It should also be recognised that ultimately, for the community to enjoy significant reductions in transport associated emissions, an improved public transport system is required. The Brighton Council community is considered by most to be a satellite community to the larger business districts of Glenorchy and Hobart. As a result, it is likely that significant commuter traffic occurs between the municipality and these centres. Brighton Council should encourage and support regional modeling of the transport network in order to assess the validity of this perception and to find solutions for the community to minimise vehicle mileage, improve public transport and thus reduce transport associated emissions. This process will also better inform State Government planning of highways, Council planning of local roads as well as future land use planning, thus supporting a future of more sustainable, transit oriented development.

There is also another perspective from which Council and the community should consider transport technology and that is in he context of peak oil, future fuel scarcity and fuel price rises. As an example, if Council was to convert its fleet to an alternative fuel it would in effect be hedging against future increases in petroleum based fuel costs. It would also be building its resilience to climate change. It would however potentially become reliant on that fuel source and thus dependant on the production of the fuel. These issues are beyond the scope of the present study and are simply mentioned here for completeness.

# Chapter 9

# Electricity

As is evident from the inventory data discussed in the previous chapters, electricity accounts for a significant percentage of both the corporate and community emission profile. From the corporate perspective, table 6.1 shows that emissions attributed to streetlights constitute 12% and emissions attributed to buildings, 8.6%. As these sectors represent all of Council's emissions from electricity we can say that Council's electricity emissions constitute 20.6% of the entire emission profile. From the community perspective, electricity is clearly the second most substantial contributor to the area's emission profile after fuel usage due to travel for all sectors except for the industrial sector which derives its largest proportion of emissions from fuel usage in its processes.

There are a range of options that Council and the community should consider for reducing emissions associated with electricity. Broadly speaking, these options include reductions in electricity consumption by improved efficiency, generation of renewable energy and the purchase of green energy and other economic strategies.

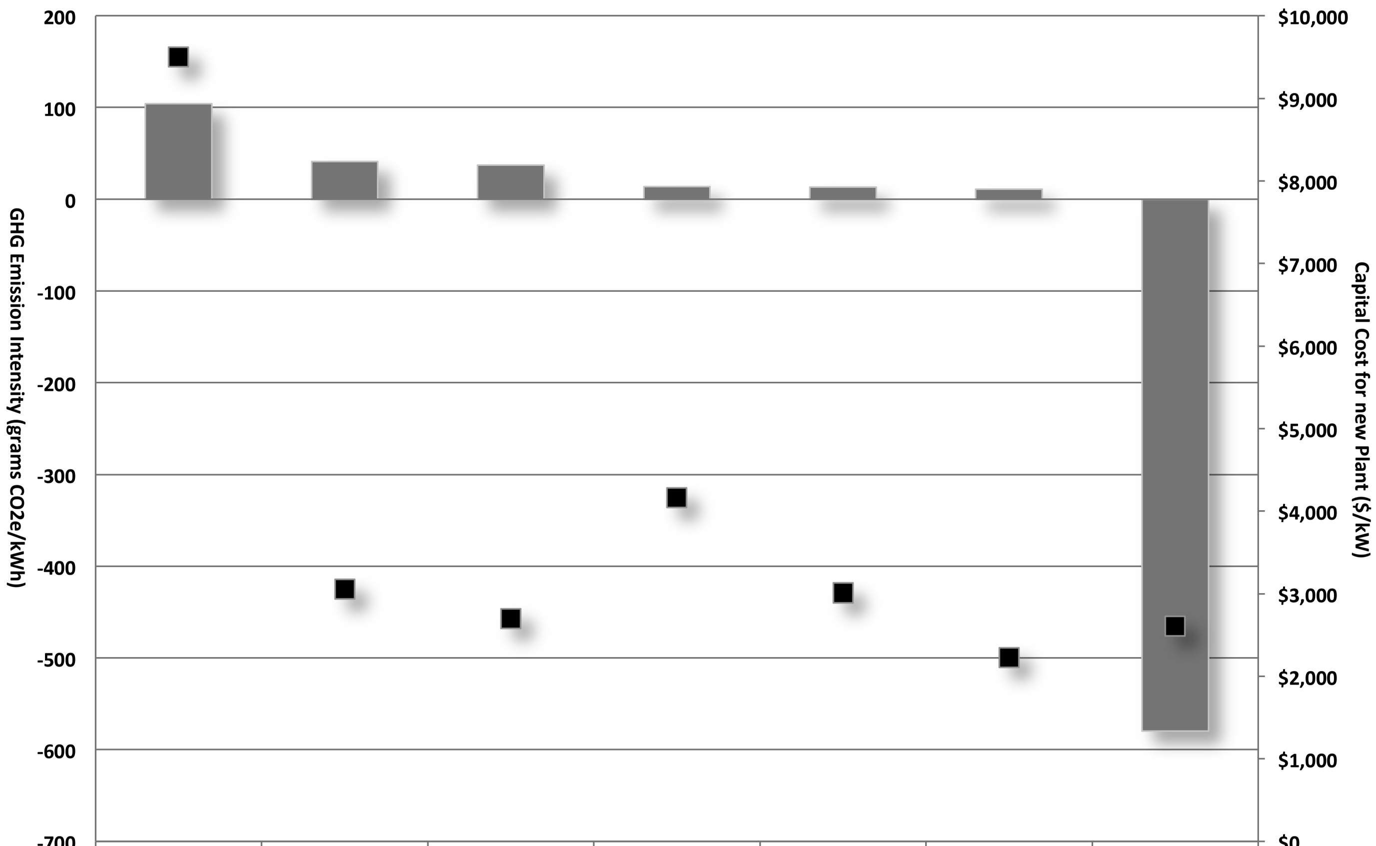
Improved efficiency is likely to be the most cost effective since it is directly reducing energy costs as well as emissions. There is also not likely to be significant implementation costs. Council is however dependant on energy for a number of its functions and it is therefore limited in its capacity to reduce emissions by simply improving efficiency.

## 9.1 Comparison of Renewable Energy Options

There are a number of technologies available to Council, and other organsiations within the municipality, that would enable the production of electricity in a renewable and sustainable manner. The economics and lifecycle emission reduction potential differing significantly between them.

Renewable energy generation is an attractive option for investment into emission reductions since in many cases it offers the opportunity to offset not only emissions associated with electricity, but the entire emission profile. By scaling a system such that it produces a greater amount than is required and then on selling the excess to the grid, Council for example could offset its entire emission profile or even a greater amount depending on what is economically justified. In this capacity it is a better option than investment into alternative fuels which is limited by its proportion within the organisation's emission profile. Further to this, electricity is not variable in its quality in the way that alternative fuels are. In that respect, provided Council's energy requirements are met there will be no impact on Council's ability to perform is function as was demonstrated to be the case for biodiesel.

Moreover, if a renewable energy facility was to fail, Council could revert back to grid power without disruption. That is, while Council could potentially reduce its dependence on grid electricity and offset a significant amount of its emissions in this way, it would not become completely reliant on the facility. Through an integrated system it could become buffered from failure in the grid as well as failure in its onsite generation. It would in this way increase its resilience to climate change.




| | PV | Geothermal | Waste wood - steam turbine | Solar thermal | Hydro power 300kW | Wind 1.5MW | Wood gasification - IC engine |
|---|---|---|---|---|---|---|---|
| grams CO2e/kWhr | 104 | 41 | 37 | 14 | 13 | 11 | -580 |
| $/kW | $9,500 | $3,050 | $2,698 | $4,163 | $3,010 | $2,228 | $2,609 |

Figure 9.1: Comparison of Renewable Energy Technologies. Data from Access Economics Pty Ltd [2009] & Pehnt [2006]

Figure 9.1 compares a number of conventional renewable energy options both in terms of lifecycle emissions, as well as economics. While the technologies presented are utility scale and potentially larger than would be appropriate for Brighton Council or other organisations within the municipality, their comparison is indicative of smaller scale systems. That is, while the values for grams $CO_2e/kWhr$ and $\$/kW$ installed capacity are likely to be inaccurate for the small scale scenario, it is assumed that they are proportionally accurate in relation to each other.

Data for the capital cost for a new plant is based on a review undertaken by Access Economics Pty Ltd [2009], summarising international literature for the capital costs associated with building new entrant power plants. Considering the economies of scale, utilities can in general establish facilities at a lower cost per kilowatt hour installed than small scale installations such as that which may be recommended to the Brighton Council. In this respect it may be appropriate for organsiations within the municipality, including Brighton Council, to assess the economies of agglomeration and consider collaboration on renewable energy projects. Comparatively however this graph shows that wind, hydro and biomass energy are significantly cheaper than either solar technology.

Considering Pehn'ts assessment of the lifecycle impact on climate change [Pehnt, 2006], figure 9.1 shows technologies ordered from most significant to least and then negative impact, meaning that over the life of a system, more greenhouse gas is removed from the atmosphere than is produced by the system. As is evident in the graph, Pehnt's assessment demonstrates that solar, geothermal and direct combustion biomass energy perform least effectively, with wind and hydro performing marginally better and then gasification of wood waste performing significantly better again. Pehn'ts report details the impact assessment, showing that wood waste gasification's exceptional performance is due to the offsetting of methane and nitrous oxide that would otherwise have been generated from the anaerobic degradation of waste wood in landfill.

Expressed in another way, table 9.1 presents data from Access Economics Pty Ltd [2009] and Pehnt [2006], normalised and multiplied together to provide a ranking tool for decision making purposes.

| | Relative GHG Emission Intensity (normalised) | Relative Capital Cost for New Plant (normalised) | (Emission Intensity) x (Capital Cost) |
|---|---|---|---|
| Wood gasification - IC engine | 0 | 0.27 | 0 |
| Wind 1.5MW | 0.86 | 0.23 | 0.2 |
| Waste wood - steam turbine | 0.9 | 0.28 | 0.26 |
| Hydro power 300kW | 0.87 | 0.32 | 0.27 |
| Geothermal | 0.91 | 0.32 | 0.29 |
| Solar thermal | 0.87 | 0.44 | 0.38 |
| PV | 1 | 1 | 1 |

Table 9.1: Ranking of Renewable Energy Options. Based on data from Access Economics Pty Ltd [2009] & Pehnt [2006]

This method provides a mechanism for comparison of these available renewable energy options, where the lower the number in the right hand column, the better the option is. Clearly, wood gasification is the best option when compared in this way, while solar PV, at the other end of the scale, is the most costly and emission intensive and thus is the least preferable.

A further consideration in the assessment of renewable energy generation is the capacity to hedge against increasing energy costs and grid outages. This could be of considerable benefit to Council and other organisations under a future climate change scenario.

## 9.2 Capacity Factor and Options for Electricity Revenue

The capacity factor for an electricity generation facility is a measure of its ability to produce electricity relative to its power rating. It is calculated by dividing the actual annual energy output by the annual energy output if it was running constantly at its rated power output [Freris and Infield, 2008]. Table 9.2 presents a desktop analysis of different energy sources for the Brighton locality.

| **SOLAR** | | | |
|---|---|---|---|
| Name plate rating of PV | 1 | kW | |
| hours per year | 8760 | hours | |
| Yearly energy output for Brighton locality | 1600 | kWh | (App. H) |
| Yearly energy output of continuous operation at rating | 8760 | kWh | |
| **Capacity Factor** | **18.26** | **%** | |
| **WIND** | | | |
| Name plate rating of turbine | 1.2 | kW | |
| hours per year | 8760 | hours | |
| Yearly energy output for Brighton locality | 3,352 | kWh | (App. I) |
| Yearly energy output of continuous operation at rating | 10512 | kWh | |
| **Capacity Factor** | **31.89** | **%** | |
| **BIOMASS GASIFICATION** | | | |
| **Capacity Factor** | **80** | **%** | |

Table 9.2: Available Renewable Energy Resources

The capacity factor for biomass gasification ranges between 70% and 90% in the literature and thus an average estimate of 80% has been provided in table 9.2.

The capacity factor characterises a renewable energy project's performance in a certain location. When considered in conjunction with the economics of a system, the capacity factor can be used to assess the appropriateness of the technology against other technologies and against other potential sites. Based on the energy resource available within the Brighton municipality for these technologies, it is evident that small scale solar and wind systems perform poorly in comparison to biomass gasification.

At the time of writing there was no feed in tariff incentive for renewable energy projects in Tasmania. While this could potentially change under new legislation in the future, the viability of a project should be assessed based on its present known economics. The following options exist for revenue generated directly from electricity:

- Sale of electricity directly into the market and accept the spot price as set by the energy regulator (peak load strategy)
- Sale of electricity at the wholesale price to the energy retailers (base load strategy)
- Offset the tariff at a site where there is an electricity demand

The options that are available and the option that presents the best return on investment depend on the nature of the installation. For example, if a biomass gasification facility can stock pile its feedstock it has the capacity of monitoring the spot price of electricity and exporting power to the grid only during peak times when electricity prices are above a set threshold. For a wind energy facility, where the operator does not have the option of producing power during peak times only, a base load revenue strategy may be the most effective. Alternatively, if there is a good wind resource at a location of high electricity demand, the facility could be used to lessen the amount of electricity that is purchased at tariff.

Council is an unusual electricity user in that its power usage is distributed. That is, it has a number of facilities that are not metered together and are physically distributed across the municipality. As a result, for a renewable energy system to offset Council's energy usage (and therefore its emissions attributed to electricity) it would require integration with the grid. Council's distributed power usage could also effect the revenue potential of a project as it would only be able to offset the tariff price for one site, the site at which it is located, with all excess power sold back onto the grid at either the energy regulator's spot price for electricity, or the wholesale price at which the energy retailers purchase their electricity.

Council's largest electricity demand is at its Council Chambers. This site would not be appropriate for biomass gasification due to the transportation and stockpiling requirements of the feedstock. It is therefore suggested that the capacity factor specific to that site be determined for solar and wind energy in order to assess the economics of these options.

As discussed above, biomass gasification has a 80% capacity factor, it can therefore take advantage of the peak load price of electricity. Location for this technology option from this perspective is thus less critical and can be selected around logistical issues of operation as well as the source of feedstock.

## 9.3 Green Energy and Other Economic Solutions

In purchasing electricity from the electricity retailers, organisations have the option of paying a higher tariff for electricity that has an emission factor of zero. This option is commonly known as the purchase of 'green energy' and has the capacity to remove all electricity associate emissions. Using an independent green energy monitoring organisation as a guide to assess the cost of this option, at the time of writing an additional 5 cents per kWhr would be added to the current tariff for the Brighton locality for 100% accredited green power [Green Electricity Watch, 2010].

This option provides a very simple way for Council to reduce its corporate emissions by 28% however it comes at a significant cost with no return on investment. Table 9.3 summarises the assessment of this option.

In a similar way to the purchase of green energy, Council could opt to purchase renewable energy certificates and simply take them out of the market. Renewable energy certificates are a government system to encourage the uptake of renewable energy in Australia. Each REC has an associated amount of $CO_2e$ and by voluntarily purchasing them, that amount is directly prevented from entering the atmosphere. It can therefore be accredited to an organisation for the purpose

| **Green Energy** | | |
|---|---|---|
| Streetlights | 1,518,056 | kWh |
| Buildings | 316,389 | kWh |
| Total energy | 1,834,444 | kWh |
| Total $CO_2e$ | 244 | tonnes |
| **Percentage of total emissions** | **28.37** | **%** |
| **Total cost of green energy*** | **$91,722.22** | **per year** |

*Additional cost for green energy above current electricity costs

Table 9.3: Green Energy Option

of reducing their carbon footprint. Table 9.4 summarises the assessment of this option.

| **Renewable Energy Certificates** | | |
|---|---|---|
| Energy equivalence of one REC | 1,000 | kWh |
| Esimated cost of one REC | $43 | |
| Conversion factor | 0.13 | $kgCO_2e/kWhr$ |
| $CO_2e$ saved per REC | 0.13 | tonne |
| **Cost to offset electricity usage*** | **$80,707.69** | **per year** |
| **Cost to offset total emissions**** | **$284,461.54** | **per year** |

*The total additional cost to Council to offset emissions associated with electricity

**The total additional cost to Council to offset all of Council's emissions

Table 9.4: Renewable Energy Certificates Option

Again this option provides a very simple economic mechanism for Council to reduce its corporate emissions. This analysis demonstrates that purchase of renewable energy certificates is a more cost effective way for reducing emissions. It also provides opportunity to negate all of Councils emission profile and not just emissions associated with electricity. However, since it will still create a significant economic burden to Council with no return on investment it is not considered here to be a feasible option.

# Chapter 10

# Waste

The waste component of the community inventory is comparatively less than the other primary, common emission sources for all sectors except for general fuel usage in the residential sector. From the community perspective it is therefore less critical than the other emission sources. In Brighton Council's corporate inventory, waste represents 96 tonnes of $CO_2e$ per year and is 14.5% of the entire emission profile. While this is significantly less than is attributed to fuel usage for transport, it is a comparable percentage to that attributed to electricity when streetlights and buildings are combined.

Interestingly, it is only the waste that is generated by Council in its processes that is referred to in the above statements. Council is in fact the waste manager and authority within the municipality. It therefore has control of the emission source and has the opportunity to invest in emission minimising, waste management technologies for the community. Council is thus in a unique position since it can use community generated waste as a resource for reducing emissions, where the emission reduction is owned by Council. These reductions can therefore be attributed to Council's net emission profile.

The conventional approach to waste management in Tasmania, including for the Brighton municipality, is landfill. The primary source of greenhouse gas resulting from conventional landfill practices is due to the anaerobic break down of organic materials contained within the waste stream. The strategy for reducing landfill associated emissions should therefore either be to lessen the amount of organic waste that is deposited in landfill or alternatively to capture the landfill gas, preventing it from entering the atmosphere.

Landfill gas capture is a maturing technology that provides significant revenue and emission reductions for landfill sites throughout Australia. At the time of writing, all waste generated in the Brighton municipality is transported to the Glenorchy landfill site and thus this option is not directly available to Brighton Council, it is therefore not discussed in detail here.

If organic material is prevented from degrading aerobically in landfill then the generation of landfill gas is prevented. Methane is the principle component of landfill gas and is 21 times more harmful than carbon dioxide in terms of its global warming potential [Department of Climate Change, 2008a]. One strategy would therefore be to simply incinerate the material and avoid the production of landfill gas by generating carbon dioxide prior to any anaerobic degradation. While this approach would have a comparably good environmental outcome, a highly stringent quarantining process would be required to ensure only organic material entered the incinerator. Incineration of the inorganic waste component would lead to an unpredictable emission profile that could potentially create a significantly worse global warming effect than it would have under normal landfill conditions. Furthermore, this process would not result in any economic returns and would waste a significant heat resource that could in fact be utilized for the purpose of revenue generation.

Other approaches to reducing organic material in landfill include a range of recycling options such as mulching; composting; biochar for soil amendment or waste to energy initiatives. These strategies provide value added products that would likely provide a significantly better economic outcome than simple incineration.

Given Brighton Council's management of the waste transfer station, Council has the capacity to separate out green waste in order to process it for value added products. Such an initiative would lead to direct cost avoidances including transport and landfill gate fees. There could also be a new revenue stream created dependant on the sale of products. The establishment of such an initiative would however likely require additional infrastructure and operational costs and thus from an economic perspective a business case is necessary to assess the viability of each option. From an emission reduction point of view, landfill emissions are avoided but there may be other associated emissions that should be considered.

## 10.1 Mulching and Composting

Mulching and composting are common waste management strategies in many municipalities across Australia. They provide a mechanism to reduce waste to landfill volumes and thus extend landfill life, they also provide an additional revenue stream for the waste manager through their sale.

Depending on the turnover rate, composted green waste is produced through a combination of anaerobic and oxygen rich decomposition. In terms of its lifecycle emissions it is thus similar or slightly better than landfill. Additional infrastructure can provide efficient gas collection, and therefore provide an additional value added product. Mulch however is still predominantly non-degraded plant matter and will degrade in an oxygen rich environment once it is applied. It is considered slightly better than carbon neutral, emitting less $CO_2$ into the atmosphere than was sequestered during the plant's growth with the remaining carbon sequestered into the soil [Jarecki and Lal, 2006].

The use of either compost or mulch act to improve efficiency of the land in terms of its plant growth potential and thus offset the use of other emission intensive soil conditioners and fertilisers.

Accurate lifecycle emission modeling specifically for green waste was not available in the literature at the time of writing. It is therefore not fully assessed here.

## 10.2 Biochar

Biochar is a carbon dense product that can be generated from green waste or other biomass for the purpose of sequestering carbon and improving soil quality. The process for conversion of biomass to biochar is pyrolysis and the quality and characteristics of the biochar depend on the composition of feedstock and the conditions under which pyrolysis occurs. At the time of writing there was no established market for biochar in Tasmania from which a revenue stream may be generated and there was little in the literature that characterised biochar quality in terms of its effect on Tasmanian soils. Despite these short comings the concept was gaining community interest and research in the area was becoming more established. Roberts et al. [2010] discuss the life cycle economics of biochar as well as its life cycle potential to contribute to climate change mitigation, their findings are as follows:

| | | | |
|---|---|---|---|
| Sequestration potential | = | 885 | kg$CO_2e$ per tonne dry green waste |
| High Net Revenue Scenario | = | $69 | per tonne dry green waste |
| Low Net Revenue Scenario | = | $16 | per tonne dry green waste |

With respect to the sequestration potential of green waste generated biochar, Roberts et al. [2010] consider the following factors:

- Avoided landfill emissions.
- Reduced soil N2O emissions.
- Avoided fossil fuel generation and combustion (This factor assumes an amount of fossil fuel that does not need to be produced since energy is produced through pyrolysis, as well as avoided fossil fuel combustion or fossil fuel that does not need to be combusted for heat).
- Stabilised (sequestered) Carbon.

- Other (an aggregation of minor contributors such as biochar transport; chipping; plant construction etc.)

Roberts et al. [2010] consider two scenarios based on two values for sequestered carbon, $80USD and $20USD per tonne $CO_2e$ offset. Their assessment considered the following factors:

- Biomass collection
- Pyrolysis
- Biochar application
- Tipping fee
- Carbon value
- Biomass and biochar transport costs
- Lost compost revenue
- Biochar improved fertilizer use
- Syngas heat

Roberts et al. [2010] consider a range of waste biomass feedstock sources including yard waste which is of relevance to the present study. The key assumption adopted by Roberts et al. [2010], supporting the applicability to the present study, is that yard waste is diverted from an industrial-scale composting facility, and no environmental burdens are assigned to its production. The study demonstrates that biochar has significant potential to provide both good net emission reductions as well as revenue when applied to such a waste stream. Brighton Council has the opportunity to adopt biochar as a mechanism to negate its corporate emissions. Based on the Roberts et al. [2010] study, 566.1 tonnes of dry green waste would be required for the production of biochar to offset all of Council's emissions. Considering that green waste is accepted at the transfer station with a high moisture content, this may equate to 1132.2 tonnes of green waste (assuming a 50% moisture content). It must be recognised that for such an initiative to be economically justified it would have to work to a strategy for the creation and growth of a biochar market in Tasmania. This would be a long term investment that would require ongoing effort with little returns until such a market is established. Once the market is established, the Roberts et al. [2010] economic assessment suggests that revenue of between $10,782.89AUD and $46,501.21AUD (Assuming $1USD = $0.84AUD) could be generated by producing sufficient biochar to offset all of Councils emissions.

## 10.3 Gasification - Electricity Generation

As is evident in the studies discussed in section 9.1, there is real potential to achieve greenhouse gas emission reductions as well as generate revenue and achieve a reasonable rate of return, through green waste gasification. By adopting such a technology, Council has the opportunity to reduce net emissions not only by avoiding landfill emissions, but also by reducing its electricity usage and associated emissions. There is also potential for Council to produce a revenue stream from electricity which could act to further increase the viability of a project. A detailed study is required in order to assess the specific feasibility of green waste gasification and electricity production for the Brighton Council scenario.

Further to the direct benefits of a green waste to electricity plant, there may be opportunity to design the process or structure a project such that additional efficiency improvements and cost savings are realised. For example, there is potential for collaboration with any industry that requires heat for its processes. Heat is a byproduct of the gasification process and the associated energy will be predominantly lost if it is not directed towards a use in some way. This is called a cogeneration or combined heat and power system, designed to greatly improve overall thermodynamic efficiency and thus cost.

There may also be an opportunity to provide renewable natural gas distributed via the existing gas reticulation network. This would avoid major efficiency losses due to conversion from gas to electricity.

Furthermore, as discussed in section 9.2, there is opportunity to stockpile green waste and generate only during times of peak electricity costs, thus gearing the system's economics for a peak electricity load.

A more detailed, comprehensive study is necessary to properly assess the effects of these options with respect to Brighton Council.

# Chapter 11

# Technology Options - Conclusions and Recommendations

As discussed throughout part II of the present thesis, there are a range of technologies that provide the opportunity for both Brighton Council and the community to reduce greenhouse gas emissions. These technology options come at varying costs and levels of effectiveness and it has been the purpose of the present chapters to discuss and compare the options relative to Brighton Council and the Brighton Council community.

In terms of Council's corporate options, the objective has been to identify opportunities that do not impact on Council's capacity to perform its function. Furthermore, in considering Council triple bottom line decision making, the objective has been to assess both the net greenhouse gas emission reduction potential, as well as the economics of the initiative.

Similarly for the community, technologies that demonstrate both positive environmental outcomes and reasonable economic returns have been focused on, acknowledging the differences and similarities between Council as a corporate organisation and other organisations and community members within the Brighton municipality.

The corporate inventory demonstrates that the fuel usage component of Council's emission profile is 51.5% (or 60.3% if staff commute is included). Major investment such as the uptake of alternatives could therefore at best achieve a 51.5% (or 60.3%) emission reduction of the corporate wide emission profile. Other investment options have been identified that provide the opportunity to reduce emissions for a wider percentage of Council's corporate profile, with less risk, for example through better management of green-waste. Investment in alternative fuels is therefore not justified. It is noted however that opportunity for efficiency improvements exists to reduce fuel associated emissions, such as a fuel efficient vehicle policy. Such initiatives should be included in Council's corporate abatement strategy.

The community is not subject to the same financial barriers and transport usage requirements as Council. It is identified that fuel usage due to transport is the most significant contributor to emissions in the community. Organisations outside of Council may therefore find opportunity to make financially justified reductions in greenhouse gas emissions by changing the technology base for transport.

From an electricity perspective, it is identified that improved efficiency is likely to be the most cost effective option for reducing emissions since this approach is directly reducing energy costs at the same time. Organisations should explore options to improve their usage of electricity as a first step to reducing electricity associated greenhouse gas emissions. In the context of the present study, the primary objective is to identify and explore a major engineering solution for Brighton Council and thus detailed discussion of energy efficiency improvements is not provided. It is also noted that Brighton Council's involvement with CCP has already led to many minor efficiency improvements in Council buildings.

While electricity usage contributes only 20.6% to Council's emission profile, it is noted that in generating renewable energy, Council and other community members have the opportunity to not only offset their usage, but to sell excess electricity to the grid for greater economic and environmental returns. A range of renewable energy technologies have been compared. It is identified that for organisations with an organic waste stream, waste to energy technologies provide the greatest potential for achieving greenhouse gas emission reductions. Furthermore, such technologies demonstrate good economics when compared to small scale wind and solar, particularly when considering capacity factor for the Brighton locality. Organisations, including Brighton Council, should assess the uptake of organic waste to energy both individually and in terms of the economies of agglomeration. For organisations and other community members that do not have an organic waste stream, it is suggested that the capacity factor of both wind and solar be assessed at the point at which their largest energy usage is, in order to quantify the economics of offsetting their electricity tariff costs.

From a waste perspective it is identified that Brighton Council is in the unique position of managing the bulk waste stream throughout the municipality. The green waste component should be considered a resource from which both electricity and biochar can be derived. It is demonstrated that these value added products have the potential to offset Council's entire emission profile or more and produce substantial revenue for Council.

Based on this assessment, the most justified investment in technology, for Brighton Council to reduce its greenhouse gas emissions, is through green waste gasification and as such, a more detailed technical analysis specific to the Brighton Council green waste stream is justified. It is also identified that biochar maybe produced through a similar process. Council may therefore consider the establishment of a facility that has the capacity to produce either electricity or biochar. A system could be integrated that monitors the spot price of electricity and that of biochar and automates the process for maximum revenue.

Specific recommendations to Brighton Council are as follows:

- Establish a council policy to purchase only vehicles of high efficiency and low emissions.
- Encourage and support regional modeling of the transport network in order to improve public transport and minimise community vehicle mileage.
- Assess the capacity factor for wind and solar at the Brighton Council Chambers and other points of significant electricity usage.
- Assess the business case for a combined green waste to energy and biochar facility.

The proceeding part to this thesis analyses Brighton Council's green waste stream and presents a preliminary analysis of a gasification system, geared to offset Council's entire emission profile. The analysis should be considered preliminary and suitable for assessment of the business case. It is a precursor to a more detailed design that would be required for the development of a facility.

# Part III

# Waste to Energy - Green Waste Gasification

# Chapter 12

# Waste to Energy System Design Overview

While there is plenty of information available on conversion of biomass to electricity, at the time of writing, there is little available in credible literature that actually quantified the electricity production potential of a green waste stream. That is, information on precisely how much electricity may be produced for a given flow rate of a given biomass type and what the environmental implications were. From the literature however, it is clear that production of electricity by means of green waste processing does have the potential to produce revenue and achieve environmental goals, for example as discussed by Gevorkian [2007]. Given that management of waste is a core Council function, the concept therefore warrants some investigation in terms of the present study.

The problem that presents itself is how can we convert green waste into electricity in the most cost effective and environmentally sustainable manner? Following from this we ask a series of questions: Can sufficient revenue be produced by a system to offset the running costs and provide an acceptable capital payback period? Are the greenhouse gas emission reductions and offsets achieved by the system better than the status quo and are they sufficient enough to justify investment in the processing system? In answering these questions, we can therefore make conclusions about where the concept sits in relation to the other avenues of greenhouse gas emission reductions that have been discussed throughout this thesis and thus decide if further exploration of the concept is justified.

## 12.1 Design Methodology and Overview

For most practical scenarios, the fundamental process for conversion of biomass to electricity is combustion and thus actuation of a mechanism designed to drive a generator. In such a system it is preferable to try to minimise any form of energy loss and thus maximise the system's overall conversion efficiency. In order to achieve this, it is common in many industrial applications to refine the organic material so as to increase its combustibility and energy content. In doing this you are also able to homogenise the material in order to produce a fuel that may be stored, transported and converted easily and cheaply to electricity by means of well refined technologies such as the internal combustion engine.

The green waste stream available at Council's waste transfer station is essentially an organic, carbon based, solid material. While it is combustible in its existing state, it may be refined to produce a much more useable fuel with a significantly better combustibility. By varying the process in which it is refined, the product may become an activated-carbon solid, a tar liquid or a gas known as syngas. For the purpose of electricity production, syngas provides the most useable qualities as it is highly combustible, it is easily managed and it is easily cleaned to minimise impurities and ensure homogeneity.

The processes by which refinement can be achieved are known as pyrolysis and ultimately gasification. Fundamental to the oil and gas industry, these processes are commonly used to crack mined organic materials into simpler compounds and thus, more useable fuels. For example, pyrolysis is the fundamental process by which large hydrocarbon molecules are converted to ethylene.
Ahmed and Gupta [2009] provide definitions of the terms pyrolysis and gasification as follows:

“Pyrolysis is a thermal degradation process of organic compounds in the absence of oxygen or air to produce various gaseous component yield as well as yield of tar and char residues”

“Gasification is heating-up of solid or liquid carbonaceous material with some gasifying agent to produce gaseous fuel”

Essentially gasification can viewed as a two stage process which includes an initial pyrolysis stage in the absence of oxygen, followed by the reaction of pyrolysis products with a gasifying agent such as oxygen or steam to produce a gaseous fuel, syngas.

The present part of this thesis develops a model that assesses the application of a gasification based technology, common place in the oil and gas industry, for conversion of green waste to syngas.

Figure 12.1 provides a schematic of the modeled system.

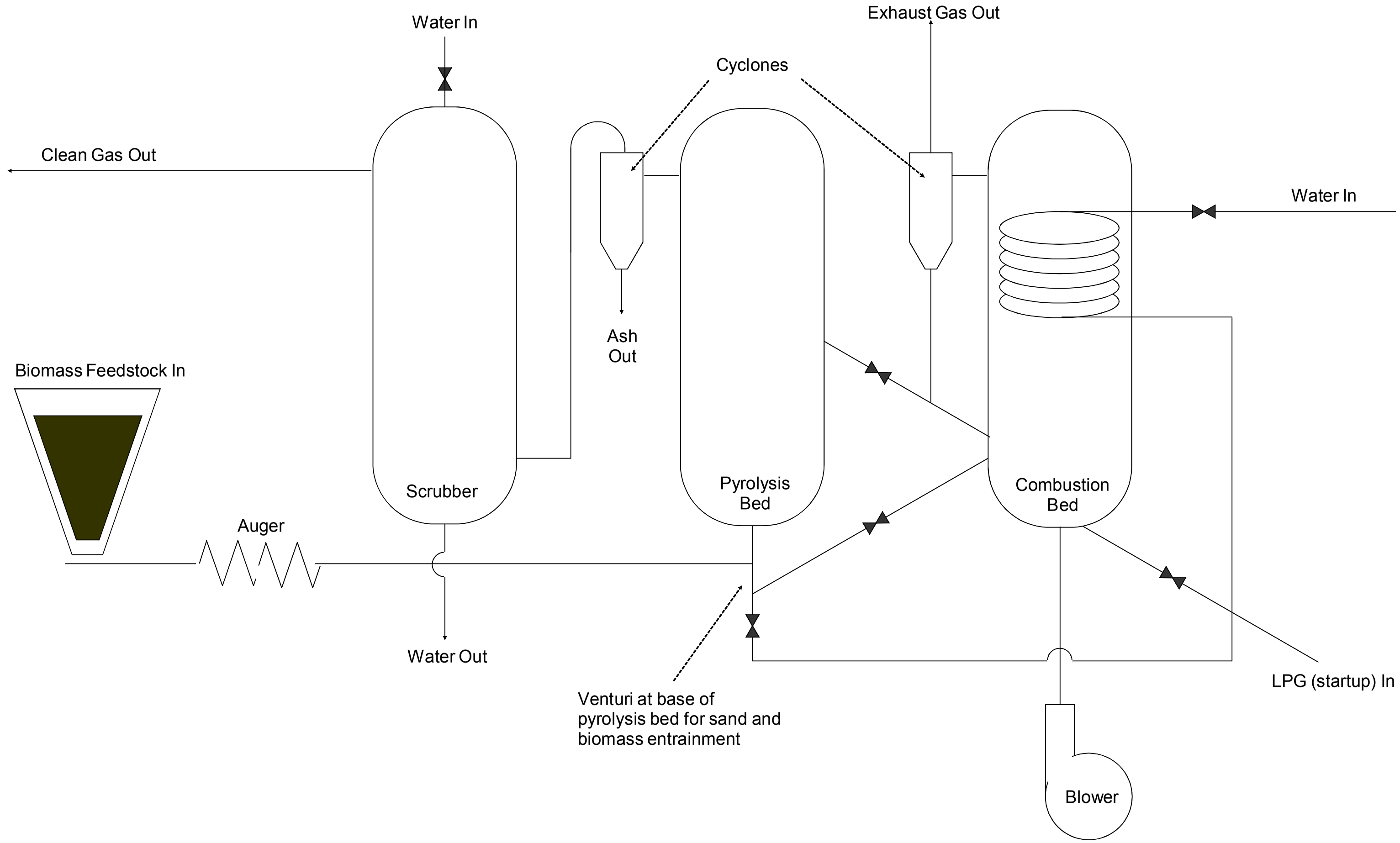



Figure 12.1: Schematic of Modeled Green Waste to Energy System

The process employs two fluidising beds, labeled in the schematic as the pyrolysis bed and the combustion bed. A venturi, at the base of the pyrolysis bed, entrains hot sand and biomass in steam which is then injected into the bed at a rate sufficient to achieve fluidisation. The steam in the pyrolysis bed acts to both fluidize the sand and biomass and also to displace air in order to create an environment conducive of gasification. A valve at the top of the pyrolysis bed extracts the gaseous product and some amount of volatiles in the form of ash. Some amount of the biomass is left unpyrolysed and is extracted out of the pyrolysis bed along with the cooled sand, into the combustion bed. Sand and unpyrolysed biomass in the combustion bed are fluidised with air by a blower which is also used to combust the unpyrolysed biomass in order to heat the sand for recirculation. Exhaust gas is extracted from the top of the combustion bed and is cleaned by means of a cyclone before being released. The hot sand is then re-entrained with more biomass into the steam and the cycle is repeated. Water is fed into a heat exchanger that is powered by excess heat from the combustion bed to produce steam for the pyrolysis bed. Gas from the pyrolysis bed is cleaned through a cyclone and a scrubber to produce a syngas mix of predominantly hydrogen and carbon-monoxide which may be directly fed into an internal combustion engine for electricity production. The process becomes self sustaining after an initial startup phase which requires the addition of LPG into the combustion bed. It is a continuous flow system.

The methodology used to model the system here is a structured and rigorous approach that involves performing an energy and mass balance on each component of the system. Both sensible and calorific heats are assessed, considering all inputs and outputs of the system components and the system as a whole. Assuming a likely efficiency for an internal combustion engine, we can assess the amount of electricity that may be produced out of a given feedstock flow rate.

Further to this, a simple analysis of the fluid dynamics within each bed is undertaken. This provides input to the energy and mass balance calculations as well as helping to specify the geometry of the beds.

A simple design for control and instrumentation of the system is also provided in order to define a list of components.

The entire model is setup in an excel spreadsheet so that the system can be analysed. Furthermore, we can compare different scenarios for the various manually set parameters such as flow rates and temperatures and therefore optimise the system.

Finally, waste heat streams in the system are identified and quantified in order to assess the potential for improved efficiency through heat reclamation.

## 12.2 Waste Transfer Station Survey

As previously discussed in section 5.6, greenhouse gas emissions that are attributed to the Brighton municipality's waste stream are a result of the decomposition of waste organic materials in landfill. In assessing the potential for Brighton Council to reduce its emission profile by means of a waste to energy facility, it is therefore important to analyse the flow of organic waste in Council's waste transfer station. Moreover, it is important to quantify the organic waste that is separable or available for processing through a waste to energy facility. This fraction of the waste stream is primarily large green waste that could be separated out prior to mixing with other, inorganic components, at the waste transfer station.

To this end, a survey was conducted by Council staff at the transfer station; refer to table K.1. Vehicles of different types carting green waste on to the site were recorded along with the percentage of green waste in their load. This survey was conducted over a period of 199 days between the fourteenth of August and the first of March, 2010. This period included a range of time over winter spring and summer, representing a good mix of non-growing and fast growing garden seasons. It can thus be assumed to be representative of an entire year.

Assumptions are made as to the average volume of each vehicle class, as well as the conversion factors of volume to mass. This enabled the flow rate of separable green waste through the site to be estimated, thus providing input into the model.

The following values were used:

| | | |
|---|---|---|
| Average volume UTE: | 2 | $m^3$ |
| Average volume TRAILER: | 3 | $m^3$ |
| Average volume CAR BOOT: | 0.5 | $m^3$ |
| Average bulk density: | 240 | $kg/m^3$ |

Where the average bulk density is taken from Department of Climate Change [2008a]. In summary of the survey, the following results are obtained:

| | | |
|---|---|---|
| Total Tonnage: | 678 | tonnes |
| Aproximate Annual Tonnage: | 1243 | tonnes |
| Aproximate Monthly Tonnage: | 104 | tonnes |
| Period of Survey: | 199 | days |
| | | |
| WTS hours open per month: | 128 | hrs |
| Average rate of green waste: | 0.81 | tonnes/hour (WTS open) |
| | **0.225** | **kg/sec** |

Therefore a value is given for the available flow rate of separable green waste from the waste transfer station (WTS) in terms of the opening hours of the waste transfer station. This is an appropriate unit since if Council was to pursue such an option, it would likely be operated at the waste transfer station and thus its operating hours would also be that of the site.

It is noted that there is a minor seasonal cycle evident in the green waste stream however there is space available for stockpiling the waste in order for the system to operate with an average flow rate, as discussed above.

# Chapter 13

# Technical Design

## 13.1 Pyrolysis Product Analysis

Accurate modeling of a biomass gasification system requires some understanding of the chemical changes that occur to the biomass during the process. Therefore the methodology must go beyond the standard energy and mass balance approach.

Pyrolysation is the process that occurs as an organic material is heated in an environment void of oxygen. Under normal, oxygen rich conditions any type of organic material will eventually combust. However, with a lack of oxygen, combustion can not occur. Rather, the material is cracked to produce simpler compounds and elements that generally maintain their combustibility.

The composition of products that result from pyrolysation and gasification can be complex and extremely difficult to predict through analytic methods. It will be a result of a number of conditions including the precise composition, structure and homogeneity of the organic material prior to pyrolysation; the precise rate of temperature increase and final temperature that the biomass is held at; the pressure of the environment; the chemical composition of the environment and so on.

The biomass that is relevant to the present study and model is green waste that has been diverted from landfill. It is thus extremely complex and unpredictable in terms of its composition. It is also likely to be inconsistent and non-uniform. Accurate prediction of its product following pyrolysation and gasification is therefore not achievable through theoretical means.

In order to overcome the issue outlined above, a review of the literature was undertaken and an approach identified that is applicable to the current work. Various studies have been conducted that employ the use of experimentation to determine the composition of products following pyrolysation and gasification of biomass. Results of these studies have been directly considered in the present model.

Olazar et al. [2001] analyse the composition of product states at different temperatures during the pyrolysation phase. The study considered only temperatures between 400°C and 500°C however for the purposes of this study; these results have been extrapolated out to 600°C in order to approximate the point at which the pyrolysation phase transitions to pure gasification. This also allows us to assess the minimum temperature at which we are likely to see no liquids present in the product stream.

The study from Olazar et al. [2001] was based on a similar experimental setup to that proposed in the present model however the fluidizing atmosphere was nitrogen as opposed to steam and thus results must be considered a first approximation only. Further to this, Olazar et al. [2001] used a sawdust biomass which maybe significantly finer than the green waste feed stock considered in this design. Importantly however, it is likely to be of similar composition.

Table 13.1 and Figure 13.1 present findings from Olazar et al. [2001] and the extrapolated results.

In terms of the present study, the key learning from Olazar et al. [2001] was that temperatures above 600°C are likely to yield only gas. This then becomes the critical temperature since it is important for the system to entirely avoid tar production. For any temperature above 600°C, the temperature may be set and

| | **Liquid** | **Gas** | **Char** | **Total** |
|---|---|---|---|---|
| **T(°C)** | **Yield(wt%)** | **Yield(wt%)** | **Yield(wt%)** | **Yield(wt%)** |
| | | **Study Results** | | |
| 400 | 61.5 | 15 | 22.5 | 99.0 |
| 420 | 64 | 15 | 20.5 | 99.5 |
| 440 | 66 | 17 | 17.5 | 100.5 |
| 460 | 66.5 | 19 | 14 | 99.5 |
| 480 | 60 | 28.5 | 11 | 99.5 |
| 500 | 56 | 35 | 9 | 100.0 |
| | | **Extrapolated** | | |
| 520 | 47.3 | 45.7 | 7.8 | 100.8 |
| 540 | 36.7 | 57.7 | 6.5 | 100.9 |
| 560 | 23.7 | 71.3 | 5.3 | 100.4 |
| 580 | 8.4 | 86.3 | 4.4 | 99.1 |
| 600 | 0.0 | 102.8 | 3.6 | 106.4 |

Table 13.1: Composition with Temperature Variation [Olazar et al., 2001]

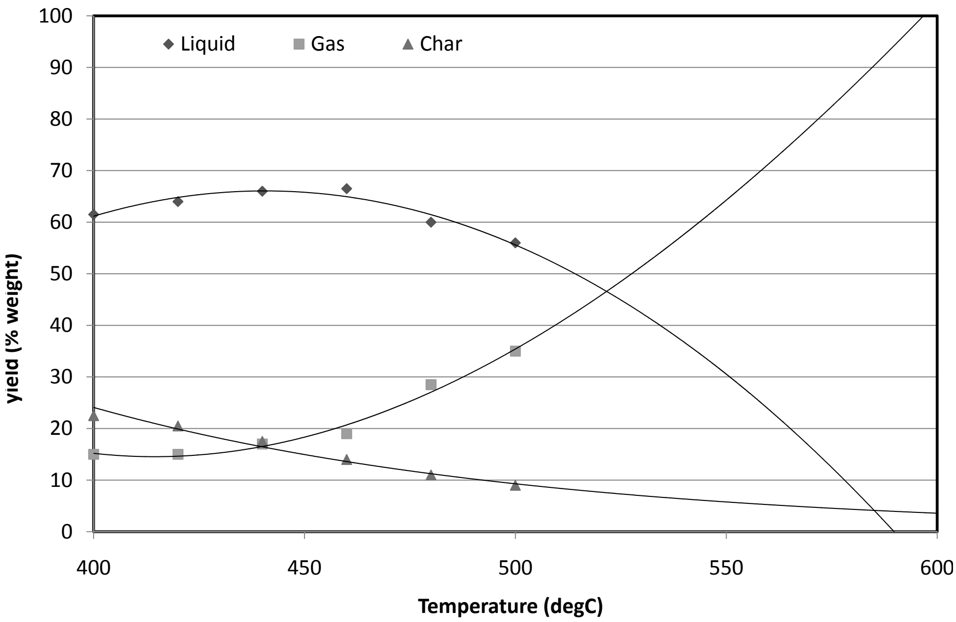



Figure 13.1: Composition with Temperature Variation [Olazar et al., 2001]

the time of residence varied in order to vary the output of ungasified char and gas. Based on this concept, the model may be balanced such that the ungasified char stream is sufficient but no more than is required by the combustion bed for use as a heating fuel. In this way the gas stream maybe maximized and thus, the system optimised.

Further to this, Fox [1988] notes that under wood combustion conditions, volatiles evolve from the wood at between 250°C and 600°C. Beyond 600°C all of the volatiles burn off. Therefore it follows that if combustion bed temperatures are maintained above 600°C, exhaust smoke will be minimised and fouling of the equipment due to tar build up will be prevented.

Ahmed and Gupta [2009] discusses the characteristics of gaseous yield from steam gasification, also based on experimental results. Data is provided in terms of the energy content of the gas when produced under steam gasification conditions, at temperatures between 600°C and 1000°C. This also is directly applicable to the present study and provides input into the model in its assessment of the quality of syngas under different temperature conditions.

Table 13.2 and Figure 13.2 present findings from Ahmed and Gupta [2009].

| **Temperature** (°C) | **Energy** (KJ/kg Syngas) |
|---|---|
| 600 | 1550 |
| 700 | 6500 |
| 800 | 9118 |
| 900 | 10777 |
| 1000 | 11180 |

Table 13.2: Energy Content of Gaseous Yield from Steam Gasification [Ahmed and Gupta, 2009]

Evident in figure 13.2 is the increase in energy yield with production temper-

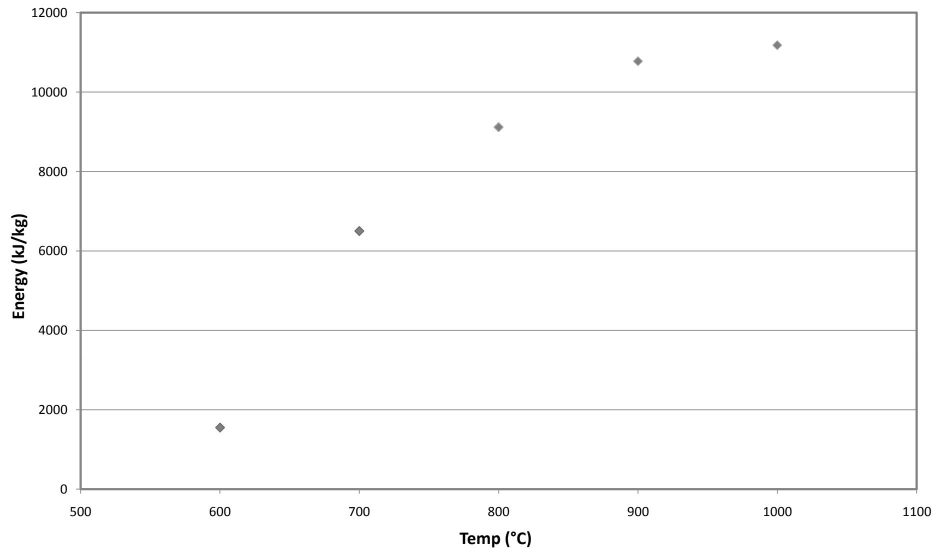



Figure 13.2: Syngas Energy Yield with Temperature Variation [Ahmed and Gupta, 2009]

ature, to a limiting value near 1000°C. This apparent increase in energy density is a result of a varied composition and proportion of gas type. That is, under gasification conditions, the biomass is cracked to produce some combination of carbon monoxide, hydrogen and other constituents. The energy density of each of these constituents is different and thus by varying the proportions, the combined energy density is changed. Ahmed and Gupta [2009] show that this change in proportions occurs relative to the temperature in which the biomass is cracked. Intuitively, this leads to the conclusion that the model will be optimised by maximising the temperature and thus producing the best quality syngas. Given the design of the overall system however, the drawback to this thinking is that greater amounts of combustion fuel will be required to produce the higher temperatures, and thus less syngas is produced. There is therefore a trade off between quantity and quality of the syngas that maybe produced. A later section of this chapter discusses the optimisation of the system based on results from Ahmed and Gupta [2009], thus providing clarity to this tradeoff.

For reference, Basu [2010] suggests that the optimal temperature range for fluidized bed gasification of biomass is 700°C and 900°C.

## 13.2 Energy and Mass Balance

The system is balanced here for a given scenario and the energy and mass flows are presented and discussed for each component and sub-component of the system. The fundamental concept applied in conducting an energy and mass balance is simply to calculate heat flow and mass flow into and out of each component and balance it for any unknown quantities such that energy (heat) and mass are both conserved.

### 13.2.1 Background Theory

A number of fundamental formulas exist that are relevant to the model. The present section provides a list of these relationships and shows how they are inter-related in the system and as such, enable the system to be balanced.

Specific enthalpy, denoted as $h$, is a thermodynamic property that is used to calculate heat transfer in the system. Its units are $kJ/kg$:

$$h = c_p \times T \tag{13.1}$$

[Moran and Shapiro, 2000]

Where: $c_p$ = Specific Heat $(kJ/(kg.K))$
$T$ = Temperature $(Kelvin)$

Heat flow rate, denoted as $\dot{Q}$, is a measurement of the transfer of energy between components and into and out of the system. Its units are kW:

$$\dot{Q} = \mathring{m} \times h \tag{13.2}$$

Where: $\overset{\circ}{m}$ = Mass flow rate ($kg/sec$)

[Moran and Shapiro, 2000]

Heat is either consumed or exerted in a reaction. This energy may be accounted for in the model by using the relevant heat of reaction constant. For the pyrolysis bed, the primary reaction is endothermic and is between carbon and water vapor to produce carbon monoxide and hydrogen. For the combustion bed the primary reaction is exothermic and is the combustion of carbon in oxygen to produce carbon dioxide. The heats of reaction are as follows:

$$C + H_2O \Rightarrow CO + H_2 : \qquad -131.32 \quad kJ/mol \tag{13.3}$$

$$C + O_2 \Rightarrow CO_2 : \qquad 393.79 \quad kJ/mol \tag{13.4}$$

[Green and Perry, 2007]

The heat of reaction may be multiplied by the molar flow rate to calculate the heat flow rate.

Specific heat is the measure of heat energy that is required to increase the temperature of a unit amount of a substance by a unit of temperature. Different materials possess different specific heats. Furthermore, specific heats are dependant on the temperature of the material. Since equation 13.1 is fundamental to the model and requires knowledge of specific heat, it is critical that specific heats are known for the various gases that are passed around the system. Moreover, since the system temperatures vary significantly from component to component and depending on the condition of the various manually set parameters, calculating the specific heat for a gas at a given point in the system becomes complex. To overcome this issue, curves are fitted onto graphs of each relevant gas, relating temperature to specific heat. The equation of the curve is then used to determine specific heat from temperature in the model. The relationship equations are as follows:

$$\text{Nitrogen:} \quad c_p = 0.12\ln(T) + 0.35 \tag{13.5}$$

$$\text{Carbon Dioxide:} \quad c_p = 0.23\ln(T) - 0.44 \tag{13.6}$$

$$\text{Hydrogen:} \quad c_p = -1.25 \times 10^{-7}T^2 + 2.02 \times 10^{-3}T + 13.4 \tag{13.7}$$

$$\text{Carbon Monoxide:} \quad c_p = 0.12\ln(T) + 0.35 \tag{13.8}$$

$$\text{Water Vapour:} \quad c_p = 0.52\ln(T) - 1.16 \tag{13.9}$$

[The Engineering ToolBox, 2005]

The various parameters and formulas presented here become inter-dependant in the model due to the process of energy and mass balance and the various feedback loops that exist.

### 13.2.2 Overview

Figure 13.3 shows the energy and mass inputs and outputs of the gasification component of the model which provides the conversion mechanism from biomass to syngas.

A stream of chipped green waste provides the feedstock for the system and is set to 0.11kg/sec, sufficient to meet the environmental requirements of the design that will be discussed in a later section of this chapter. The moisture content is assumed to be 50%, described by Fox [1988] as typical in the composition of green wood. This moisture content will react with the carbon in the biomass and will be extracted in the stream of steam and gas out of the pyrolysis bed and thus out of the char/gas separation unit. The separation unit is a cyclone that separates out solids into the combustion bed and gases that go on to be cleaned.

As was discussed previously, post startup phase, the system becomes a continuous cycle with sand being passed from the pyrolysis bed, to the combustion bed for re-heating, and then back into the pyrolysis bed, providing the heat energy for the pyrolysis process. The heat recovery unit takes some of the excess heat from the combustion bed and produces steam for fluidization of the pyrolysis bed. Inlet water temperature is assumed to be 15°C. Out of this unit the emission constituents and waste heat are quantified.

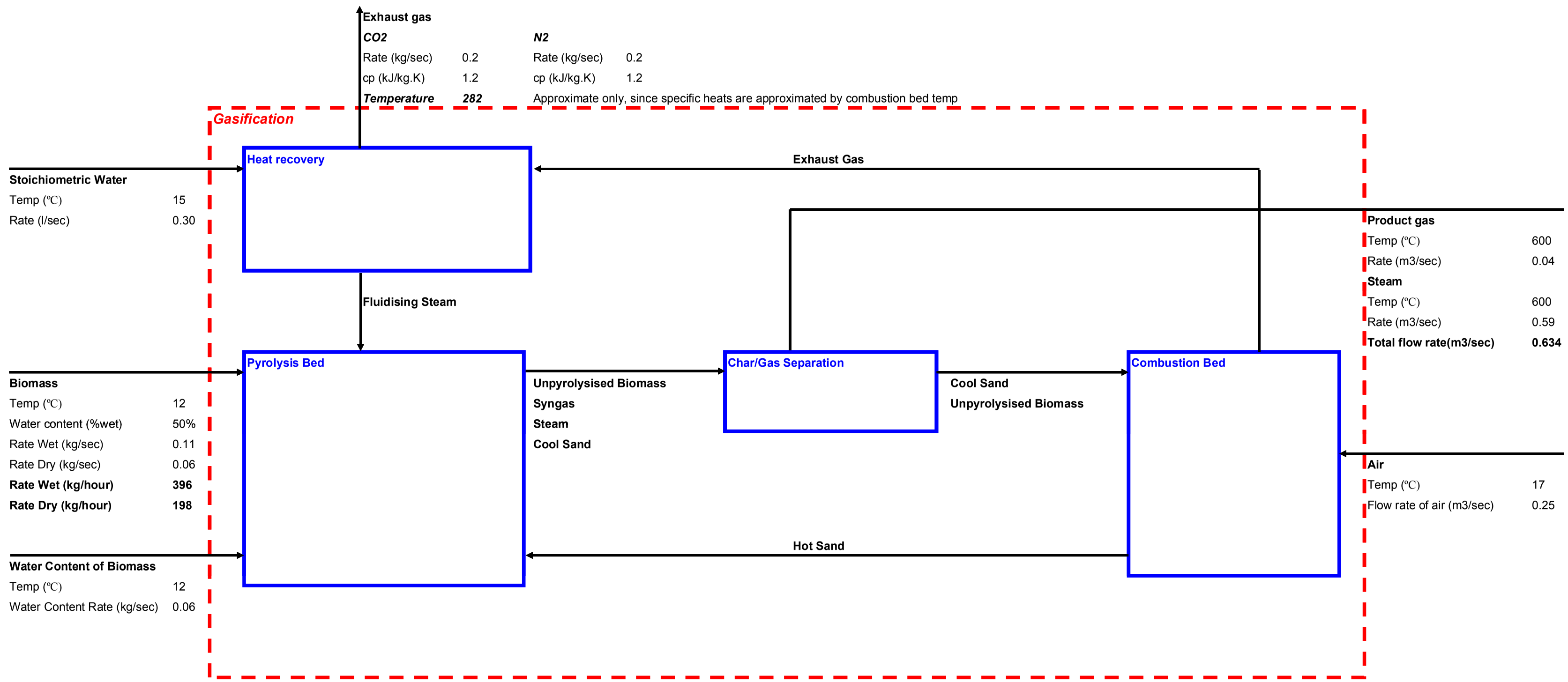



Figure 13.3: Gasification Overview

Since in the case of the exhaust we need to back calculate to obtain the temperature from the heat that has been extracted by the water, the flow rates of $CO_2$ and $N_2$ and the specific heats, we have to approximate the specific heats. This is done by using the specific heats that were calculated for the exhaust prior to heat recovery and then using them to calculate the other parameters. This should be considered a first approximation only but sufficient for the model.

It should be noted here that there is opportunity for further development of the model to recover more of the exhaust heat for efficiency improvement or added electricity generation. A possible use could be drying and pre-heating of the feedstock as will be discussed in greater detail in section 13.7.

Air temperature is assumed to be 17°C and its flow rate into the combustion bed is set according to the fluid dynamic calculations, discussed in a later section of this chapter.

The product gas and steam output is 600°C which is based on the model optimisation, discussed in greater detail in section 13.6.

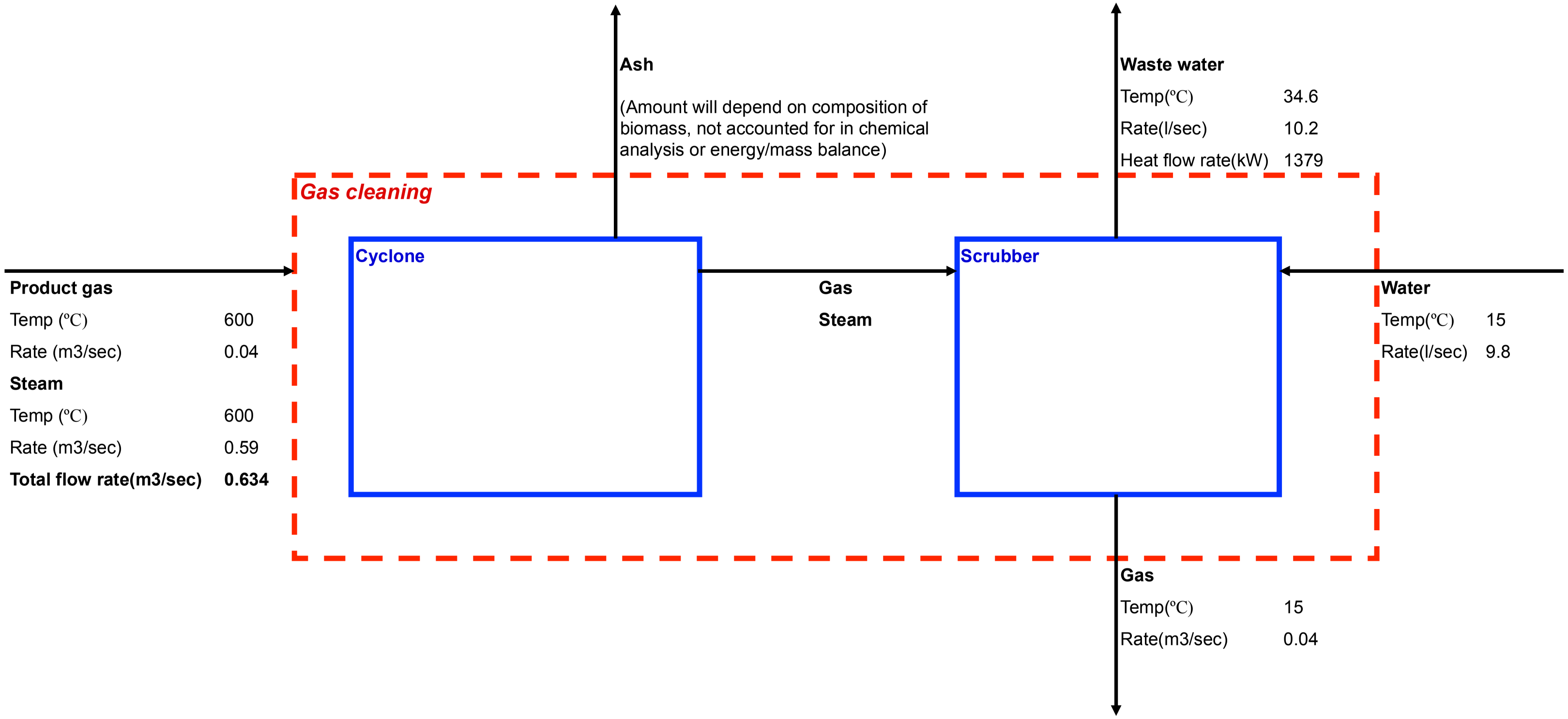



Figure 13.4: Gas Cleaning Overview

Figure 13.4 shows an overview of the product gas cleaning arrangement. This component of the system is necessary to remove water vapor from the gas and to clean out any remaining particulate. Furthermore, the gas is cooled to provide a more useable and manageable fuel.

Out of the gasification component, the gas and steam is passed through the secondary cyclone to remove as much small particulate as possible. Note that the amount of ash particulate extracted at this point has not been quantified. The ash here will be predominantly made up of the volatiles that could not be gasified in the pyrolysis bed. They will primarily be a result of the complex and varying composition of the biomass feedstock. Fox [1988] suggests that green wood will have 2% ash in its composition. Since Fox [1988] states also that green wood will typically have a moisture content of 50%, we can assume that of the dry component, ash will constitute approximately 4%. Some percentage of the ash will come out of the system at the gas cleaning stage with the remainder coming out as smoke with the combustion exhaust. Further cleaning mechanisms will therefore likely be required on the combustion exhaust as well in order to remove the ash particulate which would otherwise cause an aesthetically unpleasing smoke. This study has not considered this aspect of the system design since it is not going to impact on the overall efficiency. It is thus beyond the scope of the study.

From the cyclone, the gas and steam is passed through a scrubber which removes any remaining particulate contaminants and water vapor. A flow rate of 9.8 litres per second has been selected to provide sufficient heat removal from the gas. There is also opportunity here for further development of the model to recover heat for further efficiency improvement.

The syngas output is 0.04 $m^3$ per second, at a temperature of 15°C which is directed to an internal combustion engine for power generation. An assumption is made that the output gas has been cooled to the temperature of the scrubber water. It is noted that there will be some residual heat left in the syngas however this has not been fully evaluated here. An alternative approach to power generation may be to use a fuel cell. There is potential to substantially improve the electricity generation capacity of the system through this method but at a much greater cost. This option has not been reviewed in the present study.

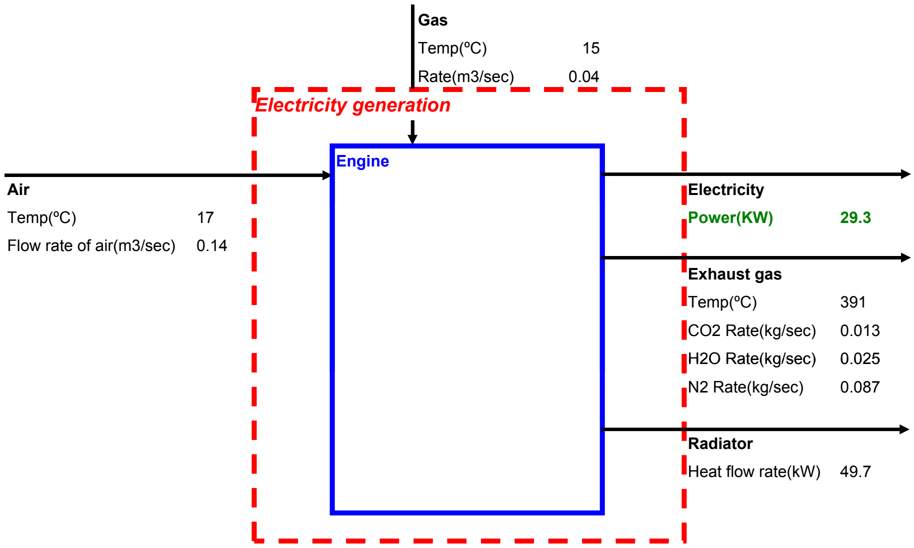



Figure 13.5: Electricity Generation Overview

Figure 13.5 shows the final stage of the model in which the produced syn-gas is converted into electricity. The model takes an internal combustion engine with a typical conversion efficiency of 25% [Green and Perry, 2007], to produce 29.3kW. Therefore, with the optimised model presented here, a feedstock flow rate of 0.11kg/sec can produce 29.3kW of electricity.

Air is taken in at an assumed 17°C with a flow rate of 0.14 $m^3$ per second, calculated for stoichiometry.

Significant energy losses are apparent in the exhaust gas and radiator, with the radiator extracting 49.7kW of heat.

The exhaust gas flow rates are also calculated in order to provide input into the environmental assessment of the model. The nitrogen being passed through directly from the air; water vapor due to the oxygen and hydrogen reaction and carbon dioxide from the oxygen and carbon-monoxide reaction.

### 13.2.3 Pyrolysis Bed

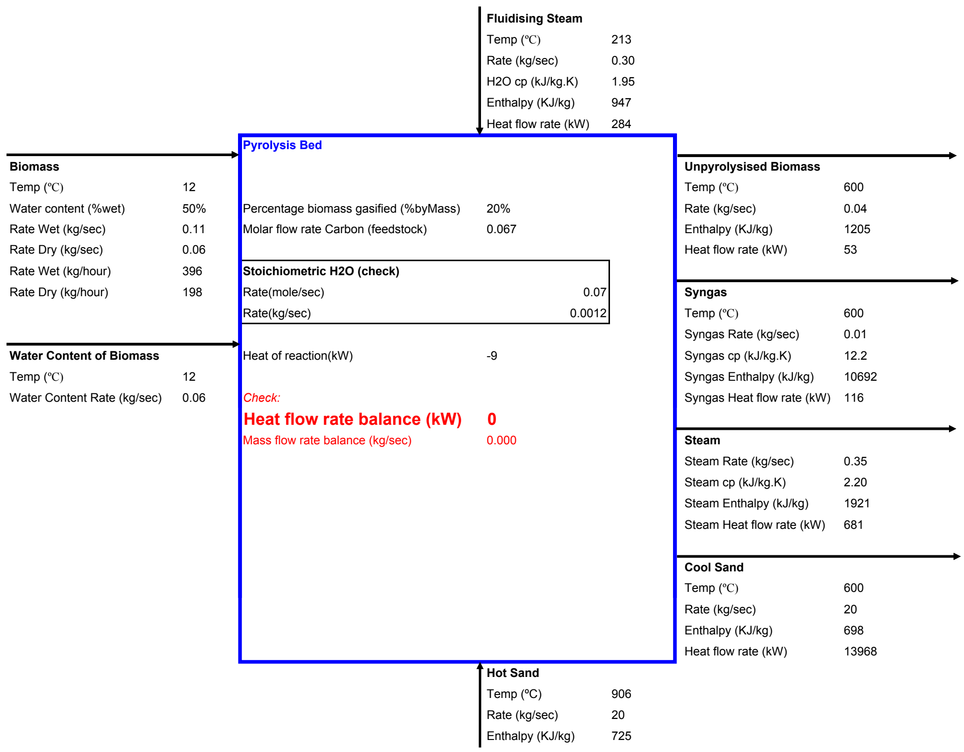



Figure 13.6: Pyrolysis Bed

Figure 13.6 shows the energy mass balance diagram for the pyrolysis bed. Each stream into and out of the bed is identified and quantified in terms of its heat and mass flow rate.

The percentage biomass gasified is set here at 20%. This parameter is manually set in the model but can physically be set by adjusting the residence time of the biomass which may be achieved by adjusting the geometry of the bed. Importantly, some amount of the biomass must be left ungasified and sent to the combustion bed to provide fuel for heating the sand. This parameter is thus critical since it defines exactly how much gas is produced. For the purpose of the model, this parameter is manually set in order for the model to be solved.

By defining the amount of gas that is produced, mass flow rates for unpyrolysed biomass and gas are defined. The mass flow rate of steam out of the bed is taken as the sum of that coming in from the fluidising steam and the moisture content of the biomass. For the purpose of the model, the mass flow rate of the sand is manually set. In a physical model, this would be a fixed parameter however as part of the design process of solving the model, where the model is optimised, it is manually set.

For the outputs of the pyrolysis bed the temperature is set at 600°C for optimisation reasons that are discussed in a later section of this chapter. This enables calculation of specific heat for the steam using equation 13.9 and thus the specific enthalpy using equation 13.1. Ahmed and Gupta [2009], in the analysis of pyrolysis and gasification product, present findings on composition of syngas. When produced at 900°C, they find approximate proportions of hydrogen and carbon-monoxide of 60% and 12% respectively, along with a mix of other constituents. For the purpose of estimating an appropriate value for syngas specific heat, the other constituents are neglected, making the proportions of hydrogen and carbon-monoxide, 83% and 17% respectively, where $83\% = \frac{60\%}{60\%+12\%}$ and $17\% = \frac{12\%}{60\%+12\%}$.

Applying these proportions to equations 13.7 and 13.8 respectively and summing the result provides a first approximation of specific heat for the syngas. While neglecting the minor constituents of the gas in this way will lead to inaccuracy in the specific heat value, temperature is still considered and it is thus a better approximation than simply selecting a fixed value.

Application of equation 13.1 therefore gives a value for specific enthalpy. Specific heats for solids are less dependant on temperature and thus are taken as constants for the respective materials. Equation 13.1 also provides values for specific enthalpy for sand and unpyrolysed biomass. Given values for specific enthalpy and mass flow rate for each output of the pyrolysis bed, equation 13.2 provides the heat flow rates.

Checks are presented also in figure 13.6 to ensure the energy and mass flows are balanced and also that there is sufficient water vapour in the pyrolysis bed to achieve the stoichiometric requirements of the process. The mass flow rate required for stoichiometry is 0.0012 kg/sec which is significantly less that is present in the fluidising steam flow.

The mass flow rate of the fluidising steam is set according to the fluid mechanics of the pyrolysis bed, sufficient to ensure fluidisation. The temperature of the steam may be manually set in the model and will depend on the efficiency of the heat recovery boiler. The specific heat may therefore be determined by means of equation 13.9, thus enabling calculation of the specific enthalpy and heat flow rate, again using equations 13.1 and 13.2 respectively.

The heat of reaction is shown as -9kW and is determined by multiplying the molar flow rate of the feedstock with the heat of reaction constant, equation 13.3.

The hot sand is used to balance the energy and mass flow, considering all inputs and outputs of the pyrolysis bed. Temperature is then back calculated using equations 13.2 and 13.1 respectively. Shown in red is a check for both the energy and mass balance.

### 13.2.4 Char/Gas Separation

The char and gas separation component shown in figure 13.7 models the outlet of the pyrolysis bed. Bulk solids including the low temperature sand and the unpyrolysed biomass are gravity fed out of the pyrolysis bed and into the combustion bed. The gas, steam and light solids are extracted out of the top of the pyrolysis bed and are moved on to the cleaning components.

This component is essentially a passive component in that there are no chemical reactions occurring. There is therefore no addition or removal of chemical heat energy. The component simply separates out the constituents of the pyrolysis output into the required streams.

Input to the component is a duplicate of the output from the pyrolysis bed.

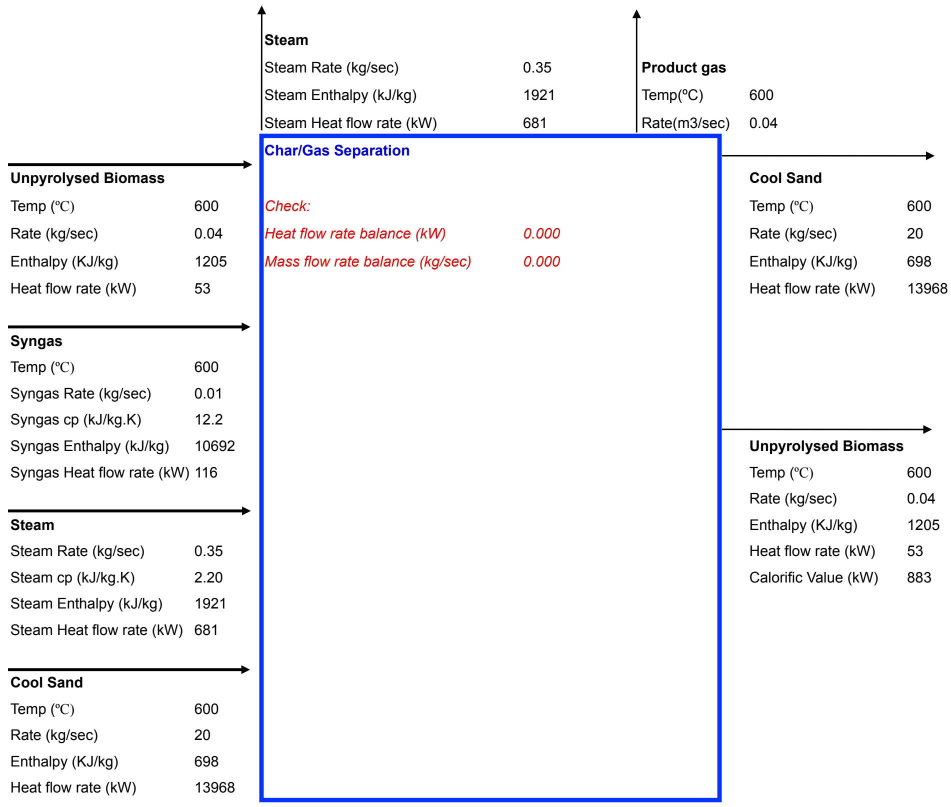



Figure 13.7: Separation

Outputs of the component are then duplicated from the respective inputs. A check is shown in red demonstrating that both energy and mass is conserved.

### 13.2.5 Combustion Bed

From the char and gas separation component, the solid materials are passed on to the combustion bed, shown in figure 13.8. The mass flow rate of the unpyrolysed biomass is converted to a molar flow rate by making the assumption that it is carbon. Based on stoichiometry the mass flow rate of oxygen required for complete combustion and carbon dioxide in the exhaust gas stream are calculated. Given that the approximate composition of air is 21% oxygen to 79% nitrogen by volume, the corresponding flow rate for nitrogen is calculated. Nitrogen is not

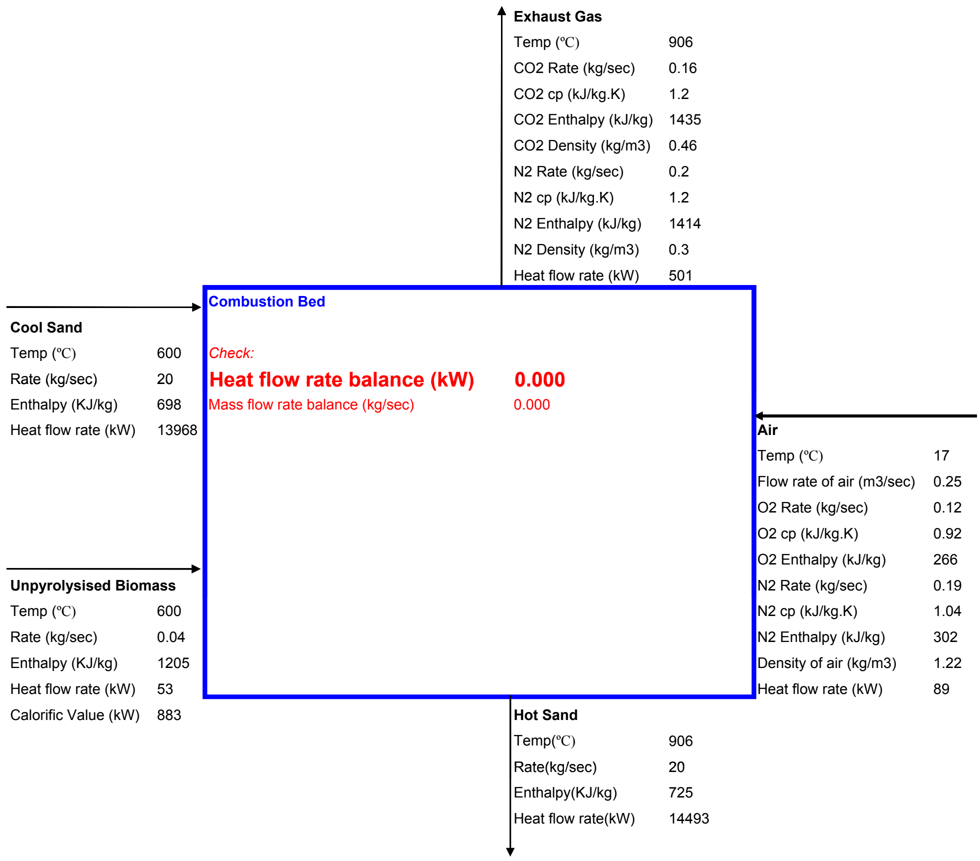



Figure 13.8: Combustion Bed

affected in the combustion bed and thus it passes through with the same mass flow rate.

Values for hot sand are duplicated from the pyrolysis bed and its temperature is applied to all other outputs. Using equations 13.5 and 13.6 the specific heats are obtained which enable calculation of specific enthalpy and thus heat flow rate.

Again, shown in red is a mass and energy flow balance check. The zeros indicate that the component is balanced.

### 13.2.6 Boiler

Designed to produce steam for the pyrolysis bed and make use of some of the excess heat from the combustion bed, this heat recovery component is the only efficiency improving aspect to the design that has been considered in detail and modeled. In a physical system, the boiler would likely be located within the combustion bed in order to minimise efficiency loss. It is however a separate component and has been modeled as such here. Figure 13.9 shows its energy and mass flow diagram.

Properties of the inlet water are based on the assumption that the ambient water source is 15°C. The mass flow rate of the water is set according to the fluidising steam requirements and specific enthalpy is determined from the steam tables [Moran and Shapiro, 2000]. From this, heat flow rate is determined using equation 13.2.

Properties of the hot exhaust gas have been duplicated from the combustion bed outlet. The heat flow rate of the fluidising steam determines the energy requirements and thus the efficiency of the boiler.

The mass flow rates of the outlet exhaust gas are simply duplicated from the inlet. Their heat flow rate values are determine by what remains in the gas after the requirements of the fluidising steam are subtracted out. An assumption is made on the specific heat values for the exhaust gas outlet to enable calculation of its temperature. These values are approximated by the corresponding values of the hot exhaust gas from the combustion bed.

A significant heat loss of 236kW remains in the exhaust gas and further development of the model may consider more heat recovery to improve the overall efficiency.

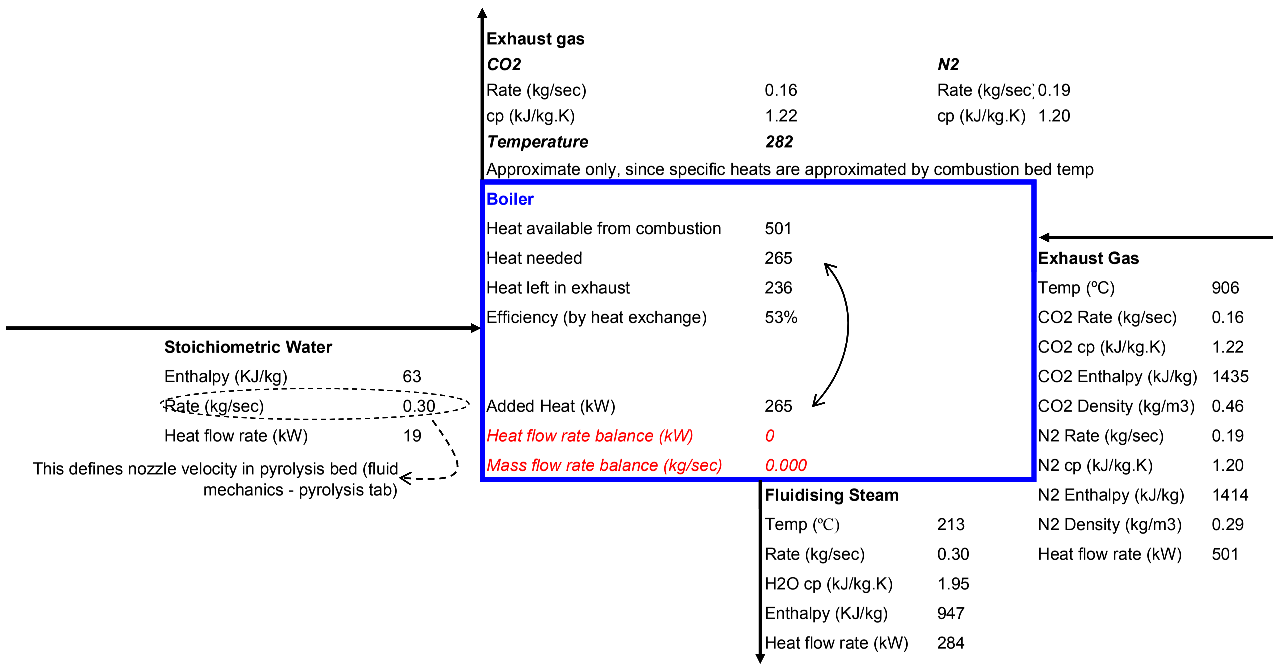



Figure 13.9: Boiler

Green and Perry [2007] present Sankey diagrams for various types of boilers. Relevant to the present application, the diagrams show that for subcritical-pressure boilers the available heat is 88% and for supercritical-pressure boilers the available heat is 90%. Further to this, Fox [1988] suggests a typical overall heat exchanger efficiency of 60% can be achieved by appropriate design in a wood fired system. For the scenario presented here a conversion efficiency of 53% is achieved, well inside this achievable conversion efficiency. Significant heat loss is therefore identified at this point in the model and as such it could be looked at as a potential for efficiency improvement in more detailed design iterations in the future.

### 13.2.7 Scrubber

The scrubber, shown in figure 13.10, is designed to take gas and steam from char and gas separation and clean out the steam and any remaining particulate to produce a useable syngas. Essentially, the hot gas and steam are bubbled through cool water in order to condense out the steam and wash and cool the gas.

Parameters for the incoming steam and gas are duplicated from the char and gas separation. The water inlet temperature is set to the assumed ambient water temperature (15°C). The flow rate of water is manually set in the model at 9.8 litres per second. This value is set such that the outlet water temperature is appropriately low. The inlet water specific enthalpy is determined from the steam tables [Moran and Shapiro, 2000]. From this, heat flow rate is determined using equation 13.2.

It is assumed that the temperature of the syngas at the outlet is close to the inlet water temperature and is 15°C. This enables calculation of the syngas specific heat, specific enthalpy and thus, the heat flow rate. The calorific value of the gas does not affect the energy and mass flow rate balance for this component as it is not combusted. It is shown in figure 13.10 for interest only.

Parameters for the waste water are determined by accounting the energy and mass flow rates into and out of the component. With knowledge of the specific enthalpy of the waste water, steam tables [Moran and Shapiro, 2000] are used to calculate the temperature.

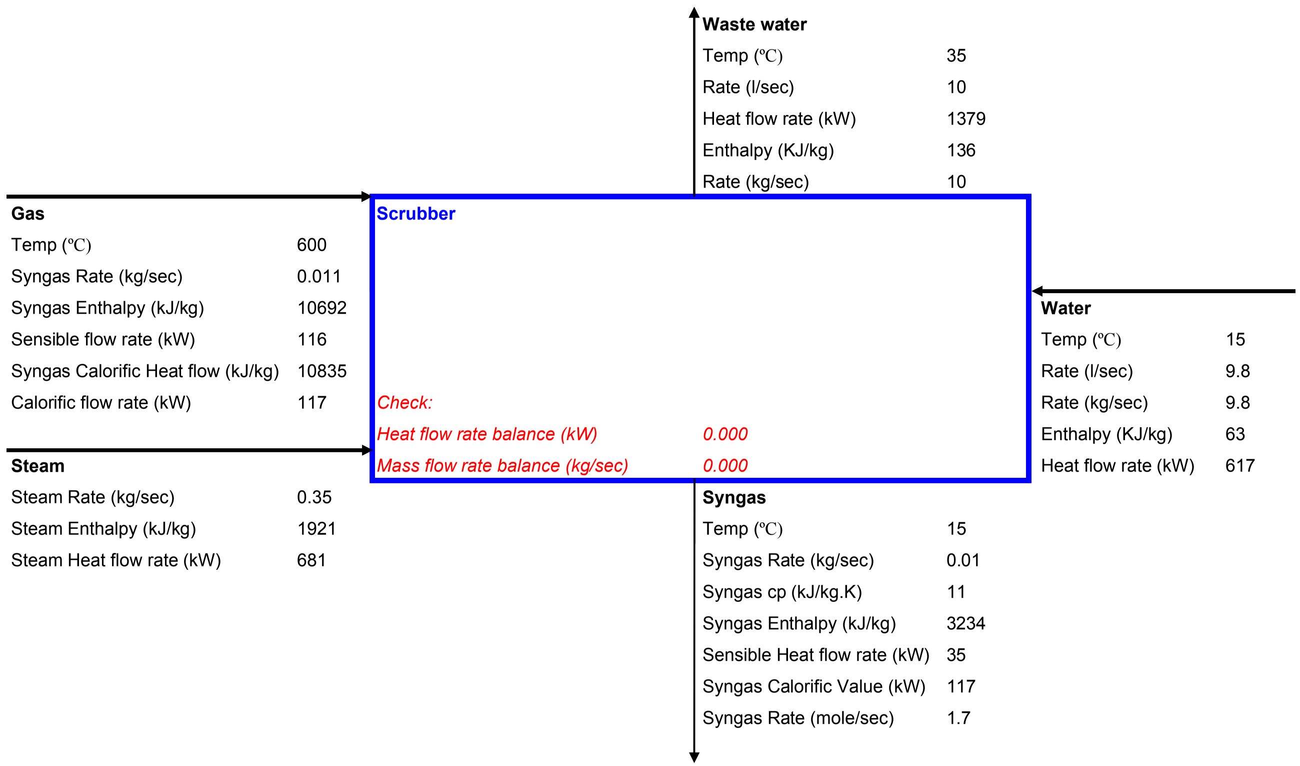



Figure 13.10: Scrubber

## 13.2.8 Engine

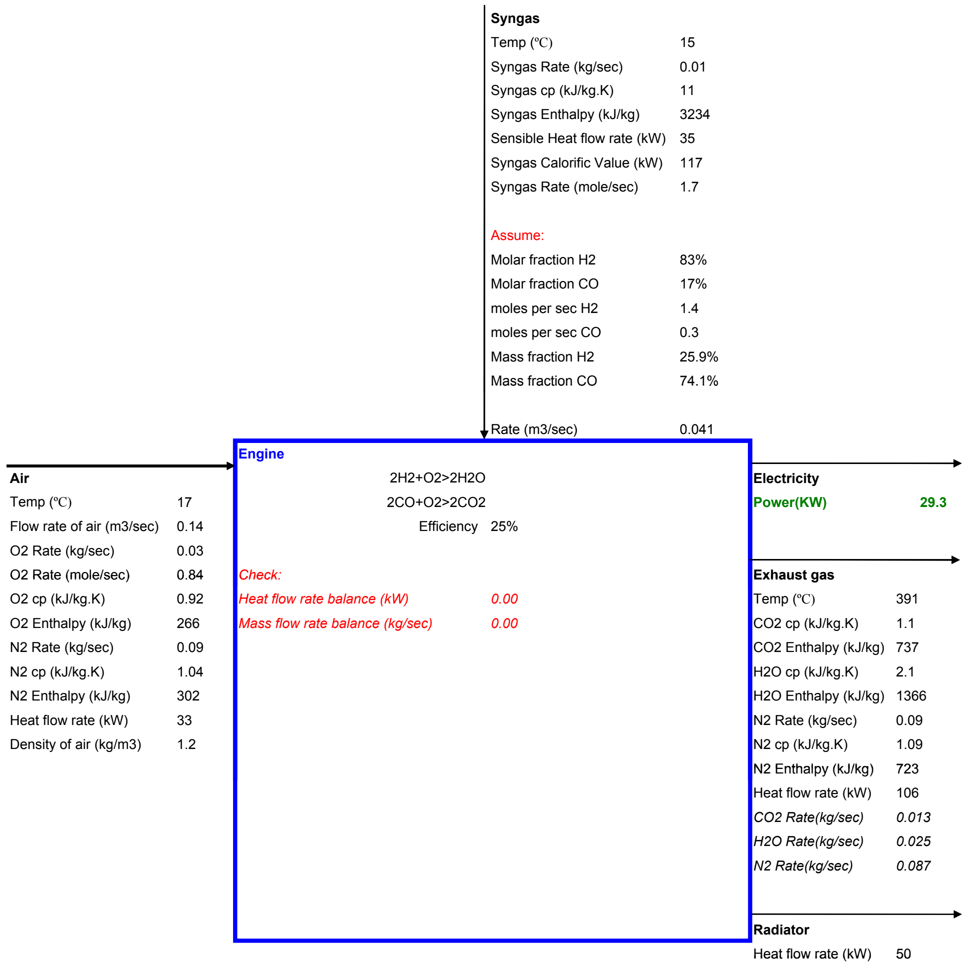



Figure 13.11: Engine

The final component of the model is the engine, shown in figure 13.11.

Properties of the syngas are taken from the preceding components including an approximation of the composition of the syngas, discussed earlier in the pyrolysis bed section.

The ambient air temperature is assumed to be 17°C and based on a stoichiometric air fuel ratio, the mass flow rate of oxygen and thus nitrogen is calculated. Following from this, specific heats, enthalpies and finally the heat flow rates of the inlet air are determined, again using the equations presented in section 13.2.1.

The engine is assumed to have a conversion efficiency of 25%, a common estimate for an internal combustion engine's efficiency [Green and Perry, 2007]. With knowledge of the syngas calorific value, the mechanical power output of the engine may be calculated and is 29.3kW.

The model allows for the exhaust gas temperature to be set and for this scenario it is arbitrarily set at 391°C. Based on stoichiometric combustion, the mass flow rates for carbon-dioxide and water vapor are calculated, thus enabling the remaining exhaust parameters to be determined.

Conducting an energy and mass balance of the component, a value for heat loss out of the radiator is determined. This provides another potential source of overall efficiency improvement.

## 13.3 Fluid Dynamics

By analysing the fluid dynamics of the fluidising beds it is possible to predict the condition of the atmosphere and particles at various points within the beds. Furthermore, by adjusting the bed geometry, the fluid dynamics are varied and thus the beds may be optimised to ensure they achieve good fluidisation and meet the requirements of the design. This section discusses the process of optimising the geometry of the pyrolysis bed and the combustion bed for the given scenario.

A number of detailed models for the analysis of fluid dynamics within fluidising beds were assessed within the context of the present study including those discussed in Cheremisinoff and Cheremisinoff [1984], Kunii and Levenspiel [1969] and Howard [1989]. These models go beyond the preliminary design requirements of the present study and are thus considered beyond the scope of the study. A simplified approach, sufficient to achieve the goals of the study is discussed throughout this section.

### 13.3.1 Pyrolysis Bed

The following properties are calculated for the pyrolysis bed:

| | | |
|---|---|---|
| Bed temp | = | 906°C |
| Biomass particle mass | = | $2.09\times10^{-3}$ kg |
| Sand particle mass | = | $9.82\times10^{-8}$ kg |
| Biomass particle area | = | $3.14\times10^{-4}$ m$^2$ |
| Sand particle area | = | $1.96\times10^{-7}$ m$^2$ |
| Terminal velocity sand particle | = | 6.62 m/s |
| Terminal velocity biomass particle | = | 24.17 m/s |
| Time to reach terminal velocity Sand | = | 0.67 sec |
| Time to reach terminal velocity Biomass | = | 2.46 sec |
| Total bed volume | = | 0.07 m$^3$ |

The bed temperature is taken from the energy and mass balance calculations and is the value for temperature at the base of the bed where the hot sand is injected. The biomass and sand particle mass, area and drag values are determined based on the average particle density and geometry, refer to appendix J. Neglecting the buoyancy effects, the particle terminal velocity of the biomass and sand may therefore be calculated using the following formula, [Benson, 2008]:

$$V_t = \sqrt{\frac{2mg}{\rho A C_d}} \tag{13.10}$$

| | | | |
|---|---|---|---|
| Where: | $V_t$ | = | terminal velocity |
| | $m$ | = | mass of particle |
| | $g$ | = | acceleration due to gravity |
| | $C_d$ | = | drag coefficient |
| | $\rho$ | = | density of the fluid |
| | $A$ | = | projected area of the particle |

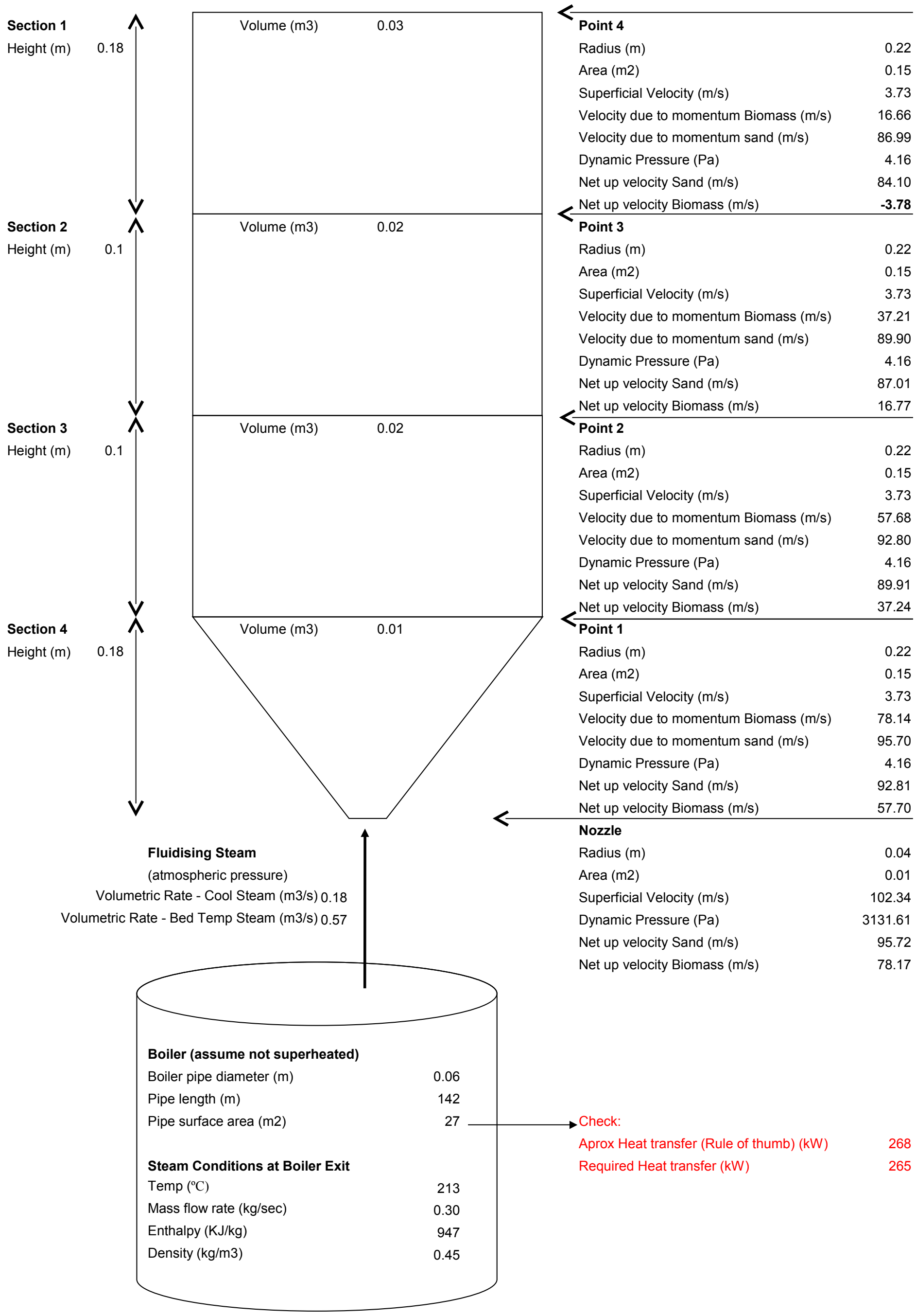



Figure 13.12: Pyrolysis Bed Fluid Dynamics

Figure 13.12 shows a schematic of the bed with four points defined on the vertical axis. The points define three dimensional sections of the bed as shown, the volumes of which are summed to provide a total bed volume.

From the energy and mass flow rate calculations, steam temperature, mass flow rate and specific enthalpy are known. The fluidising steam density and thus volumetric flow rate are therefore calculated from the standard steam tables [Moran and Shapiro, 2000]. Note that volumetric flow rate is given for the steam at both the boiler temperature and the pyrolysis bed temperature. There is a significant difference between these values due to the large temperature difference and it is the value calculated for the bed temperature that is relevant to the fluid dynamic calculations.

A first estimate of the boiler geometry approximates heat transfer, using equation 13.11. Equivalence to what is required by the heat exchanger is shown as a check in red in figure 13.12. A more detailed analysis of the boiler would be required for a detailed design.

$$\dot{Q} = 10A_s \tag{13.11}$$

Where: $A_s$ = Surface area of boiler pipe

For each point on the fluidising bed, the radius and area are specified and since the steam volumetric flow rate is known, values for the superficial velocity may be determined, where superficial velocity is defined as the gas flow rate divided by the cross-sectional area, neglecting the effect of particle displacement [Reed et al., 1999].

With vertically up defined as the positive direction, the velocity of the sand and the biomass particles at the nozzle are calculated by summing the particle terminating velocity and the superficial velocity.

At point one, the velocity due to momentum of the particles is calculated using the following equation of motion, [Beer and Johnston, 1999]:

$$v_m = \sqrt{u^2 + 2as} \tag{13.12}$$

Where: $v_m$ = velocity due to momentum

$u$ = initial velocity

$a$ = acceleration (due to gravity)

$s$ = displacement (distance between previous point and point of interest)

The actual velocity of the particle at point one may therefore be calculated, considering the particle terminal velocity, superficial velocity and the velocity due to momentum. The same procedure is then used to calculate particle velocities for each of the subsequent points.

The geometry of the bed is then optimised such that the velocity of the biomass particles at point four are negative. With this result we are achieving fluidisation of the biomass without blowing the average particle size out the top with the steam and syngas.

At point four the sand particles are still moving at a significantly large velocity. They will thus come out of the cyclone and will move to the combustion bed for reheating.

### 13.3.2 Combustion Bed

The fluid dynamics of the combustion bed is assessed in much the same way as that for the pyrolysis bed. The objective of the analysis being to shape the bed such that the sand is sufficiently fluidised and the average particle size is not blown out of the top of the bed with the exhaust.
The following properties are calculated for the combustion bed:

$$
\begin{aligned}
\text{Bed temp} &= 906^\circ\text{C} \\
\text{Terminal velocity sand particle} &= 7.51 \text{ m/s} \\
\text{Time for sand particle reach terminal velocity} &= 0.77 \text{ sec} \\
\text{Total bed volume} &= 0.153 \text{ m}^3
\end{aligned}
$$

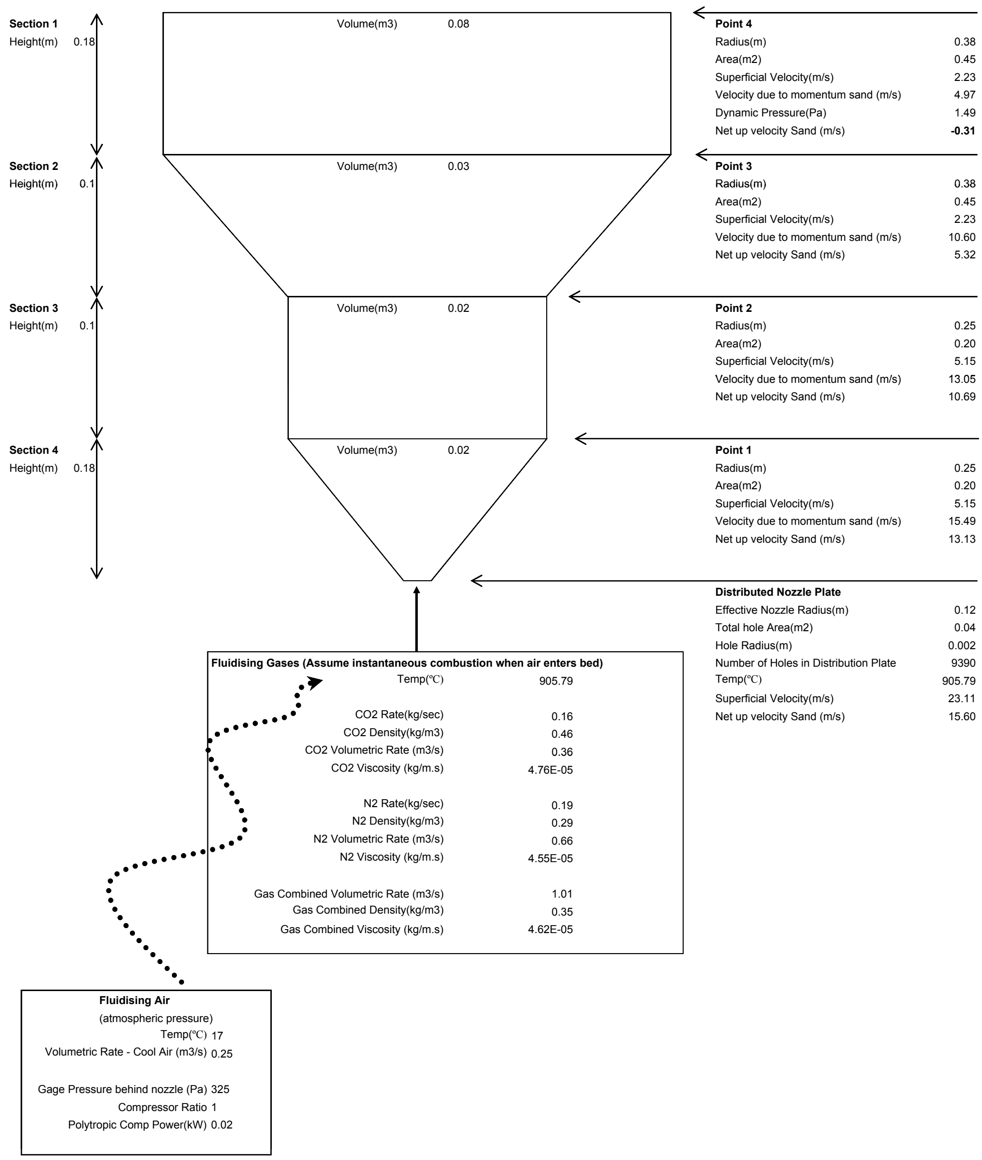



Figure 13.13: Combustion Bed Fluid Dynamics

The key approximation made in the analysis is that the unpyrolysed biomass is instantaneously combusted as it enters the combustion bed. It is therefore not necessary to assess the state of the biomass particles throughout the bed. Furthermore, the fluidising gas becomes the exhaust gas rather than the air, as is shown in figure 13.13.

Similarly to the pyrolysis bed, the bed temperature is taken from the energy and mass balance calculations and is the temperature resulting from combustion. Neglecting buoyancy effects, the terminal velocity of the sand particle is calculated using equation 13.10.

Figure 13.13 shows a schematic of the combustion bed. Similarly to the pyrolysis bed it is divided up into four sections defined by four points along the vertical axis. These sections define the three dimensional geometry and volume of the bed.

The fluidising air flow rate is taken from the energy and mass balance calculations and is based on stoichiometry. Compressor power is calculated with equation 13.13 using gage pressure, calculated using Bernoulli's principle and compression ratio. This provides an estimate only of what the compressor power requirements will be, [Green and Perry, 2007]. It is sufficient to use as a first approximation.

$$P = 2.78 \times 10^{-4} Q_a p_1 ln(p_2/p_1) \tag{13.13}$$

Where: $P$ = Power (kW)

$Q_a$ = Volumetric flow rate ($m^3$/s)

$p_1$ = Initial pressure (Pa)

$p_2$ = Compressed pressure (Pa)

The superficial velocity is calculated from the geometry of the bed at each of the points. The resulting particle velocity is calculated at the nozzle and is a summation of the particle's terminal velocity and the superficial velocity, taking vertically up as the positive direction. The velocity due to momentum is then calculated at point one as discussed in the previous section. The resulting particle velocity is then calculated for this point considering terminal velocity, superficial velocity and the velocity due to momentum. Particle velocity is calculated for the remaining points in the same way.

The bed geometry is manipulated until the particle velocity at point four is close to zero and is negative. This ensures that good fluidisation is achieved and that the average particle will not be blown out of the top of the bed with the exhaust. In order to achieve this, the nozzle is designed as a distribution plate with a number of holes at a specified size. This enables a larger nozzle area to be achieved and thus the superficial velocity at that point is minimised. Furthermore, the section between points three and four is conical in order to achieve a significant reduction in superficial velocity between these points.

It should be noted that this approach to bed fluid dynamics neglects any effect of interaction between particles and between the bed walls and the particles. It also neglects the displacement of fluidising gas by the particles which may have significant effect on the superficial velocity. The simplistic approach presented here provides enough information for the purpose of the present study and thus these complexities have been neglected.

## 13.4 Particle Heat Transfer

In the design of a fluidising bed system it is necessary to establish the required residence time of the particles. This information is then contributed to the size and geometric specification of the bed. Residency time required in a pyrolysis bed is simply the time it takes for the pyrolysis reaction to occur in an average particle. For the purposes of the present study, the assumption is made that pyrolysis occurs the moment that the material is brought to the required temperature for pyrolysation. Therefore, as heat is transferred from the surface of a particle, to the particle's centre, the particle is progressively pyrolysed.

The assumption makes calculation of pyrolysation rate a first approximation only. This is because in reality there is not a single temperature at which pyrolysis occurs, there is a range. However, due to the lack of homogeneity in the feedstock particles, this is an appropriate approximation.

The following presents a series of calculations for heat transfer and thus residency time in the pyrolysis bed:

Conduction in a particle:

| | | | |
|---|---|---|---|
| Radius of particle | = | 0.01 m | |
| Surface area | = | $1.3\times10^{-3}$ $m^2$ | |
| Initial temp | = | 12°C | |
| Final temp | = | 906°C | |
| dT | = | 894°C | |
| | | | |
| Heat flow from surface to centre of particle | = | 13.48 W | |

Internal energy change of particle:

| | | | |
|---|---|---|---|
| Volume of particle | = | $4.19\times10^{-6}$ $m^3$ | |
| Mass of particle | = | $2.09\times10^{-3}$ kg | (assuming particle is a sphere) |
| U2-U1 | = | 2583 J | |
| | | | |
| Time to transfer heat | = | 192 sec | |
| Time to transfer heat | = | 3.19 min | |

Effect on Bed:

| | | |
|---|---|---|
| Residency time in pyrolysis bed | = | 38 sec |
| Mass of biomass in pyrolysis bed | = | 4.15 kg |
| Packed bed volume of biomass | = | 0.02 $m^3$ |
| Percentage packed bed of total bed volume | = | 24% |

The particle radius, specified in appendix J, is based on an assumption made on the average particle dimension. Assuming a spherical particle, this value is then used to determine surface area of the particle. Initial temperature, final temperature and thus change in temperature are values taken from the energy and mass balance calculations, as discussed previously. A value for heat flow from the surface to the centre of the particle is then derived using Fourier's law shown in equation 13.14.

$$\dot{Q}_x = -\kappa A \frac{dT}{dx} \tag{13.14}$$

[Moran and Shapiro, 2000]

| | | | |
|---|---|---|---|
| Where: | $\dot{Q}_x$ | = | Heat transfer in the x direction (W) |
| | $\kappa$ | = | Thermal conductivity within the particle (W/mK) |
| | $A$ | = | Surface area ($m^2$) |
| | $dT$ | = | Change in temperature (K) |
| | $dx$ | = | Distance in x direction (radius of particle) (m) |

The thermal conductivity for wood is defined in appendix J.

The volume of the particle is calculated from the radius, assuming that the particle is spherical. The mass of the particle is calculated using the volume and an assumed particle density, defined in appendix J.

The following equation is therefore used to calculate the change in internal energy in the particle:

$$c_v = \frac{du}{dT} \tag{13.15}$$

[Moran and Shapiro, 2000]

| | | | |
|---|---|---|---|
| Where: | $c_v$ | = | Specific heat (J/kgK) |
| | $du$ | = | Change in specific internal energy (J/kg) |

Solving for $du$ and multiplying mass therefore provides a value for the change in internal energy ($U_2 - U_1$), in Joules.

Since the units for $\dot{Q}$ are Watts, or Joules per second, the change in internal energy is divided by $\dot{Q}$ to provide a value for time in seconds. This is the time that it takes for heat to be transferred from the surface of the particle to its centre, through conduction. As was mentioned earlier, it is assumed that pyrolysis occurs instantaneously as the material reaches the required temperature. We can therefore assume that as the particle is entirely pyrolysed in the time it takes for the heat to transfer to its centre. That is the time calculated above.

The energy and mass balance calculations define a value for the percentage of biomass that is gasified (or pyrolysed). By taking this percentage and multiplying it by the time it takes for a particle to be pyrolysed, a value for the residency time in the bed is calculated. The approximation that pyrolysis occurs linearly with time is a close enough approximation for the purposes of the present study. Following from this, since the mass flow rate of biomass into the bed is defined, the bulk mass of biomass in the bed can be calculated. Assuming a bulk density for the biomass, as defined in appendix J, a volume is calculated and thus, based on the volume of the bed calculated in the fluid dynamics section of this chapter, the percentage packed bed of the total volume of the bed may be calculated. That is, under non-fluidisation conditions, the percentage of the bed that contains biomass.

The volume of the bed must allow for expansion of the biomass under fluidisation conditions. This information is therefore used to verify that the designed and specified bed size and geometry is appropriate.

A similar procedure is then followed for the combustion bed where the following calculations are relevant:

Conduction in a particle:

| | | |
|---|---|---|
| Radius of particle | = | $2.5\times10^{-4}$ m |
| Surface area | = | $7.9\times10^{-7}$ $m^2$ |
| Initial temp | = | 600°C |
| Final temp | = | 906°C |
| dT | = | 306°C |
| Heat flow from surface to centre of particle | = | 2.88 W |

Internal energy change of particle:

| | | | |
|---|---|---|---|
| Volume of particle | = | $6.54\times10^{-11}$ $m^3$ | |
| Mass of particle | = | $9.82\times10^{-8}$ kg | (assuming particle is a sphere) |
| U2-U1 | = | $2.40\times10^{-2}$ J | |
| Time to transfer heat | = | $8.33\times10^{-3}$ sec | (taken as instantaneous) |

Effect on Bed:

| | | |
|---|---|---|
| Flow rate sand | = | 20 kg/sec |
| Mass of sand in combustion bed | = | 0.17 kg |
| Packed bed volume of biomass | = | $1.16\times10^{-4}$ $m^3$ |
| Packed bed of total bed volume | = | 0.143% |

Here the particle of interest is the sand rather than the biomass. It is a much smaller particle with different characteristics to that of the biomass. The resultant time to transfer heat is very small and can thus be taken as instantaneous. Therefore, there is not a minimum required residency time for the sand in the combustion bed to ensure that the sand is sufficiently heated. The size and geometry of the combustion bed is therefore dependant only on the fluid dynamics, as was discussed previously.

The percentage packed bed of the total volume of the bed is calculated and is essentially negligible. The sand will therefore be in the combustion bed for longer than required to heat it.

## 13.5 Control System

Until now, the sections of this chapter have only considered design and analysis from a technical validation point of view. In order to properly cost out the system an assessment of the control system, including piping and instrumentation, is necessary. Control system design looks at the system as a whole and considers the logistics of managing all of the components together. A series of integrated and automated feedback loops employ the use of P, PI and PID controllers to run the system, without significant input from the user to run the system.

Methods discussed in Shinskey [1979] and Raven [1995] have been reviewed and a simplified approach adopted for control system design, suitable for the purposes of the present study. That is, a first pass look at control system design is made, sufficient to demonstrate technical feasibility and while the system is not fully costed out here, it will help to inform future costing analysis of the system components. Table 13.3 shows the control system design based on this approach and defines a code system for each control component, where the components include controllers, valves and sensors. Figures 13.14 and 13.15 show schematics of the control system design, displaying the code system graphically.

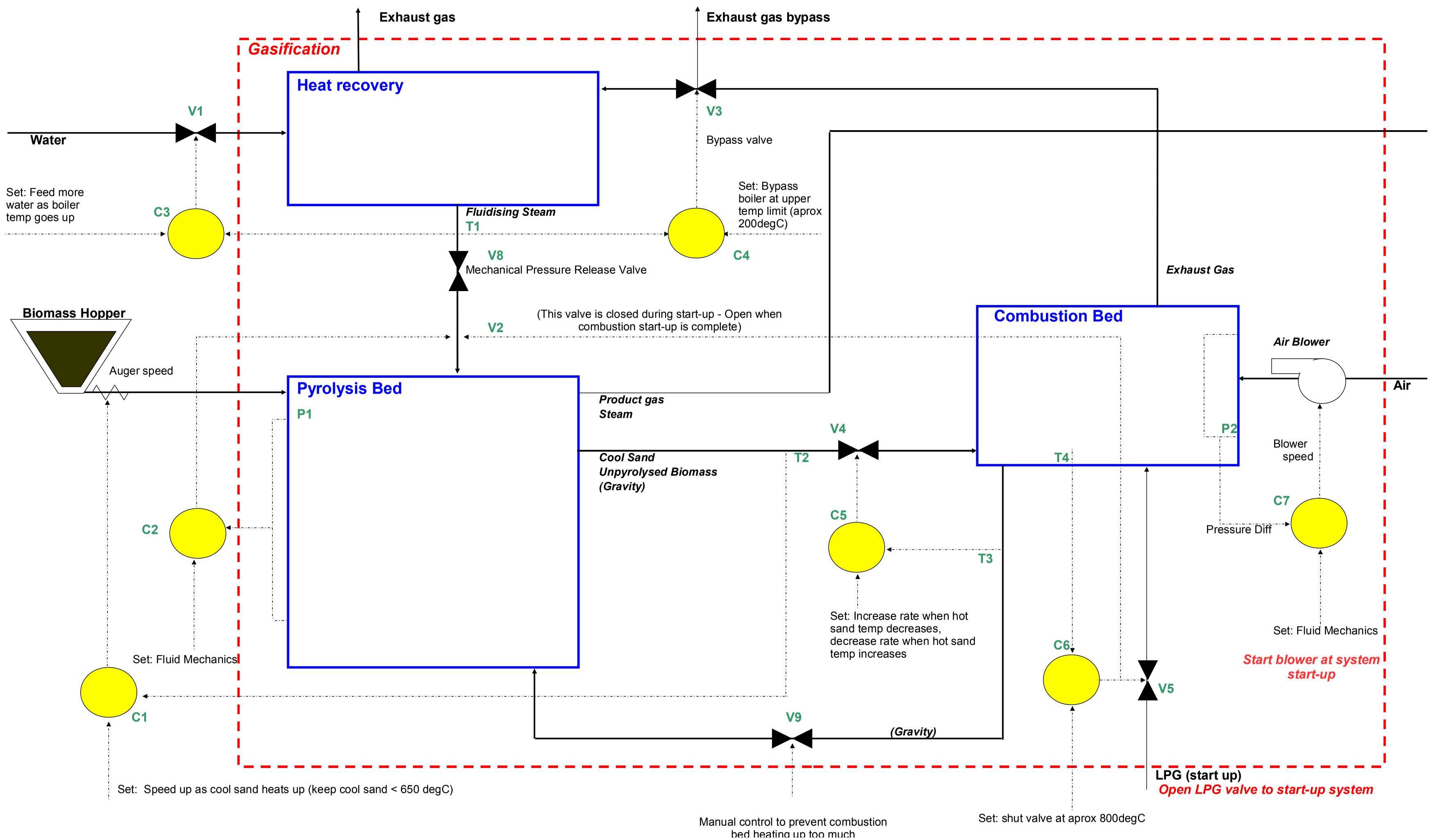



Figure 13.14: Piping and instrumentation diagram - Gasification

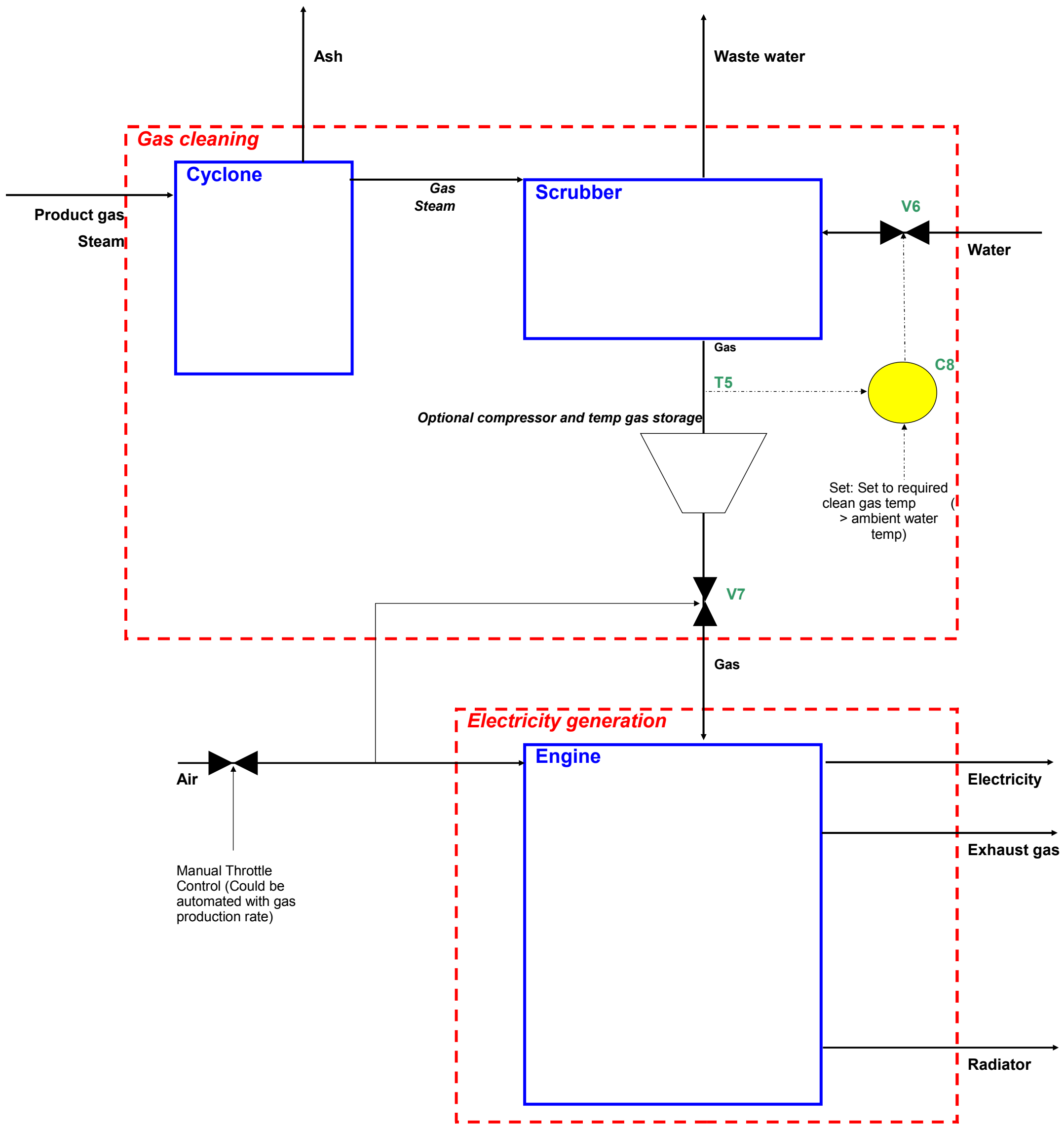



Figure 13.15: Piping and instrumentation diagram - Gas cleaning and electricity generation

**Controllers**

| Code | Type | Component Controlled | Process Variable | Manipulated Variable | Set |
|---|---|---|---|---|---|
| C1 | PID | Biomass Auger | T2 | Auger speed | Less than 650°C |
| C2 | PI | V2 | P1 | Steam flow rate | Fluid Mechanics |
| C3 | PI | V1 | T1 | Boiler feed water | Proportional to T1 |
| C4 | PID | V3 | T1 | Exhaust gas | Upper temp limit (aprox 200°C) |
| C5 | PID | V4 | T3 | Cool sand flow rate | Proportional to T3 |
| C6 | on/off | V5 | T4 | LPG - open/shut | 800°C |
| C7 | PI | Air Blower | P2 | Blower speed | Fluid Mechanics |
| C8 | PID | V6 | T5 | Scrubber water flow rate | Manual |

**Valves**

| Code | Type | Fluid Controlled | Controller | Actuator |
|---|---|---|---|---|
| V1 | Globe valve | Boiler feed water | C3 | Electromechanical (motor) |
| V2 | Butterfly valve | Fluidising steam | C2, C6 | Electromechanical (motor) |
| V3 | 3 way ball valve | Comb bed exhaust gas | C4 | Electromechanical (motor) |
| V4 | Butterfly valve | Cool sand/biomass | C5 | Electromechanical (motor) |
| V5 | Solenoid valve | LPG | C6 | Electromechanical (solenoid) |
| V6 | Globe valve | Scrubber feed water | C8 | Electromechanical (motor) |
| V7 | Butterfly valve | Clean gas | Engine throttle | Manual |
| V8 | Pressure release valve | Steam | Manual set | Mechanical |
| V9 | Butterfly valve | Hot sand | Manual (drives system) | Manual |

**Sensors**

| Code | Type | Component Measured | Output Sent To |
|---|---|---|---|
| P1 | Pressure differential | Pyrolysis bed | C2 |
| P2 | Pressure differential | Combustion bed | C7 |
| T1 | Temperature | Fluidising steam | C4 |
| T2 | Temperature | Cool sand | C1 |
| T3 | Temperature | Hot sand | C5 |
| T4 | Temperature | Combustion bed | C6 |
| T5 | Temperature | Clean gas | C8 |

Table 13.3: Control System Design

During the startup phase, the blower is switched on and since T4 is less than the set temperature of C6, LPG is introduced to the combustion bed. When the T4 set temperature is reached, a signal is sent to V2 in order to introduce steam to the pyrolysis bed, thus completing the system startup phase and moving into the system continuous phase. C2 maintains fluidisation within the pyrolysis bed by measuring the pressure differential within the bed and adjusting the valve controlling steam accordingly. This control loop is to be set according to the fluid dynamic calculations for the bed. C1 maintains the correct temperature range within the pyrolysis bed by monitoring T2 at the outlet and adjusting the auger speed and thus the feedstock flow rate accordingly. C3 monitors T1 and ensures that the steam temp is within the set range. This is done by adding more water into the boiler as the temperature goes up. C4 is essentially a backup system that bypasses heat from the boiler if it goes beyond its temperature range, thus preventing the boiler from overheating. C5 is designed to increases the rate through V4 when T3 decreases and decrease the rate through V4 when T3 increases. In this way the temperature of the hot sand is maintained within the set range. C7 monitors the pressure differential within the combustion bed with P2 and thus keeps the fluidising air within range of fluidisation. Again, this control loop is to be set according to the fluid dynamic calculations for the bed. Finally, C8 controls water flow rate through the scrubber, set to a specified clean gas temperature.

The control system is designed to require only minimal involvement from an operator. V9 is the manually controlled valve that adjusts the gravity fed hot sand flow rate, essentially driving the system. By allowing a greater flow rate of hot sand, heat energy is taken out of the combustion bed. T3 begins to decrease causing C5 to further open V4, thus providing more fuel for the combustion bed. As greater amounts of heat energy are removed from the combustion bed, a greater amount is thus introduced to the pyrolysis bed. T2 begins to increase causing C1 to increase the auger speed and thus increase the production rate of the system. Similarly, by manually reducing the hot sand flow rate through V9, an overall reduction in the production rate occurs.

As stated previously, this is a preliminary design for a control system sufficient for the purposes of the present study. The next design iteration would require analysis of each controller's time constant and thus optimisation of the performance of the control system. The mathematical relationship between the controlled variables and associated actuated signal should be assessed by establishing a mathematical description of each component's operation in relation to its signal. Such an analysis is beyond the scope of this study.

## 13.6 Optimisation

The design process adopted here for the circulating, twin bed gasifier involves development of a fully integrated spreadsheet. As discussed throughout this chapter, each component is assessed in terms of its own function, as well as its relationship to the rest of the system. This assessment involves rigorous consideration for energy and mass flows, fluid dynamics and system control and instrumentation. In balancing the model such that all parameters are accounted for, there are many solutions that may result in any number of outcomes in terms of system efficiency and production rate. A procedure has thus been derived to determine an optimum solution for the system for a given set of environmental conditions and feedstock flow rate. Firstly, the procedure for balancing the model is as follows:

1. Set ambient variables - water temp; air temp.
2. Set technical variables - steam temp; scrubber water rate; engine efficiency; engine exhaust temp; biomass moisture content.
3. Set biomass flow rate - This can correspond to Waste Transfer Station analysis or otherwise.
4. Select sand flow rate and percentage biomass gasified

5. Vary the cool sand temperature to balance the heat flow rate in the combustion bed.

For the system to be balanced, the heat flow rate balance in the combustion bed must equal zero.

In following this procedure, a complication arises in selection of the appropriate values for sand flow rate and percentage biomass gasified. These values can be set anywhere within a large range and the model will still balance. It is however preferable to find a combination of input values such that the gas production rate per unit feedstock rate is maximised, thus maximising electricity production and revenue from the system. Solutions for a number of scenarios are run in order to identify the optimum configuration. Table 13.4 and figure 13.16 show the resulting power output from each of these scenarios. What is evident in the graph is that each sand flow rate scenario tends to peak at some percentage biomass gasified leading to a maximum power output.

| Percentage biomass gasified | Hot sand °C | Cool sand °C | Power out of Engine kW |
|---|---|---|---|
| **Sand rate = 2 kg/sec** | | | |
| 0% | 1289 | 680 | 0 |
| 10% | 1216 | 611 | 13.6 |
| 20% | 1138 | 542 | 33.9 |
| 30% | 1055 | 475 | 57 |
| 40% | 966 | 406 | 78.3 |
| 50% | 870 | 336 | 91.1 |
| 60% | 764 | 264 | 88.6 |
| **Sand rate = 5 kg/sec** | | | |
| 0% | 1342 | 939 | 0 |
| 10% | 1239 | 832 | 12.4 |
| 20% | 1134 | 727 | 34.2 |
| 30% | 1026 | 623 | 58.2 |
| 40% | 915 | 520 | 76.4 |
| 50% | 800 | 415 | 79.8 |
| 60% | 680 | 309 | 59.6 |
| **Sand rate = 10 kg/sec** | | | |
| 0% | 1314 | 9727 | 0 |
| 10% | 1206 | 864 | 14.1 |
| 20% | 1098 | 755 | 36.2 |
| 30% | 988 | 647 | 58.8 |
| 40% | 876 | 539 | 73.5 |
| 50% | 761 | 431 | 73.3 |
| 60% | 643 | 320 | 41.7 |
| **Sand rate = 20 kg/sec** | | | |
| 0% | 1298 | 990 | 0 |
| 10% | 1189 | 880 | 14.9 |
| 20% | 1079 | 770 | 37.1 |
| 30% | 968 | 660 | 58.7 |
| 40% | 855 | 550 | 71.3 |
| 50% | 741 | 438 | 68.7 |
| 60% | 624 | 325 | 30.9 |

Table 13.4: Model optimisation - Scenario results

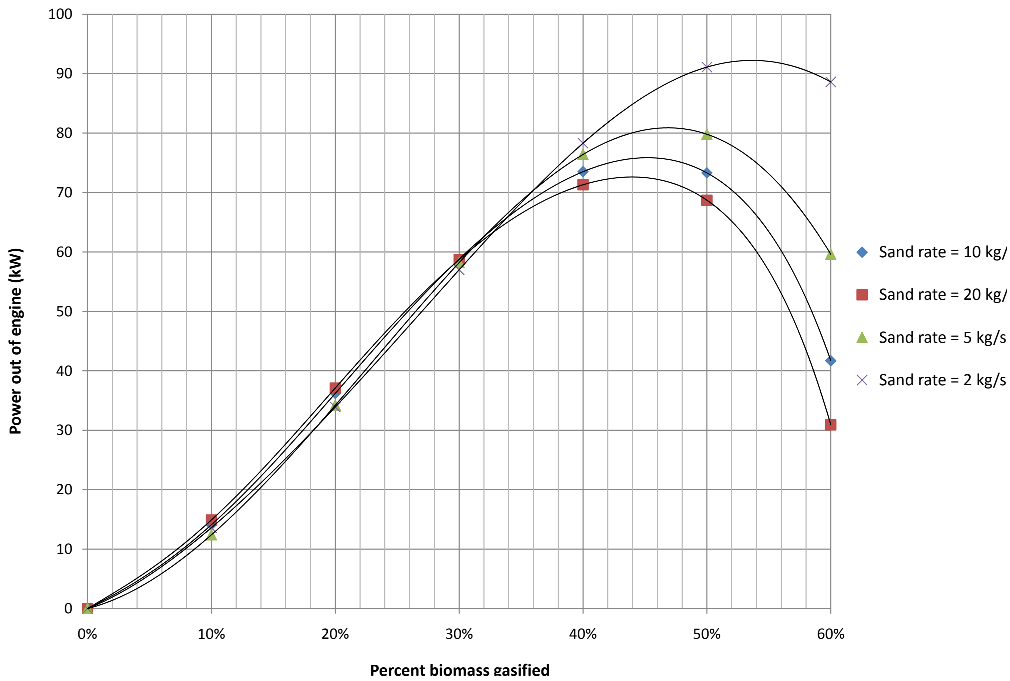



Figure 13.16: Model optimisation graph - Scenario results

Differentiating the equations of the curves shown in figure 13.16 and solving for zero finds the point at which the curve reaches maximum power output. Table 13.5 summarises these results.

| | | | Maximum Power Output | |
|---|---|---|---|---|
| **Sand Rate kg/sec** | **Hot sand °C** | **Cool sand °C** | **Power out of Engine kW** | **Biomass gasified** |
| 2 | 832 | 310 | 91.9 | 53.65% |
| 5 | 786 | 393 | 72.9 | 46.86% |
| 10 | 757 | 420 | 65.4 | 45.19% |
| 20 | 744 | 438 | 61 | 43.97% |

Table 13.5: Model optimisation summary

Evident in table 13.5 is that the lower the mass flow rate of the sand, the higher the power output of the system. Lowering the mass flow rate of the sand however tends to lower the bed temperatures. The limiting factor thus becomes the cool sand temperature, which must be kept greater than 600°C to prevent tars forming in the pyrolysis bed, as discussed in section 13.1.

Following from this, table 13.6 shows the series of power outputs that result by holding the cool sand temperature at 600°C and varying the sand flow rate. Shown in graphical terms in figure 13.17 there is a clear increase in power output with greater sand flow rates. This curve however tends towards some asymptote and thus a value for sand flow rate must be selected that is as high as possible but still within a manageable range in terms of the logistics of transporting the sand around the system.

| **Percentage biomass gasified** | **Hot sand** | **Sand Flow Rate** | **Power out of Engine** |
|---|---|---|---|
| **%** | **°C** | **kg/sec** | **kW** |
| 12 | 1204 | 2 | 16.4 |
| 19 | 1055 | 4 | 35.7 |
| 21 | 998 | 6 | 41.5 |
| 22 | 968 | 8 | 43.9 |
| 23 | 950 | 10 | 45.1 |
| 24 | 937 | 12 | 45.8 |
| 24 | 928 | 14 | 46.2 |
| 24 | 921 | 16 | 46.5 |
| 24 | 916 | 18 | 46.7 |
| 25 | 912 | 20 | 46.9 |

Table 13.6: Power output with cool sand set to 600°C

In summary, under this feedstock flow rate scenario, the optimum arrangement is found to be as follows:

- Dry biomass flow rate = 0.07kg/sec
- Cool sand temperature = 600°C
- Sand flow rate = 20 kg/sec (Considered the greatest manageable flow rate)
- Percentage biomass gasified = 25%

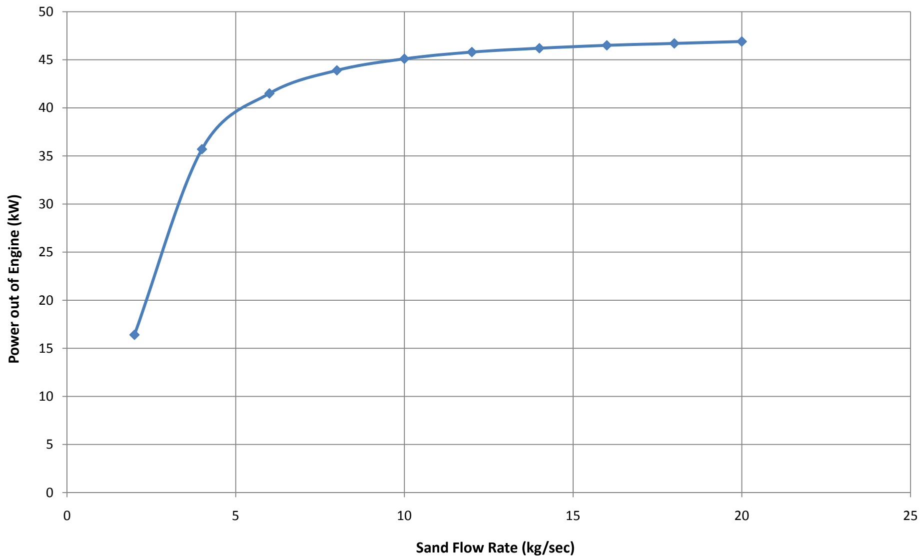



Figure 13.17: Power output with cool sand set to 600°C

- Resultant power output from the model = 46.9 kW

While this is the only dry biomass flow rate scenario that has been assessed, it is expected that other feedstock flow rate arrangements would be optimised also by **minimising the cool sand temperature and maximising the sand flow rate**.

The configuration presented throughout this chapter has taken one further consideration into account. That is the carbon offset potential of the system. Discussed in detail in a later section, the model has been optimised such that its power output is maximised (as discussed above), but also such that Brighton Council's corporate emissions may be entirely offset by the system.

## 13.7 Options for Efficiency Improvements

The design, as discussed throughout this chapter, considers the fundamentals of the design only, sufficient to demonstrate feasibility of the system. Further development of the design would require more comprehensive consideration for efficiency losses through the system. This extra detail in the design would likely lead to a better overall efficiency in terms of the electricity output to feedstock flow rate ratio. The present section identifies some of the concepts that may lead to improved system efficiencies, their comprehensive investigation being beyond the scope this study.

In terms of heat energy flow throughout the system, it is preferable to try to conserve the energy within the system and minimise losses in the waste streams. For the optimised feedstock flow rate scenario discussed, there remains significant energy flow rates at the following points in the model:

- Boiler exhaust (236kW)
- Scrubber waste water stream (1379kW)
- Engine radiator (50kW)
- Engine exhaust (106kW)

While these values for heat flow rate appear very high, it should be noted that only a percentage has potential to be reclaimed. It is not the heat flow rate it's self but the difference between that and the ambient value that has any potential for recovery. The heat flow rate of the ambient water stream into the scrubber for example is 617kW.

Furthermore, there will be a limit to the achievable efficiency on the approach to heat recovery, i.e. since one hundred percent efficiency is not achievable, some amount of loss will be unavoidable.

There are a number of points in the model that could benefit from addition of heat that may improve the component efficiency and thus the overall efficiency. These points include the following:

- Biomass drying
- Biomass preheating

- Combustion bed fluidising air preheating
- Engine air preheating
- Engine syngas preheating

Thus there potentially exists an opportunity to recycle waste heat by rerouting it within the model.

In terms of the energy and mass balance calculations, recovery of waste heat is theoretically simple. It is the practical application of the theory that becomes complex. For example, if the boiler exhaust heat is used to dry and preheat the biomass, the process must occur without igniting or pyrolysing the biomass and thus there is a limit to how much energy may be conserved in this way. There is also a logistical issue in achieving the maximum heat recovery without combustion or pyrolysation.

The transfer of temperature between fluid streams also poses a complication. While there is significant energy flow available in the scrubber waste water stream, its temperature is only 35°C. Recovery of this waste heat stream is therefore limited and would most likely not be appropriate for the uses of heat identified above.

Identified as a significant point of loss in the model is the conversion of syngas to electricity. The model discussed specifies an engine efficiency of 25%, appropriate for standard internal combustion engine technology [Green and Perry, 2007]. An alternative means of conversion that has not been explored in this study is the use of hydrogen fuel cells. Such a technology would come at a much greater cost but that cost may be justified by improved efficiency and thus electricity revenue.

An alternative approach to recovery of waste heat may be to locate the plant close to an alternative demand for heat, there is opportunity to setup a larger system similar to a conventional combined heat and power, cogeneration facility. This approach would likely achieve good efficiency improvement on a larger scale.

There is also opportunity for further electricity production by including a waste heat recovery power plant on one or more waste heat streams. Such a system could operate by means of a steam turbine in a Rankine cycle or by any other heat to electricity conversion technology.

In order to ascertain the technical, economic and environmental implications of these suggestions, a comprehensive assessment is required and should be incorporated into a detailed design. This preliminary investigation into the options for energy efficiency improvements has identified that there are many potential opportunities that could act to further justify the economics and environmental benefit of the system.

In concluding this chapter it is necessary to provide reference to a number of publications that have been highly valuable for the purpose of developing understanding, but have not yet been referenced in the text. These references include Hydro-Electric Commission, Planning and Public Affairs Group [1986]; W.A. Timber Industry Training Committee (Inc.) et al. [1988]; Australia. Dept. of Resources and Energy et al. [1984]; Leva [1959]; Gilchrist [1977]; Nowacki [1981] & Akbarzadeh [1992].

# Chapter 14

# Environmental Assessment

## 14.1 Emission Reduction Potential

Core to the present assessment of green waste gasification, and the study as a whole, is the emission reduction potential of the technology relative to its economic implication and relative to the other potential avenues for emission reduction. This section aims to consider that emission reduction potential and the broader environmental context of the system.

As stated earlier, the objective here is to test whether the greenhouse gas emission reductions and offsets achieved by the model are better than the status quo and whether they are sufficient enough to justify the system.

In order to provide a meaningful assessment, this study adopts the methodology and guidelines established by the Australian Government's Department of Climate Change. This methodology has been designed for use by companies and individuals to estimate greenhouse gas emissions for reporting under various government programs and for their own purposes, [Department of Climate Change, 2009a] & [Department of Climate Change, 2009b].

From the process and scenario for conversion of biomass to electricity discussed in the previous chapter, the following emission data is derived:

$$
\begin{aligned}
\text{Gasification Exhaust } (CO_2) &= 0.162 \text{ kg/sec} \\
\text{Electricity Generation Exhaust } (CO_2) &= 0.013 \text{ kg/sec} \\
\text{Total } (CO_2) &= 0.174 \text{ kg/sec} \\
\text{Annual } (CO_2) &= 1045 \text{ tonnes/year}
\end{aligned}
$$

While these emissions appear to be significant, in accordance with the National Greenhouse Accounts Technical Guide [Department of Climate Change, 2009b], they may be neglected. The report states that carbon dioxide produced from the flaring of methane from landfill gas, or other emission sources derived from biomass, should not be reported. While this technology is not directly flaring methane from landfill gas, it is preventing the generation of methane gas by diverting the green waste stream away from landfill. Furthermore, it is converting the green waste stream to carbon dioxide, as would be the case if it was to be disposed of in landfill with the resultant methane gas flared.

The rationale for the above statement is based on the assumption that the organic material going to landfill (or in this case to a gasification facility) consists only of material that has recently lived or grown. That is, it has recently existed in a state that required it to sequester carbon from the atmosphere. If the organic material has been mined or rather, it has not in recent time's sequestered carbon from the atmosphere, then the above emissions would require consideration. Green waste, the focus of the present assessment, has recently been grown and in doing so has taken carbon dioxide out of the atmosphere. The effect of the emissions discussed above is to simply replace the sequestered greenhouse gases. In doing that the carbon cycle is balanced. Any greenhouse gas reductions that are achieved in conversion of the green waste back into carbon dioxide should be considered a contribution to a net environmental benefit. These benefits are discussed throughout the remainder of this chapter.

There are two perspectives from which direct emission prevention is achieved by the system. Firstly, with the prevention of methane gas generation, significant greenhouse gas emissions are avoided. Secondly, with the generation of environmentally sound electricity, emissions produced by dirty electricity are offset, where dirty electricity refers to electricity that has a greater than zero emission factor associated with it. There are in fact further environmental benefits to green waste gasification that are by the present study considered indirect and complex. They will be discussed in brief later in this chapter, without numeric evaluation.

The quantity of methane that would be generated from green waste disposal at landfill is estimated using a carbon mass balance approach [Department of Climate Change, 2009b]. The following equation applies:

$$CH_4(t) = dC_a(t) \times F \times 1.336 \times 21 \tag{14.1}$$

| | | | |
|---|---|---|---|
| Where: | $CH_4$(t) | = | Mass of methane in year t (tonnes of $CO_2$e/year) |
| | $dC_a(t)$ | = | Quantity of decomposable, degradable organic carbon from newly deposited waste arriving at the landfill in year t (tonnes/year) |
| | $F$ | = | Fraction of $CH_4$, by volume, generated in landfill gas (equal to 0.5) |
| | 1.336 | = | Conversion factor from mass of C to mass of $CH_4$ |
| | 21 | = | Conversion factor from $CH_4$to $CO_2$e |

Further defining $dC_a(t)$:

$$dC_a(t) = C_a(t) \times DOC_F \times MCF \tag{14.2}$$

Further defining $C_a(t)$:

$$C_a(t) = Q(t) \times DOC \tag{14.3}$$

| | | | |
|---|---|---|---|
| Where: | $C_a(t)$ | = | Total quantity of degradable organic carbon in newly deposited waste at the landfill during the year t (tonnes/year) |
| | $DOC_F$ | = | Fraction of degradable organic carbon dissimilated (equal to 0.5) |
| | $MCF$ | = | Methane correction factor for aerobic decomposition (equal to 1) |

| | | | |
|---|---|---|---|
| Where: | $Q(t)$ | = | Total quantity of green waste stream in year t (tonnes/year) |
| | $DOC$ | = | Fraction of degradable organic carbon by waste type (green/garden type) (equal to 0.2) |

[Department of Climate Change, 2009b]

Here, an abbreviated version of the procedure is presented, neglecting any decomposable, degradable organic carbon accumulated in the landfill prior to the time of green waste going to landfill. This is because in the present application there is no prior accumulation of biomass to consider.

Furthermore, the abbreviated procedure is considered for the entire life of the decomposable, degradable organic carbon in landfill. That is, it is not limited to the single year for which it is reported as per the procedure presented in Department of Climate Change [2009b]. This is appropriate for the application since all emissions that would have occurred if the green waste was to go to landfill are avoided and not just those of the present year.

From the above procedure, the following results are obtained:

$$
\begin{aligned}
\text{Wet biomass flow rate} &= \text{659 tonnes/year (sourced from the energy and mass balance)} \\
C_a(t) &= 131.79 \text{ tonnes/year} \\
dC_a(t) &= 65.89 \text{ tonnes/year} \\
CH_4 &= 924 \text{ tonnes } CO_2\text{e/year}
\end{aligned}
$$

That is, the mass of carbon dioxide equivalent that is offset by diverting the green waste stream from landfill and thus avoiding methane gas production due to anaerobic decomposition.

As mentioned earlier, the second perspective from which emission reductions are recognised from the implementation of such a system is through the generation of environmentally sound electricity and thus the offset of emissions produced by dirty electricity. The following is calculated for this consideration:

$$
\begin{aligned}
\text{Energy Produced Per Year} &= 48803 \text{ kW}\cdot\text{hrs/year} \\
CO_2\text{e if Taken from Grid} &= 6 \text{ tonnes } CO_2\text{e/year}
\end{aligned}
$$

Assuming that the plant is sited at the waste transfer station and thus its hours of operation are the same as waste transfer station (1664 hours per year), the energy produced per year is determined. Following from this, the annual carbon dioxide equivalent is calculated by multiplying the energy produced per year by the electricity conversion factor, as defined in appendix J. That is, the amount of emissions that would have been generated by usage of the calculated amount of energy, in Tasmania, during the year 2007. Electricity demand across Australia is projected to continue to rise which is likely to lead to increased electricity imports into Tasmania [Energy Supply Association of Australia, 2008]. As this electricity is predominantly produced through high emission processes the electricity conversion factor is likely to increase, thus leading to greater emission offsets in this way, from the plant in future years.

Combining the two values for carbon dioxide equivalent reductions gives a total emission offset of **931 tonnes $CO_2$e/year**.

Neglecting emissions associated with water and sewer, Brighton Council's combined corporate greenhouse gas emission profile for 2007 was 891 tonnes $CO_2$e. The potential offset of the system discussed throughout this chapter is thus 104% of the Council's corporate emission profile, therefore providing a better than carbon neutral outcome for the Council.

The approximate annual tonnage of separable green waste through the waste transfer station is 1243 tonnes, based on the survey shown in table K.1. Thus for Brighton Council to offset 104% of its corporate emissions through gasification of green waste, it would be able to source well in excess of its feedstock from the waste transfer station. In fact the system would only require 53% of the waste transfer station's separable green waste stream to make Brighton Council carbon neutral.

As mentioned earlier, further to the direct emission savings that are discussed above, there are indirect emission savings that would occur from such a system. Distributed power generation is a concept now commonly recognised as having significant potential for providing communities with energy security and thus resilience to climate change [Gore, 2009]. Small scale biomass gasification lends itself very well to distributed power generation as it can be scaled according to a biomass waste stream and located at or near a biomass waste stream source or electricity demand point. Moreover, such systems could be operated during periods of high electricity demand and shut down during periods of excess electricity in the grid, essentially using the biomass as stored energy that could be accessed as required. A distributed generation grid avoids significant transmission losses in the system as electricity can be produced and used at and when it is required. There is thus a larger context in which this technology should be considered. That is, while climate change mitigation from a local government perspective is the focus of the present study, adoption of this technology may be equally applicable to industry and agriculture in the wider community.

## 14.2 Other Environmental Considerations

Further to the greenhouse gas emission flux discussed in the previous section, there are a number of other environmental considerations that must be looked at in the viability assessment of such an initiative. While their full investigation is not undertaken here, it is important for completeness that the issues are raised.

Known to be an issue in the combustion of organic materials, particularly at high temperatures, is the formation of $NO_x$. $NO_x$ can be created in varying concentrations depending on the conditions under which combustion occurs and the actual composition of the fuel. They are a form of greenhouse gas and are a component of smog, therefore contributing to many other environmental and health related issues. While it is unclear from the model how significant the issue of $NO_x$ is, the impacts of $NO_x$ maybe minimised by implementing pollution control measures such as selective catalytic reduction at the combustion bed exhaust [Green and Perry, 2007]. This should be assessed during detailed design and commissioning of a facility.

In order to maintain the environmental integrity of a facility and the system's efficiency, the provenance and therefore quality of feedstock is of critical importance. If contaminated material was to be passed through the facility, there could be many negative follow on effects to the system's function and emission profile. This is particularly of concern with a facility located at a general waste landfill site or waste transfer station, as is proposed here. In order to avoid the issue, stringent regulation of the facility must be implemented such that all feedstock is properly quarantined and processed prior to being introduced to the system. This may lead to an additional but necessary cost in the operation of the facility. Further to this there maybe emissions associated with the degradation of feedstock during the quarantining or stockpiling stages. This has not been evaluated or considered in the model.

The composition of the ash that is removed as part of the gas cleaning stage is unknown and will depend on the composition of the feedstock and conditions under which pyrolysation occurs. As part of the commissioning phase of a facility, the composition of the ash will require analysis so as to ensure that it is properly disposed of.

# Chapter 15

# Desktop Economic Assessment

Further to the environmental assessment, discussed in the previous chapter, justification of a green waste gasification facility must also consider the business case in terms of its economics. That is, for a system to be viable it must demonstrate a favorable cost-to-benefit ratio both in terms of its environmental and economic outcomes.

The present section discusses the issues of capital investment and return on investment and based on a preliminary 'desktop' analysis, looks at whether a financially justified business case exists for the development of a green waste gasification system, located at the Brighton Council waste transfer station.

Table 15.1 provides a desktop economic assessment based on a hypothetical loan or capital investment. It should be considered preliminary only since it may have neglected costs that would become apparent in a more detailed assessment.

Both the sale values of electricity and renewable energy certificates (RECs) will change in time. The values used here are thus estimates of what might be a likely average. The Glenorchy landfill offset and transport to Glenorchy offset are the amount of money that would be saved by not taking the green waste to landfill. This is based on the cost per tonne as at July 2007 and the annual amount of material that would be processed by the facility. The Public Utility Regulatory Policies Act (or PURPA) is a law that was passed in the USA in 1978 making the

| **Annual Expenditure** | | |
|---|---|---|
| Maintenance | $7,370.24 | (5% of capital) |
| Labour for operation | $12,500 | (25% of a wage including oncosts) |
| Decommissioning | $0.00 | |
| Feedstock transportation | $0.00 | |
| **Annual Revenue** | | |
| Electricity sales | $9,760.54 | |
| RECs | $2,098.52 | |
| *Cost per tonne to Glenorchy Landfill* | *$27.14* | (as at July 2007) |
| Glenorchy landfill offset | $17,883.74 | |
| *Cost per tonne to transport to Glenorchy* | *$18.00* | (as at July 2007) |
| Transport to Glenorchy offset | $11,860.99 | |
| *Gate fee, per tonne* | *$5.00* | (assume one load = one tonne) |
| Gate fee | $3,294.72 | |
| **Annual Cash Flow** | | |
| Gross Revenue | $44,898.50 | |
| Net Revenue | $25,028.26 | |
| **Loan** | | |
| Loan interest rate | 11% | (assumed) |
| Loan repayment | $25,028.26 | (annual repayment) |
| Payback period | 10 years | (interest compounded annually) |
| **Justified investment limit** | **$147,404.85** | |

Table 15.1: Ongoing costs and payback period

'avoided cost' approach to the economic assessment of a renewable energy project both valid and best practice [United States Government, 1978].

Annual expenditure and revenue are summed to provide a value for net revenue which is then specified as the annual loan repayment.

The maximum investment that is justified in economic terms is calculated based on an assumed interest rate of 11% (likely to be conservative for Council as Council has access to low interest loans) and payback period of 10 years. That is, based on conditions that might be considered a reasonable return on investment.

The final value (justified investment limit) must include all initial costs including site works, pre-processing equipment and so on.

It should also be noted here that this assessment is based on a system designed only to offset Brighton Council's carbon emissions. That is, it is designed to process just 53% of the available green waste in order to make Council carbon neutral. If the model was reconfigured to process all of Council's green waste stream and therefore achieve significantly better environmental gains, it would likely increase the economic viability also. This option is explored further in appendix L.

This analysis has not considered the potential to generate revenue through the sale of carbon credits. At the time of writing legislation in Tasmania did not allow for the sale of carbon credits generated from this type of system and thus it is not evaluated here. If in the future the sale of carbon credits becomes available to this project it could become a significant additional revenue stream and therefore greatly improve the economics of the facility.

In the future there is also the possibility of a government legislated higher feed in tariff for small scale renewable energy installations. If higher feed in tariffs were to eventuate it would result in a significantly improved revenue steam from electricity sales and thus act to reduce the payback period.

There is also good potential to improve the economics through a 'peak load' arrangement where green waste is stockpiled during times of low electricity value and processed only when electricity prices on the open market move above a set threshold.

Further development of the business case is beyond the scope of the present study however the next phase should be to seek expressions of interest from commercial operators for the detailed design and construction of the facility. These could then be examined against the analysis presented here in order to assess the viability of a project.

# Part IV

# Study Conclusions

# Chapter 16

# Conclusions

As stated in the introduction there has been two primary objectives of this study. The first aimed to assess the validity of the hypothesis that climate change mitigation can effectively be approached on the local or municipal level. The literature review provided good insight into this hypothesis, revealing that local government's direct connection with the community provides it with a significant capacity to make direct emission reductions both within the community and within its own processes. This finding was supported throughout the present study, evident particularly in part II, with the identification of a number of opportunities that are available to local government for the purpose of reducing emissions.

The second objective aimed to assess the technology options for climate change mitigation, from the local government perspective, with the intention of developing mitigation strategy for the Brighton Council. The technology review in part II effectively applied the inventory model findings of part I, in order to assess the appropriateness of a range of technologies. This process identified initiatives that were opportunities, as well as some that should not be considered. One option, green waste gasification, demonstrated particularly good opportunity from the triple bottom line perspective, thus leading to its detailed analysis in part III. Sufficient information was therefore derived from the present study to support a justified climate change mitigation strategy for Brighton Council, provided for reference in appendix L.

The methodology was designed to follow a logical progression. First, a base line data set was established; second, an assessment of the options was undertaken in relation to that data set; third, the most justified option was identified and considered in more detail. The outcomes described above demonstrate successful achievement of the study aims and therefore demonstrate the applicability of this research methodology.

A methodology for community greenhouse gas emission inventory development was established, designed to provide an appropriate input to the proceeding part to the study. This methodology was compared to alternative methodologies including a linear breakdown of the national inventory methodology as well as the CCP methodology. The derived methodology was shown to be the most applicable, however without the inclusion of the bottom up, survey based data it was lacking in information specific to the Brighton municipality. As a result it is possible that a similar outcome to the study may have eventuated by simply adopting one of the alternative, and comparatively simplistic methodologies.

The most significant difficulty that was encountered throughout the course of the study was in the attempt to take the bottom-up perspective to community inventory modeling. The response to community surveys was extremely poor and did not provide a statistically sufficient sample of the community. A good response to this survey would likely have led to identifying more specific technology opportunities for the community, based on local greenhouse gas emission problems.

In terms of project outcomes, an appropriate and justified course of action has been identified for the Brighton Council and suggestions made for its community. Given that the community inventory modeling was undertaken from the top-down perspective, it is likely that the community results will be applicable also for the other Council communities in the region. The corporate inventory was undertaken primarily from the bottom up perspective and therefore it is unclear as to its applicability to the other Council's in the region. Many of the comments made in the technology assessment were not however based purely on the inventory data sets and therefore could be considered generic for the wider community.

The main contribution of this thesis has been the identification of green waste gasification as the most justified technology approach to climate change mitigation, for the Brighton Council. It is hoped that this result will lead to a Council funding allocation or provide sufficient leverage to obtain grant funding from another source, to provide for further investigation into this technology and potentially the establishment of such a facility. Biochar was also identified as having real potential to reduce net emissions for Brighton Council, as well as derive revenue in the longer term. A combined pyrolysis initiative that has the capacity to gasify green waste for electricity, as well as produce biochar to facilitate further research in biochar use, could provide the best overall outcome to Council, discussed further in appendix L.

Adopting the recommendations of the present study will not only lead to a real saving in emissions for the Brighton Council, as well as additional revenue for the Council and its community, but it would demonstrate to the wider community that through strategic consideration of the options, real economic opportunity can be found in climate change mitigation.

# Chapter 17

# Future Research

Despite demonstrating that climate change mitigation can effectively be approached on the local level, it is relevant to question the importance of taking such a localised approach. It is possible that the same or better outcomes could have been achieved if the project was undertaken with a larger inventory scope. It is therefore suggested that further work be undertaken to assess whether Brighton Council is representative of other Councils in the region, the country or the globe. The inventories of other Councils should be assessed in terms of a triple bottom line technology comparison and then considered against that of Brighton Council.

The uniqueness of Councils as corporate entities, in terms of appropriate climate change mitigation strategy, is also left unclear. It is suggested that further work be undertaken to assess Councils against other organisations and therefore test the relevance of the present study 'corporate Council' outcomes, for other community members.

As noted in the conclusion, the importance of the present study is evident through the identification of an initiative for Brighton Council that not only demonstrates good potential to reduce emissions, but also reasonable economic returns. It is recommended that the business case for green waste gasification be further developed including the engagement of a commercial operator to provide costing for design and construct of a facility. This would allow Council to assess the true, long term cost associated with a project. It would also allow for the assessment of the proposal in the regional context, would a regional approach to green waste gasification be more economical?

Further to the above recommendations, it is recognised that climate change is a developing issue and therefore research of this type should be considered dynamic. Inventory modeling and technology comparisons should be updated as new information becomes available in order to ensure that limited funding and resources are utilised effectively and that economic opportunities in climate change are not over looked.

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# Appendices

# Appendix A

# Working Population Profile

| | Classification | Industry | Tasmania Employed | Brighton Employed | Brighton as % of State |
|---|---|---|---|---|---|
| Agricultural | A | Agriculture, forestry & fishing | 10,962 | 60 | 0.55% |
| | | **Total** | **10,962** | **60** | **0.55%** |
| Industrial | B | Mining | 1,454 | 9 | 0.62% |
| | C | Manufacturing | 20,430 | 108 | 0.53% |
| | D | Electricity, gas, water & waste services | 2,869 | 3 | 0.10% |
| | E | Construction | 12,832 | 163 | 1.27% |
| | | **Total** | **37,585** | **283** | **0.75%** |
| Commercial | F | Wholesale trade | 7,149 | 82 | 1.15% |
| | G | Retail trade | 23,744 | 198 | 0.83% |
| | H | Accommodation & food services | 13,601 | 121 | 0.89% |
| | I | Transport, postal & warehousing | 8,958 | 169 | 1.89% |
| | J | Information media & telecommunications | 3,269 | 8 | 0.24% |
| | K | Financial & insurance services | 5,252 | 6 | 0.11% |
| | L | Rental, hiring & real estate services | 2,829 | 24 | 0.85% |
| | M | Professional, scientific & technical services | 8,726 | 21 | 0.24% |
| | N | Administrative & support services | 5,246 | 49 | 0.93% |
| | O | Public administration & safety | 16,858 | 139 | 0.82% |
| | P | Education & training | 16,537 | 290 | 1.75% |
| | Q | Health care & social assistance | 22,704 | 174 | 0.77% |
| | R | Arts & recreation services | 2,826 | 37 | 1.31% |
| | S | Other services | 6,902 | 67 | 0.97% |
| | T | Inadequately described/Not stated | 2,378 | 15 | 0.63% |
| | | **Total** | **146,979** | **1,400** | **0.95%** |

Table A.1: Working Population Profile [Australian Bureau of Statistics, 1993]

# Appendix B

# Fuel Usage - Calculations

| Fuel Combustion | State | Energy content (Gross) | EF for scope 1 (Direct) | EF for scope 3 (Indirect) | Full fuel cycle EF = B+C |
|---|---|---|---|---|---|
| | | A | B | C | D |
| **Solid Fuels a** | | **GJ/t or GJ/kL** | **kg $CO_2e$/GJ** | **kg $CO_2e$/GJ** | **kg $CO_2e$/GJ** |
| Black coal for electricity | All states | 22.5 | 89.3 | 8.7 | 98.1 |
| LigniteBrown coal | All states | 10.2 | 93.2 | 0.3 | 93.5 |
| **Liquid Fuels** | | **GJ/kL** | **kg $CO_2e$/GJ** | **kg $CO_2e$/GJ** | **kg $CO_2e$/GJ** |
| Crude oil | All states | 38.2 | 69.2 | 5.3 | 74.6 |
| Other natural gas liquids | All states | 46.5 GJ/t | 60.7 | 5.3 | 66 |
| Motor gasoline (petrol) | All states | 34.2 | 67.1 | 5.3 | 72.4 |
| Aviation gasoline | All states | 33.1 | 66.7 | 5.3 | 72 |
| Aviation turbine fuel (jet kerosene) | All states | 36.8 | 69.1 | 5.3 | 74.5 |
| Kerosene | All states | 37.5 | 68.4 | 5.3 | 73.8 |
| Heating oil | All states | 37.3 | 69 | 5.3 | 74.4 |
| Diesel (Automotive Diesel Oil) | All states | 38.6 | 69.5 | 5.3 | 74.8 |
| Fuel oil | All states | 39.7 | 73.1 | 5.3 | 78.4 |
| Other petroleum products | All states | 34.4 | 69.2 | 5.3 | 74.5 |
| Liquefied Petroleum Gas | All states | 25.5 | 59.9 | 5.3 | 65.3 |
| **Biofuels b** | | **GJ/kL** | **kg $CO_2e$/GJ** | **kg $CO_2e$/GJ** | **kg $CO_2e$/GJ** |
| Ethanol (molasses) | All states | 23.4 | 0 | 54.8 | 54.8 |
| Ethanol (wheat starch waste) | All states | 23.4 | 0 | 54.5 | 54.5 |
| Biodiesel (Canola) | All states | 23.4 | 0 | 62.1 | 62.1 |
| Biodiesel (tallow) | All states | 23.4 | 0 | 57.2 | 57.2 |
| Natural Gas | Tasmania | | 51.3 | 5.8 | 57.1 |
| Wood | All states | 16.2 | 15.6 | 0 | 15.6 |

a. Energy measured as gross calorific equivalent.

b. The EF for scope 3 is indirect emissions from the extraction, production and transport of the specified fuel.

Table B.1: Fuel Usage Conversion Factors [Department of Climate Change, 2008a]

| | PJ in Tas | GJ in Brighton | kg $CO_2e$ in Brighton |
|---|---|---|---|
| **Div. A Agriculture, forestry and fishing** | | | |
| Auto gasoline-unleaded | 0.1 | 547 | 39628 |
| ADO | 3.0 | 16420 | 1228243 |
| **Div. B Mining** | | | |
| Auto gasoline | 1.5 | 9285 | 672215 |
| **Div. C Manufacturing** | | | |
| Black coal | 14.4 | 76123 | 7467700 |
| Wood, woodwaste | 3.9 | 20617 | 321621 |
| LPG | 0.6 | 3172 | 207119 |
| ADO | 0.8 | 4229 | 316335 |
| Petroleum products nec | 1.3 | 6872 | 511982 |
| Natural gas | 0.6 | 3172 | 181110 |
| **Div. D Electricity, gas and water (Excluded from fuel usage sector to avoid double counting)** | | | |
| Wood, woodwaste | 0.2 | 209 | 0 |
| LPG | 0.5 | 523 | 34141 |
| ADO | 0.2 | 209 | 15643 |
| Fuel oil | 1.4 | 1464 | 114772 |
| Natural gas | 10.5 | 10979 | 626926 |
| **Div. E Construction** | | | |
| ADO | 1.6 | 20324 | 1520249 |
| **Commercial and services *** | | | |
| Wood, woodwaste | 0.1 | 8597 | 0 |
| LPG | 0.1 | 8597 | 561393 |
| Town gas | 0.1 | 8597 | 490897 |
| **Div. I Transport & storage **** | | | |
| LPG | 0.5 | 9433 | 615969 |
| Auto gasoline-unleaded | 16.2 | 305626 | 22127341 |
| Aviation gasoline | 0.1 | 1887 | 135834 |
| Aviation turbine fuel | 1.1 | 20752 | 1546054 |
| ADO | 7.9 | 149040 | 11148189 |
| **Residential** | | | |
| Wood, woodwaste | 10.4 | 308236 | 0 |
| LPG | 0.2 | 5928 | 387074 |

* Includes divisions F, G, H, J, K, L, M, N, O, P, Q

** Energy use for transport (both for passenger and freight in all sectors) is reported under this sector

Table B.2: Energy Consumption and Associated Emissions [Australian Bureau of Agricultural Resource Economics, 2008]

## Appendix C

# Fuel Usage due to Transport - Calculations

**BUSINESS AND PRIVATE USE OF VEHICLES, Type of vehicle**

| | Laden | Unladen | All Business use (a) | To and From Work | Peronal and Other | **Total** |
|---|---|---|---|---|---|---|
| | | | **Total Kilometers Travelled in Australia (million)** | | | |
| Passenger vehicles | | | 31902 | 45257 | 80769 | **157928** |
| Motor cycles | | | ˆ206 | ˆ444 | ˆ1254 | **1905** |
| Light commercial vehicles | 17400 | 6491 | 23891 | 6742 | 6752 | **37385** |
| Rigid trucks | 5816 | 2526 | 8342 | ˆ136 | ˆ166 | **8644** |
| Articulated trucks | 5122 | 1798 | 6920 | ˆ7 | *2 | **6929** |
| Non-freight carrying trucks | | | ˆ283 | ** | ** | **ˆ283** |
| Buses | | | 2003 | ˆ22 | ˆ73 | **2097** |
| **Total Australia** | **28338** | **10816** | **73548** | **52607** | **89016** | **215171** |
| | | | **Total Kilometers Travelled in Tasmania (million)** | | | |
| Passenger vehicles | | | 669 | 785 | 2302 | **3664** |
| Motor cycles | | | ˆ4 | ˆ8 | ˆ36 | **44** |
| Light commercial vehicles | 351 | 203 | 501 | 117 | 192 | **867** |
| Rigid trucks | 117 | 79 | 175 | 2 | 5 | **201** |
| Articulated trucks | 103 | 56 | 145 | ˆ | * | **161** |
| Non-freight carrying trucks | | | ˆ6 | ** | ** | **ˆ7** |
| Buses | | | 42 | ˆ | ˆ2 | **49** |
| **Total Tasmania** | **572** | **ˆ338** | **1542** | **ˆ913** | **2537** | **4992** |
| | | | | | | |
| **Total Tasmania** | **572** | **ˆ338** | **1542** | **ˆ913** | **2537** | **4992** |
| **% Tasmania of Australia** | **2.02%** | **3.13%** | **2.10%** | **1.74%** | **2.85%** | **2.32%** |

ˆestimate has a relative standard error of 10% to less than 25% and should be used with caution

* estimate has a relative standard error of 25% to 50% and should be used with caution

** estimate has a relative standard error greater than 50% and is considered too unreliable for general use

nil or rounded to zero (including null cells)

(a) Including the business travel of non-freight carrying vehicles

Table C.1: Vehicle Type / Vehicle Use [Australian Bureau of Statistics, 2007]

| | Passenger Vehicles | Motor cycles | Light Commercial vehicles | Rigid Trucks | Articulated trucks | Non-Freight carrying trucks | Buses | Total |
|---|---|---|---|---|---|---|---|---|
| | TOTAL FUEL CONSUMPTION (million litres) | | | | | | | |
| Petrol | 15910 | ˆ124 | 2780 | ˆ25 | | *5 | ˆ32 | 18876 |
| Diesel | ˆ888 | | 1687 | 2425 | 3781 | ˆ72 | 519 | 9372 |
| LPG/CNG/dual fuel/hybrid | ˆ1296 | | ˆ442 | *12 | **4 | **1 | *43 | ˆ1799 |
| **Total** | **18094** | **ˆ124** | **4909** | **2463** | **3785** | **ˆ78** | **595** | **30047** |
| | PERCENTAGE OF TOTAL FUEL CONSUMPTION PER VEHICLE TYPE | | | | | | | |
| Petrol | 87.93% | 100% | 56.63% | 1.02% | - | 6.41% | 5.38% | 62.82% |
| Diesel | 4.91% | | 34.37% | 98.46% | 99.89% | 92.31% | 87.23% | 31.19% |
| LPG/CNG/dual fuel/hybrid | 7.16% | | 9% | 0.49% | 0.11% | 1.28% | 7.23% | 5.99% |
| Total | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |
| | AVERAGE RATE OF FUEL CONSUMPTION (a) (litres per 100 kilometres) | | | | | | | |
| Petrol | 11.1 | 6.5 | 13.2 | 21.9 | | ˆ22.1 | 14.5 | 11.4 |
| Diesel | 12.3 | | 12.5 | 28.6 | 54.6 | 28 | 29.2 | 24.5 |
| LPG/CNG/dual fuel/hybrid | 16.6 | | 16 | ˆ26.9 | ˆ64.4 | *30.9 | ˆ44.0 | 16.7 |

Table C.2: Fuel Consumption - Australia Wide

| | | Laden | Unladen | All Business use (a) | To and From Work | Peronal and Other | **Total** |
|---|---|---|---|---|---|---|---|
| Passenger Vehicles | Petrol | | | 65.3 | 76.7 | 224.7 | 366.6 |
| | Diesel | | | 4.0 | 4.7 | 13.9 | 22.7 |
| | LPG/CNG/dual fuel/hybrid | | | 8.0 | 9.3 | 27.4 | 44.7 |
| Motor cycles | Petrol | | | 0.3 | 0.5 | 2.3 | 3.1 |
| | Diesel | | | | | | |
| | LPG/CNG/dual fuel/hybrid | | | | | | |
| Light Commercial | Petrol | 26.3 | 15.2 | 37.4 | 8.7 | 14.4 | 102.0 |
| | Diesel | 15.1 | 8.7 | 21.5 | 5.0 | 8.3 | 58.6 |
| | LPG/CNG/dual fuel/hybrid | 5.1 | 2.9 | 7.2 | 1.7 | 2.8 | 19.7 |
| Rigid Trucks | Petrol | 0.3 | 0.2 | 0.4 | 0.0 | 0.0 | 0.8 |
| | Diesel | 33.1 | 22.2 | 49.2 | 0.7 | 1.3 | 106.5 |
| | LPG/CNG/dual fuel/hybrid | 0.2 | 0.1 | 0.2 | 0.0 | 0.0 | 0.5 |
| Articulated Trucks | Petrol | | | | | | 0.0 |
| | Diesel | 56.4 | 30.6 | 79.1 | | | 166.2 |
| | LPG/CNG/dual fuel/hybrid | 0.1 | 0.0 | 0.1 | | | 0.2 |
| Non Freight Carrying Trucks | Petrol | | | 1.3 | | | 1.3 |
| | Diesel | | | 1.6 | | | 1.6 |
| | LPG/CNG/dual fuel/hybrid | | | 0.0 | | | 0.0 |
| Buses | Petrol | | | 0.3 | | 0.0 | 0.3 |
| | Diesel | | | 10.7 | | 0.8 | 11.5 |
| | LPG/CNG/dual fuel/hybrid | | | 1.3 | | 0.1 | 1.4 |

Table C.3: Total litres of fuel used in Tasmania (million litres)

**All Sectors**

| | Million Litres | GJ | kg $CO_2e$ (Tasmania) |
|---|---|---|---|
| Total Petrol | 474.2 | 16219003.75 | 1174255872 |
| Total Diesel | 367.0 | 14165983.65 | 1059615577 |
| Total LPG/CNG/dual fuel/hybrid | 66.4 | (negligible and not required for the purposes of this inventory) | |

**All Sectors Neglecting Residential (i.e. ‘To and From Work’ & ‘Personal and Other’)**

| | Million Litres | GJ | kg $CO_2e$ (Tasmania) |
|---|---|---|---|
| Total Petrol | 146.9 | 5023326.16 | 363688814.1 |
| Total Diesel | 332.3 | 12826924.55 | 959453956.4 |
| Total LPG/CNG/dual fuel/hybrid | 25.2 | (negligible and not required for the purposes of this inventory) | |

**Residential Only (i.e. ‘To and From Work’ & ‘Personal and Other’)**

| | Million Litres | GJ | kg $CO_2e$ (Tasmania) |
|---|---|---|---|
| Total Petrol | 327.4 | 11195677.59 | 810567057.5 |
| Total Diesel | 34.7 | 1339059.1 | 100161620.5 |
| Total LPG/CNG/dual fuel/hybrid | 41.2 | (negligible and not required for the purposes of this inventory) | |

**Total Emissions for Brighton**

| | |
|---|---|
| All Sectors | 64391336.97 kg $CO_2e$ |
| All sectors - Residential | 38139585.90 kg $CO_2e$ |
| **Agricultural** | **1312894.52 kg** $CO_2e$ |
| **Industrial** | **6192485.84 kg** $CO_2e$ |
| **Commercial** | **30634205.54 kg** $CO_2e$ |
| **Residential Sector** | **26251751.08 kg** $CO_2e$ |

Table C.4: Fuel Usage and Associated Emissions

# Appendix D

# Electricity - Calculations

| **Present Study Sector** | **ANZSIC Sector** | **PJ** | **% ANZSIC** | **PJ** | **% Present Study** |
|---|---|---|---|---|---|
| **Agricultural** | Div. A Agriculture, forestry and fishing | 0.3 | 0.65% | 0.30 | 0.65% |
| **Industrial** | Div. B Mining | 3.4 | 7.36% | 31.20 | 67.53% |
| | Div. C Manufacturing | 25.4 | 54.98% | | |
| | Div. D Electricity, gas and water | 2.4 | 5.19% | | |
| | Div. E Construction | 0 | 0.00% | | |
| **Commercial** | Commercial and services b | 5.7 | 12.34% | 5.70 | 12.34% |
| | Div. I Transport & storage | 0 | 0.00% | | |
| **Residential** | Residential | 9.0 | 19.48% | 9.00 | 19.48% |

Note, PJ = Peta-Joule ($J \times 10^{15}$)

Table D.1: Tasmanian Electricity Usage 2006-07

| | |
|---|---|
| **Redistributing percentages neglecting residential sector:** | |
| Agricultural : | 0.81% |
| Industrial : | 83.87% |
| Commercial : | 15.32% |
| Residential : | 0.00% |
| | |
| **Consumption 2006-07 [Energy Supply Association of Australia, 2008]:** | |
| Residential : | 2,179 GWh |
| Business : | 8,116 GWh |
| Unmetered : | 24 GWh |
| **Total :** | **10,319 GWh** |

Table D.2: Tasmanian Electricity Usage 2006-07 Redistributed

| **Sector** | | **GWh Tasmania 06/07 financial year** | **GWh Tasmania 2007 (2.6% growth)** | **GWh Brighton (working population profile)** | **tonnes $CO_2e$** |
|---|---|---|---|---|---|
| **Agriculture** | (0.81%) | 65 | 67 | 0.37 | 48 |
| **Industrial** | (83.87%) | 6807 | 6984 | 52.59 | 6836 |
| **Commercial** | (15.32%) | 1244 | 1276 | 12.15 | 1580 |
| **Residential** | | 2179 | 2236 | 64.44 | 8377 |

Table D.3: Electricity consumption by sector

# Appendix E

# Waste - Calculations

| **Period** | **Tonnage** |
|---|---|
| 01/01/07 - 07/01/07 | 122.87 |
| 08/01/07 - 21/01/07 | 268.88 |
| 22/01/07 - 04/02/07 | 276.86 |
| 5/02/07 - 18/02/07 | 255.84 |
| 19/02/07 - 4/03/07 | 258.52 |
| 5/03/07 - 18/03/07 | 304.00 |
| 19/03/07 - 01/04/07 | 250.80 |
| 02/04/07 - 15/04/07 | 225.02 |
| 16/04/07 - 29/04/07 | 237.84 |
| 30/04/07 - 13/05/07 | 213.88 |
| 14/05/07 - 27/05/07 | 220.24 |
| 28/05/07 - 10/06/07 | 219.18 |
| 11/06/07 - 24/06/07 | 213.64 |
| 25/06/07 - 30/06/07 | 96.98 |
| 01/07/07 - 08/07/07 | 114.40 |
| 09/07/07 - 22/07/07 | 192.38 |
| 23/7/07 - 05/08/07 | 201.40 |
| 6/08/07 - 19/08/07 | 224.78 |
| 20/08/07 - 02/09/07 | 226.94 |
| 03/09/07 - 16/09/07 | 285.52 |
| 17/09/07 - 30/09/07 | 229.04 |
| 1/10/07 - 14/10/07 | 239.20 |
| 15/10/07 - 28/10/07 | 291.12 |
| 29/10/07 - 11/11/07 | 267.20 |
| 12/11/07 - 25/11/07 | 270.74 |
| 26/11/07 - 9/12/07 | 288.00 |
| 10/12/07 - 23/12/07 | 302.80 |
| 24/12/07 - 31/12/07 | 173.41 |
| **Total** | **6471.48** |

Table E.1: Glenorchy Landfill Records

(Kerbside Collection & Waste Transfer Station Combined)

| | **Sectoral Breakdown** | **Waste (Tonnes)** | **Emission Factor (t $CO_2e$/tonne waste)** | **Total Emission (t $CO_2e$)** | **Escaped Emissions (kg $CO_2e$)** |
|---|---|---|---|---|---|
| Municipal | 27% | 1747 | 1.11 | 1940 | 872776 |
| Commercial and Industrial | 29% | 1877 | 1.66 | 3115 | 1401916 |
| Construction and Demolition | 42% | 2718 | 0.25 | 680 | 305777 |

Sectoral Breakdown [Department of Environment Water Heritage & Arts, 2006a]
Emission Factor [Department of Climate Change, 2008a]
Escaped Emissions - Assuming a gas capture rate of 55% [Department of Environment Water Heritage & Arts, 2006a]

Table E.2: Waste Calculations (a)

**Working Population Distribution:**

Agricultural : 3.44%

Industrial : 16.24%

Commercial : 80.32%

Municipal waste will be a combination of residential and community services waste. Can assume agricultural waste is negligible since this is predominantly disposed of on site and not through municipal landfill.

Combining working populations of industrial and commercial sectors only, then calculating percentage distribution, we get:

Industrial : 16.82%

Commercial : 83.18%

Thus derive the following table:

| **Sector** | **Sectoral Breakdown** | **Waste (Tonnes)** | **Escaped Emissions (kg $CO_2e$)** |
|---|---|---|---|
| Agricultural | 0% | 0 | 0 |
| Industrial | 47% | 3034 | 541512 |
| Commercial | 24% | 1561 | 1166181 |
| Residential | 27% | 1747 | 872776 |

Table E.3: Waste Calculations (b)

# Appendix F

# Inventory Results

| | **Electricity** | **Fuel Usage** | **Fuel Usage Due to Travel** | **Waste** |
|---|---|---|---|---|
| Residential | 11029 | 387 | 26252 | 873 |
| Agricultural | 60 | 1268 | 1313 | 0 |
| Commercial | 3068 | 1052 | 30634 | 1166 |
| Industrial | 4975 | 11198 | 6192 | 542 |

Table F.1: Summary of Results

| **Priority List** | **Sector** | **Emission Source** | **Tonnes $CO_2e$ for 2007** |
|---|---|---|---|
| 1 | Commercial | Fuel Usage Due to Travel | 30634 |
| 2 | Residential | Fuel Usage Due to Travel | 26252 |
| 3 | Industrial | Fuel Usage | 11198 |
| 4 | Residential | Electricity | 11029 |
| 5 | Industrial | Fuel Usage Due to Travel | 6192 |
| 6 | Industrial | Electricity | 4975 |
| 7 | Commercial | Electricity | 3068 |
| 8 | Agricultural | Fuel Usage Due to Travel | 1313 |
| 9 | Agricultural | Fuel Usage | 1268 |
| 10 | Commercial | Waste | 1166 |
| 11 | Commercial | Fuel Usage | 1052 |
| 12 | Residential | Waste | 873 |
| 13 | Industrial | Waste | 542 |
| 14 | Residential | Fuel Usage | 387 |
| 15 | Agricultural | Electricity | 60 |
| 16 | Agricultural | Waste | 0 |

Table F.2: Priority List

| | **No. Properties** | **Electricity** | **Fuel Usage** | **Fuel Usage Due to Travel** | **Waste** |
|---|---|---|---|---|---|
| Residential | 5055 | 2.182 | 0.077 | 5.193 | 0.173 |
| Agricultural | 110 | 0.548 | 11.526 | 11.935 | 0.000 |
| Commercial | 73 | 42.024 | 14.415 | 419.647 | 15.975 |
| Industrial | 51 | 97.539 | 219.575 | 121.421 | 10.618 |

Table F.3: Summary of Results (Per Property)

| **Priority List** | **Sector** | **Emission Source** | **Tonnes $CO_2e$ for 2007** |
|---|---|---|---|
| 1 | Commercial | Fuel Usage Due to Travel | 419.647 |
| 2 | Industrial | Fuel Usage | 219.575 |
| 3 | Industrial | Fuel Usage Due to Travel | 121.421 |
| 4 | Industrial | Electricity | 97.539 |
| 5 | Commercial | Electricity | 42.024 |
| 6 | Commercial | Waste | 15.975 |
| 7 | Commercial | Fuel Usage | 14.415 |
| 8 | Agricultural | Fuel Usage Due to Travel | 11.935 |
| 9 | Agricultural | Fuel Usage | 11.526 |
| 10 | Industrial | Waste | 10.618 |
| 11 | Residential | Fuel Usage Due to Travel | 5.193 |
| 12 | Residential | Electricity | 2.182 |
| 13 | Agricultural | Electricity | 0.548 |
| 14 | Residential | Waste | 0.173 |
| 15 | Residential | Fuel Usage | 0.077 |
| 16 | Agricultural | Waste | 0.000 |

Table F.4: Priority List (Per Property)

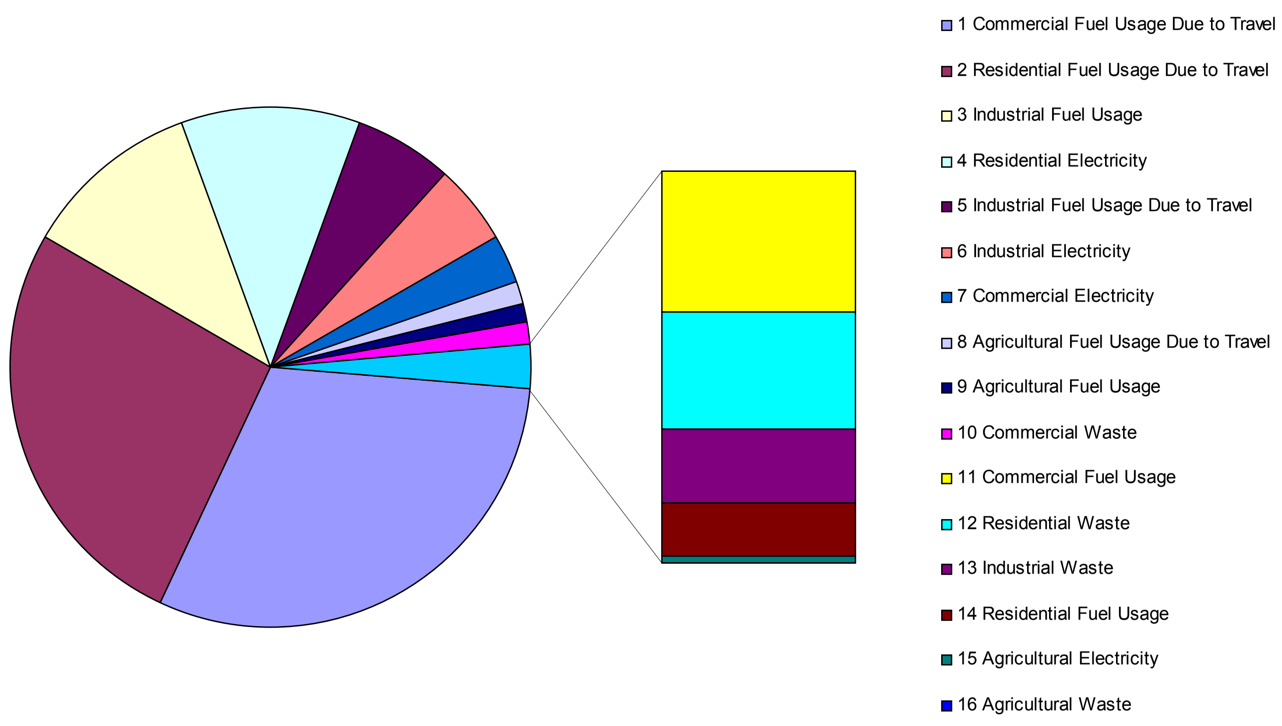


Figure F.1: Priority List Chart

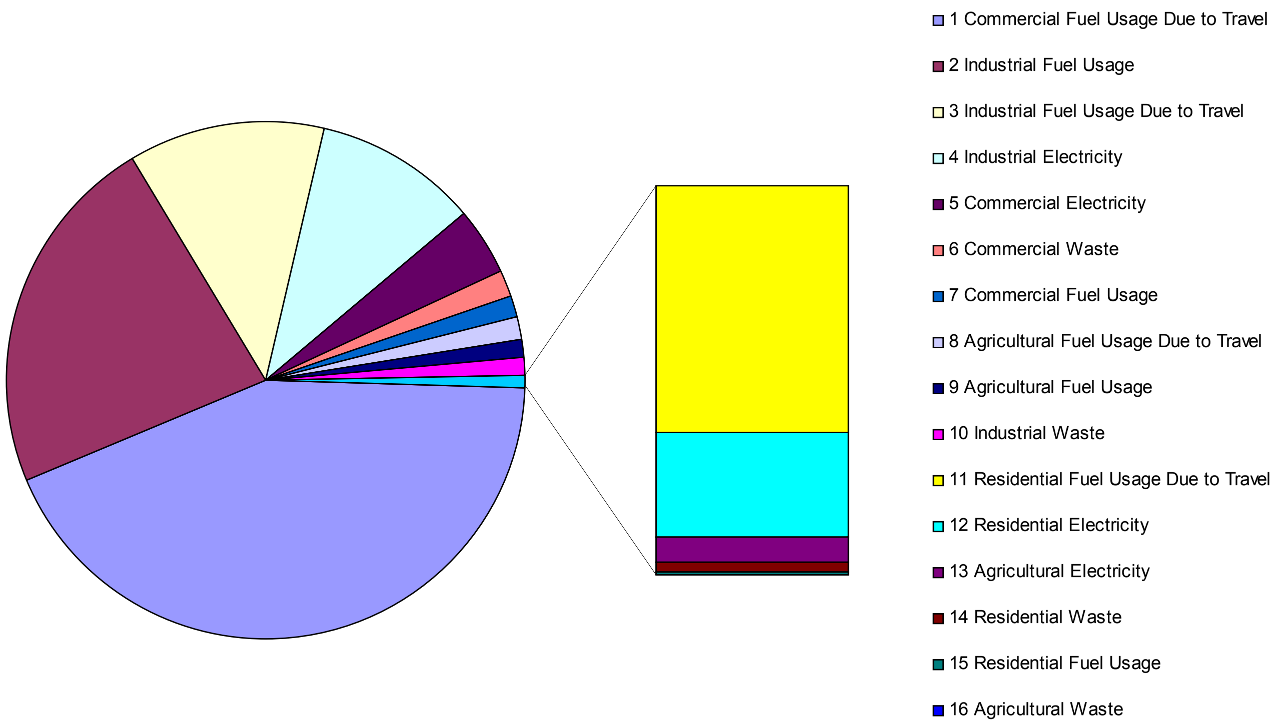


Figure F.2: Priority List Chart (Per Property)

# Appendix G

# National Inventory

### Scope 1 (Direct Emissions)

| Sector | ANZSIC Sector | Tonnes $CO_2e$ (*1000) | Total Tonnes $CO_2e$ (*1000) | Brighton Tonnes $CO_2e$ |
|---|---|---|---|---|
| Agricultural | Div A Agriculture, forestry, fishing | 2,590.32 | 2,590.32 | 14,178.00 |
| Industrial | Div B Mining | 222.34 | 3473.76 | 26156.02 |
| | Div C Manufacturing | 2,672.83 | | |
| | Div D Electricity, gas, water | 481.28 | | |
| | Div E Construction | 97.31 | | |
| Commercial | Div F-H, J-Q Commercial Services | 393.13 | 1270.93 | 12105.82 |
| | Div I Transport | storage | 877.8 | |
| Residential | Residential | 1,212.34 | 1,212.34 | 34,945.70 |

### Scope 2 (Indirect Emissions)

| Sector | ANZSIC Sector | Tonnes $CO_2e$ (*1000) | Total Tonnes $CO_2e$ (*1000) | Brighton Tonnes $CO_2e$ |
|---|---|---|---|---|
| Agricultural | Div A Agriculture, forestry, fishing | 6.92 | 6.92 | 37.88 |
| Industrial | Div B Mining | 58.85 | 493.33 | 3714.58 |
| | Div C Manufacturing | 392.94 | | |
| | Div D Electricity, gas, water | 41.54 | | |
| | Div E Construction | - | | |
| Commercial | Div F-H, J-Q Commercial Services | 98.67 | 98.67 | 939.85 |
| | Div I Transport | storage | - | |
| Residential | Residential | 154.06 | 154.06 | 4,440.78 |

Table G.1: National Inventory Results

| **Sector** | **Applied Method** | **National Inventory (Scope 1 & 2)** |
|---|---|---|
| Agricultural | 2641 | 14216 |
| Industrial | 22907 | 29871 |
| Commercial | 35920 | 13046 |
| Residential | 38541 | 39386 |
| **TOTAL** | **100009** | **96519** |

Table G.2: Comparison of Inventory Models

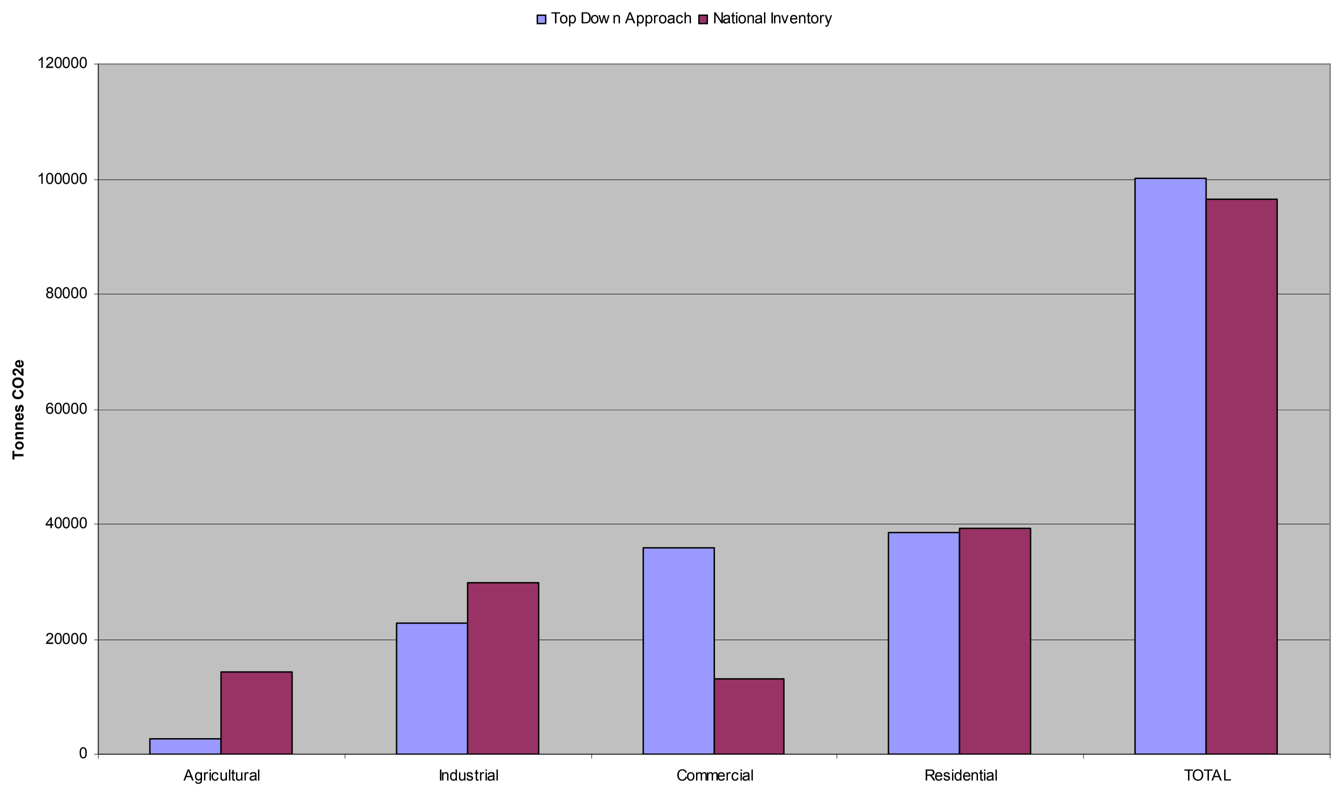


Figure G.1: Comparison of Inventory Models

# Appendix H

# Email Regarding Wind Generation Potential

-----Original Message-----
From: Simon Parker [mailto:simon@thenaturalenergyshop.com.au]
Sent: Thursday, 4 June 2009 8:57 AM
To: Heyward; Oliver
Subject: RE: General Pricing

Hi Oliver,

Based on data collected from the Bureau of Meteorology weather station, a 1kW wind power system would produce approximately 1500kWh of electricity per year. Hobart Airport (approximately 10km west) records an average annual wind speed of 4.7m/s (17km/hr). It should be noted that wind speeds can greatly vary over short distances.

As an indication, a 1kW PV solar power system would produce approximately 1600kWh of electricity per year (based on Bureau of Meteorology data for your locale.

Many Thanks
Simon.

Figure H.1: Email Regarding Wind Generation Potential

# Appendix I

# Quote Regarding Wind Generation Potential

**4x300W vert**

| | | |
|---|---|---|
| Prepared For: | **Depot** | |
| Site Location: | | |
| Data Source: | | |
| Turbine size | **1.2** | KW |
| Date: | **2/11/2009** | |

| **Inputs:** | |
|---|---|
| **Ave. Wind (m/s) =** | 6.5 |
| **Weibull K =** | 2.8 |
| **Site Altitude (m) =** | 0 |
| **Wind Shear Exp. =** | 0.200 |
| **Anem. Height (m) =** | 5 |
| **Tower Height (m) =** | 5 |
| **Turbulence Factor =** | 0.0% |

| **Results:** | |
|---|---|
| **Hub Average Wind Speed (m/s) =** | 6.50 |
| **Air Density Factor =** | 0% |
| **Average Output Power (kW) =** | 0.38 |
| **Daily Energy Output (kWh) =** | 9.2 |
| **Annual Energy Output (kWh) =** | **3,352** |
| **Monthly Energy Output =** | 279 |
| **Percent Operating Time =** | 88.2% |

**Weibull Performance Calculations**

| Wind Speed Bin (m/s) | Power (kW) | Wind Probability (f) | Net kW @ V |
|---|---|---|---|
| 1 | 0.00 | 1.07% | 0.000 |
| 2 | 0.00 | 3.63% | 0.000 |
| 3 | 0.00 | 7.11% | 0.000 |
| 4 | 0.00 | 10.78% | 0.000 |
| 5 | 0.20 | 13.71% | 0.027 |
| 6 | 0.28 | 15.12% | 0.042 |
| 7 | 0.40 | 14.62% | 0.058 |
| 8 | 0.60 | 12.43% | 0.075 |
| 9 | 0.68 | 9.28% | 0.063 |
| 10 | 0.80 | 6.06% | 0.048 |
| 11 | 1.00 | 3.44% | 0.034 |
| 12 | 1.20 | 1.69% | 0.020 |
| 13 | 1.28 | 0.71% | 0.009 |
| 14 | 1.28 | 0.25% | 0.003 |
| 15 | 1.28 | 0.08% | 0.001 |
| 16 | 1.29 | 0.02% | 0.000 |
| 17 | 1.30 | 0.00% | 0.000 |
| 18 | 1.28 | 0.00% | 0.000 |
| 19 | 1.30 | 0.00% | 0.000 |
| 20 | 1.30 | 0.00% | 0.000 |
| | Totals: | 99.99% | 0.383 |

**Weibull Calculations:**
Wind speed probability is calculated as a Weibull curve defined by the average wind speed and a shape factor, K. To facilitate piece-wise integration, the wind speed range is broken down into "bins" of 1 m/s in width (Column 1). For each wind speed bin, instantaneous wind turbine power (W, Column 2)) is multiplied by the Weibull wind speed probability (f, Column 3). This cross product (Net W, Column 4) is the contribution to average turbine power output contributed by wind speeds in that bin. The sum of these contributions is the average power output of the turbine on a continuous, 24 hour, basis.
Best results are achieved using annual or monthly average wind speeds. Use of daily or hourly average speeds is not recommended.

**Results: Hub Average Wind Speed** is corrected for wind shear and used to calculate the Weibull wind speed probability. **Air Density Factor** is the reduction from sea level performance. **Average Power Output** is the average continuous equivalent output of the turbine. **Daily Energy Output** is the average energy produced per day. **Annual** and **Monthly Energy Outputs** are calculated using the Daily value. **Percent Operating Time** is the time the turbine should be producing some power.

**Limitations:** This model uses a mathmatical idealization of the wind speed probability. The validity of this assumption is reduced as the time period under consideration (ie, the wind speed averaging period) is reduced. This model is best used with annual or monthly average wind speeds. Use of this model with daily or hourly average wind speed data is not recommended because the wind will not follow a Weibull distribution over short periods. ***Your performance may vary.***

Figure I.1: Quote Regarding Wind Generation Potential

## Appendix J

# Green Waste Gasification Table of Constants

**General Constants** [Green and Perry, 2007]

| | | |
|---|---|---|
| Density of Water | 999 | $kg/m^3$ |
| Absolute pressure | 101.3 | $kPa$ |
| Universal Gas Constant | 8.31 | $J/mol \cdot K$ |
| Molar Mass Air | 28.96 | $g/mol$ |
| Molar Mass $O_2$ | 32 | $g/mol$ |
| Molar Mass $N_2$ | 28 | $g/mol$ |
| Molar Mass $C$ | 12.01 | $g/mol$ |
| Molar Mass $CO$ | 28 | $g/mol$ |
| Molar Mass $H_2$ | 2 | $g/mol$ |
| Molar Mass $CO_2$ | 44 | $g/mol$ |
| Molar Mass $H_2O$ | 18 | $g/mol$ |
| Molar Mass Cellulose ($C_6H_{10}O_5$) | 162.14 | $g/mol$ |
| Molar Mass Syngas | 6.42 | $g/mol$ |
| Heat of Formation $CO(g)$ | -110.5 | $kJ/mol$ |
| Heat of Formation $H_2(g)$ | 0 | $kJ/mol$ |
| Heat of Formation $O_2(g)$ | 0 | $kJ/mol$ |
| Heat of Formation $CO_2(g)$ | -393.5 | $kJ/mol$ |
| Heat of Formation $H_2O(g)$ | -241.82 | $kJ/mol$ |
| Specific gas constant for dry air | 287.05 | $J/kg \cdot K$ |
| Specific gas constant $CO$ | 297 | $J/kg \cdot K$ |
| Specific gas constant $N_2$ | 296.8 | $J/kg \cdot K$ |
| Specific gas constant $CO_2$ | 188.9 | $J/kg \cdot K$ |
| Specific gas constant $H_2$ | 4,124 | $J/kg \cdot K$ |
| Specific gas constant $H_2O(g)$ | 461.5 | $J/kg \cdot K$ |
| Heat of combustion $C$ | -410 | $kJ/molC$ |
| Heat of combustion $CO$ | -283 | $kJ/molCO$ |
| Heat of combustion $H_2$ | -241.8 | $kJ/molH_2$ |
| Heat of reaction $C + H_2O \Rightarrow CO + H_2$ | -131.32 | $kJ/mol$ |
| Heat of reaction $C + O_2 \Rightarrow CO_2$ | 393.79 | $kJ/mol$ |
| Heat of reaction $2H_2 + O_2 \Rightarrow 2H_2O$ | 483.6 | $kJ/mol$ |
| Heat of reaction $2CO + O_2 \Rightarrow 2CO_2$ | 193 | $kJ/mol$ |
| Calorific Value biomass | $2{\times}10^4$ | $KJ/kg$ |
| Calorific Value $CO$ | $1.01{\times}10^4$ | $KJ/kg$ |
| Calorific Value $H_2$ | $1.42{\times}10^5$ | $KJ/kg$ |
| Specific Volume of $H_2$ | 12.1 | $m^3/kg$ |
| Specific Volume of $CO$ | 0.87 | $m^3/kg$ |

## Particle Constants

| | | |
|---|---|---|
| Specific Heat Sand | 0.8 | $kJ/kg \cdot K$ |
| Specific Heat Biomass | 1.38 | $kJ/kg \cdot K$ |
| [Lynch, 1989] | | |
| Bulk Density Wet Biomass | 240 | $kg/m^3$ |
| [Australian Government Department of the Environment and Heritage, 2006] | | |
| Bulk Density Sand | 1442 | $kg/m^3$ |
| [Walker, 2008] | | |
| Particle Density Biomass | 500 | $kg/m^3$ |
| Particle Density Sand | 1500 | $kg/m^3$ |
| Particle Diameter Biomass | 0.02 | $m$ |
| Particle Diameter Sand | $5 \times 10^{-4}$ | $m$ |
| Drag Coefficient Biomass particle (cube) | 0.5 | |
| Drag Coefficient Sand particle (cube) | 0.5 | |
| [Clayton et al., 2005] | | |
| Thermal conductivity Wood | 0.12 | $W/m \cdot K$ |
| [The Engineering ToolBox, 2005] | | |
| Thermal conductivity Sand | 3 | $W/m \cdot K$ |
| [Walker, 2008] | | |
| Specific Heat Wood | 2500 | $J/kg \cdot K$ |
| [The Engineering ToolBox, 2005] | | |

## NGA Constants for Calculation of Waste Emissions
[Department of Climate Change, 2009a]

| | | |
|---|---|---|
| Electricity Conversion Factor | 0.13 | $kgCO_2e/kWhr$ |
| DOC - fraction of degradable carbon by waste type (green) | 0.2 | |
| $DOC_F$ - fraction of degradable carbon | 0.5 | |
| F | 0.5 | |
| MCF - methane correction factor for aerobic decomposition | 1 | |

## Economic Constants

| | | |
|---|---|---|
| REC value | $43 | |
| Electricity value | 0.2 | $cents/kWhr$ |
| [Parliament of Australia, 2010] | | |

Table J.1: Green Waste Gasification Table of Constants

# Appendix K

# Waste Transfer Station Survey Data

| Record | Ute | Trailer | Car Boot | Volume (m3) | Mass (kg) | Date | Daily Mass (kg) |
|---|---|---|---|---|---|---|---|
| 1 | | 100% | | 3 | 720 | 14/08/09 | |
| 2 | | 100% | | 3 | 720 | 14/08/09 | |
| 3 | | 100% | | 3 | 720 | 14/08/09 | |
| 4 | | 50% | | 1.5 | 360 | 14/08/09 | |
| 5 | | 70% | | 2.1 | 504 | 14/08/09 | |
| 6 | 70% | 100% | | 4.4 | 1056 | 14/08/09 | |
| 7 | 100% | | | 2 | 480 | 14/08/09 | |
| 8 | 70% | | | 1.4 | 336 | 14/08/09 | |
| 9 | | 30% | | 0.9 | 216 | 14/08/09 | |
| 10 | | 100% | | 3 | 720 | 14/08/09 | |
| 11 | 100% | | | 2 | 480 | 14/08/09 | 6312 |
| 12 | | 50% | | 1.5 | 360 | 15/08/09 | |
| 13 | 100% | | | 2 | 480 | 15/08/09 | |
| 14 | | 100% | | 3 | 720 | 15/08/09 | |
| 15 | | 50% | | 1.5 | 360 | 15/08/09 | |
| 16 | | 100% | | 3 | 720 | 15/08/09 | |
| 17 | | 100% | | 3 | 720 | 15/08/09 | |
| 18 | | 30% | | 0.9 | 216 | 15/08/09 | |
| 19 | | | 100% | 0.5 | 120 | 15/08/09 | |
| 20 | | | 100% | 0.5 | 120 | 15/08/09 | |
| 21 | 30% | | | 0.6 | 144 | 15/08/09 | |
| 22 | 80% | | | 1.6 | 384 | 15/08/09 | |
| 23 | 100% | | | 2 | 480 | 15/08/09 | |

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Table K.1: Waste Transfer Station Survey Data

Table K.1 – Continued

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 24 | 100% | | | 2 | 480 | 15/08/09 | 5304 |
| 25 | | 50% | | 1.5 | 360 | 16/08/09 | |
| 26 | 70% | | | 1.4 | 336 | 16/08/09 | 696 |
| 27 | | 90% | | 2.7 | 648 | 17/08/09 | |
| 28 | 100% | | | 2 | 480 | 17/08/09 | |
| 29 | | 80% | | 2.4 | 576 | 17/08/09 | |
| 30 | 80% | | | 1.6 | 384 | 17/08/09 | 2088 |
| 31 | 100% | | | 2 | 480 | 21/08/09 | |
| 32 | | 100% | | 3 | 720 | 21/08/09 | 1200 |
| 33 | | 100% | | 3 | 720 | 22/08/09 | 720 |
| 34 | 100% | | | 2 | 480 | 23/08/09 | |
| 35 | | 100% | | 3 | 720 | 23/08/09 | |
| 36 | 100% | | | 2 | 480 | 23/08/09 | |
| 37 | 100% | | | 2 | 480 | 23/08/09 | |
| 38 | 100% | | | 2 | 480 | 23/08/09 | |
| 39 | | 100% | | 3 | 720 | 23/08/09 | |
| 40 | | 30% | | 0.9 | 216 | 23/08/09 | |
| 41 | | 100% | | 3 | 720 | 23/08/09 | |
| 42 | 100% | | | 2 | 480 | 23/08/09 | |
| 43 | | | 100% | 0.5 | 120 | 23/08/09 | |
| 44 | 100% | | | 2 | 480 | 23/08/09 | |
| 45 | 70% | 100% | | 4.4 | 1056 | 23/08/09 | |
| 46 | | 80% | | 2.4 | 576 | 23/08/09 | |
| 47 | 100% | | | 2 | 480 | 23/08/09 | |
| 48 | 100% | | | 2 | 480 | 23/08/09 | |
| 49 | 100% | | | 2 | 480 | 23/08/09 | 8448 |
| 50 | 100% | | | 2 | 480 | 24/08/09 | |
| 51 | 100% | | | 2 | 480 | 24/08/09 | |
| 52 | 100% | | | 2 | 480 | 24/08/09 | |
| 53 | 40% | | | 0.8 | 192 | 24/08/09 | |
| 54 | | 100% | | 3 | 720 | 24/08/09 | |
| 55 | 50% | | | 1 | 240 | 24/08/09 | |
| 56 | | 100% | | 3 | 720 | 24/08/09 | 3312 |
| 57 | 100% | | | 2 | 480 | 28/08/09 | |
| 58 | 100% | | | 2 | 480 | 28/08/09 | |
| 59 | 100% | | | 2 | 480 | 28/08/09 | |
| 60 | | 100% | | 3 | 720 | 28/08/09 | |
| 61 | 70% | | | 1.4 | 336 | 28/08/09 | |
| 62 | 100% | 100% | | 5 | 1200 | 28/08/09 | |
| 63 | 100% | | | 2 | 480 | 28/08/09 | |
| 64 | 100% | | | 2 | 480 | 28/08/09 | |
| 65 | 100% | | | 2 | 480 | 28/08/09 | |
| 66 | 100% | | | 2 | 480 | 28/08/09 | 5616 |
| 67 | 100% | | | 2 | 480 | 29/08/09 | |
| 68 | 100% | | | 2 | 480 | 29/08/09 | |
| 69 | 100% | | | 2 | 480 | 29/08/09 | 1440 |
| 70 | 100% | | | 2 | 480 | 30/08/09 | |
| 71 | | 70% | | 2.1 | 504 | 30/08/09 | |
| 72 | 100% | | | 2 | 480 | 30/08/09 | |
| 73 | | 100% | | 3 | 720 | 30/08/09 | |
| 74 | | 100% | | 3 | 720 | 30/08/09 | 2904 |
| 75 | | 100% | | 3 | 720 | 04/09/09 | |
| 76 | 100% | | | 2 | 480 | 04/09/09 | |
| 77 | 100% | | | 2 | 480 | 04/09/09 | |
| 78 | | 100% | | 3 | 720 | 04/09/09 | |

Continued on Next Page...

Table K.1 – Continued

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 79 | | 100% | | 3 | 720 | 04/09/09 | |
| 80 | | 100% | | 3 | 720 | 04/09/09 | |
| 81 | | 100% | | 3 | 720 | 04/09/09 | |
| 82 | | 100% | | 3 | 720 | 04/09/09 | 5280 |
| 83 | | 100% | | 3 | 720 | 05/09/09 | |
| 84 | 80% | | | 1.6 | 384 | 05/09/09 | |
| 85 | 100% | | | 2 | 480 | 05/09/09 | |
| 86 | 100% | | | 2 | 480 | 05/09/09 | |
| 87 | 100% | | | 2 | 480 | 05/09/09 | |
| 88 | 100% | | | 2 | 480 | 05/09/09 | |
| 89 | 100% | | | 2 | 480 | 05/09/09 | |
| 90 | 100% | | | 2 | 480 | 05/09/09 | |
| 91 | | 100% | | 3 | 720 | 05/09/09 | |
| 92 | 100% | | | 2 | 480 | 05/09/09 | 5184 |
| 93 | 70% | | | 1.4 | 336 | 06/09/09 | |
| 94 | 100% | | | 2 | 480 | 06/09/09 | |
| 95 | 50% | | | 1 | 240 | 06/09/09 | |
| 96 | 50% | | | 1 | 240 | 06/09/09 | |
| 97 | 100% | | | 2 | 480 | 06/09/09 | |
| 98 | | 100% | | 3 | 720 | 06/09/09 | |
| 99 | | 50% | | 1.5 | 360 | 06/09/09 | |
| 100 | | 50% | | 1.5 | 360 | 06/09/09 | 3216 |
| 101 | 50% | | | 1 | 240 | 07/09/09 | |
| 102 | | 100% | | 3 | 720 | 07/09/09 | |
| 103 | 100% | | | 2 | 480 | 07/09/09 | |
| 104 | | 100% | | 3 | 720 | 07/09/09 | |
| 105 | 50% | | | 1 | 240 | 07/09/09 | |
| 106 | | 100% | | 3 | 720 | 07/09/09 | |
| 107 | 100% | | | 2 | 480 | 07/09/09 | |
| 108 | 100% | | | 2 | 480 | 07/09/09 | |
| 109 | | 100% | | 3 | 720 | 07/09/09 | |
| 110 | | 90% | | 2.7 | 648 | 07/09/09 | |
| 111 | | 100% | | 3 | 720 | 07/09/09 | |
| 112 | | 100% | | 3 | 720 | 07/09/09 | 6888 |
| 113 | | 100% | | 3 | 720 | 11/09/09 | |
| 114 | | 100% | | 3 | 720 | 11/09/09 | |
| 115 | 100% | | | 2 | 480 | 11/09/09 | |
| 116 | 100% | | | 2 | 480 | 11/09/09 | |
| 117 | | 100% | | 3 | 720 | 11/09/09 | |
| 118 | 100% | | | 2 | 480 | 11/09/09 | |
| 119 | | 100% | | 3 | 720 | 11/09/09 | |
| 120 | 100% | | | 2 | 480 | 11/09/09 | |
| 121 | 100% | | | 2 | 480 | 11/09/09 | 5280 |
| 122 | 100% | 100% | | 5 | 1200 | 12/09/09 | |
| 123 | | 100% | | 3 | 720 | 12/09/09 | |
| 124 | | | 100% | 0.5 | 120 | 12/09/09 | |
| 125 | 100% | | | 2 | 480 | 12/09/09 | |
| 126 | | 100% | | 3 | 720 | 12/09/09 | |
| 127 | 90% | | | 1.8 | 432 | 12/09/09 | |
| 128 | | 100% | | 3 | 720 | 12/09/09 | |
| 129 | 100% | | | 2 | 480 | 12/09/09 | |
| 130 | | 100% | | 3 | 720 | 12/09/09 | |
| 131 | 100% | | | 2 | 480 | 12/09/09 | |
| 132 | 100% | | | 2 | 480 | 12/09/09 | |
| 133 | 100% | | | 2 | 480 | 12/09/09 | |

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Table K.1 – Continued

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 134 | 100% | | | 2 | 480 | 12/09/09 | |
| 135 | | 100% | | 3 | 720 | 12/09/09 | |
| 136 | | 100% | | 3 | 720 | 12/09/09 | |
| 137 | 100% | | | 2 | 480 | 12/09/09 | |
| 138 | | 100% | | 3 | 720 | 12/09/09 | 10152 |
| 139 | 100% | | | 2 | 480 | 13/09/09 | |
| 140 | | 25% | | 0.75 | 180 | 13/09/09 | |
| 141 | 25% | | | 0.5 | 120 | 13/09/09 | |
| 142 | | 100% | | 3 | 720 | 13/09/09 | |
| 143 | 25% | | | 0.5 | 120 | 13/09/09 | |
| 144 | | 50% | | 1.5 | 360 | 13/09/09 | |
| 145 | 70% | | | 1.4 | 336 | 13/09/09 | |
| 146 | 100% | | | 2 | 480 | 13/09/09 | |
| 147 | | 50% | | 1.5 | 360 | 13/09/09 | |
| 148 | 100% | | | 2 | 480 | 13/09/09 | |
| 149 | 100% | | | 2 | 480 | 13/09/09 | |
| 150 | | 100% | | 3 | 720 | 13/09/09 | |
| 151 | | 100% | | 3 | 720 | 13/09/09 | |
| 152 | 50% | | | 1 | 240 | 13/09/09 | |
| 153 | | 100% | | 3 | 720 | 13/09/09 | |
| 154 | | 100% | | 3 | 720 | 13/09/09 | |
| 155 | | | 100% | 0.5 | 120 | 13/09/09 | |
| 156 | | 100% | | 3 | 720 | 13/09/09 | |
| 157 | | 100% | | 3 | 720 | 13/09/09 | |
| 158 | | 100% | | 3 | 720 | 13/09/09 | |
| 159 | 80% | | | 1.6 | 384 | 13/09/09 | |
| 160 | 100% | | | 2 | 480 | 13/09/09 | |
| 161 | | 100% | | 3 | 720 | 13/09/09 | |
| 162 | 50% | | | 1 | 240 | 13/09/09 | |
| 163 | | 90% | | 2.7 | 648 | 13/09/09 | |
| 164 | 80% | | | 1.6 | 384 | 13/09/09 | |
| 165 | | 90% | | 2.7 | 648 | 13/09/09 | 13020 |
| 166 | 90% | | | 1.8 | 432 | 14/09/09 | |
| 167 | 90% | | | 1.8 | 432 | 14/09/09 | |
| 168 | 100% | | | 2 | 480 | 14/09/09 | |
| 169 | | 100% | | 3 | 720 | 14/09/09 | |
| 170 | 100% | | | 2 | 480 | 14/09/09 | |
| 171 | 100% | | | 2 | 480 | 14/09/09 | |
| 172 | | 90% | | 2.7 | 648 | 14/09/09 | |
| 173 | | 100% | | 3 | 720 | 14/09/09 | 4392 |
| 174 | | 100% | | 3 | 720 | 18/09/09 | |
| 175 | | 100% | | 3 | 720 | 18/09/09 | |
| 176 | | 100% | | 3 | 720 | 18/09/09 | 2160 |
| 177 | | 100% | | 3 | 720 | 19/09/09 | |
| 178 | | 90% | | 2.7 | 648 | 19/09/09 | |
| 179 | 100% | | | 2 | 480 | 19/09/09 | |
| 180 | 100% | 100% | | 5 | 1200 | 19/09/09 | |
| 181 | | 80% | | 2.4 | 576 | 19/09/09 | |
| 182 | | 100% | | 3 | 720 | 19/09/09 | 4344 |
| 183 | 100% | 100% | | 5 | 1200 | 20/09/09 | |
| 184 | 100% | | | 2 | 480 | 20/09/09 | |
| 185 | | 100% | | 3 | 720 | 20/09/09 | |
| 186 | | 100% | | 3 | 720 | 20/09/09 | |
| 187 | 100% | 100% | | 5 | 1200 | 20/09/09 | |
| 188 | 100% | | | 2 | 480 | 20/09/09 | |

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Table K.1 – Continued

| | | | | | | |
|---|---|---|---|---|---|---|
| 189 | 100% | | 2 | 480 | 20/09/09 | |
| 190 | 50% | | 1 | 240 | 20/09/09 | |
| 191 | | 90% | 2.7 | 648 | 20/09/09 | |
| 192 | | 100% | 3 | 720 | 20/09/09 | |
| 193 | 100% | | 2 | 480 | 20/09/09 | |
| 194 | | 100% | 3 | 720 | 20/09/09 | |
| 195 | 100% | 100% | 5 | 1200 | 20/09/09 | |
| 196 | 100% | | 2 | 480 | 20/09/09 | 9768 |
| 197 | 100% | | 2 | 480 | 21/09/09 | |
| 198 | | 100% | 3 | 720 | 21/09/09 | |
| 199 | | 100% | 3 | 720 | 21/09/09 | 1920 |
| 200 | | 100% | 3 | 720 | 25/09/09 | |
| 201 | | 100% | 3 | 720 | 25/09/09 | |
| 202 | | 100% | 3 | 720 | 25/09/09 | |
| 203 | | 100% | 3 | 720 | 25/09/09 | |
| 204 | | 50% | 1.5 | 360 | 25/09/09 | |
| 205 | 100% | | 2 | 480 | 25/09/09 | |
| 206 | 100% | | 2 | 480 | 25/09/09 | |
| 207 | | 100% | 3 | 720 | 25/09/09 | |
| 208 | | 100% | 3 | 720 | 25/09/09 | |
| 209 | | 100% | 3 | 720 | 25/09/09 | 6360 |
| 210 | | 100% | 3 | 720 | 26/09/09 | |
| 211 | | 100% | 3 | 720 | 26/09/09 | |
| 212 | | 100% | 3 | 720 | 26/09/09 | |
| 213 | | 100% | 3 | 720 | 26/09/09 | |
| 214 | | 100% | 3 | 720 | 26/09/09 | |
| 215 | | 100% | 3 | 720 | 26/09/09 | |
| 216 | 100% | | 2 | 480 | 26/09/09 | |
| 217 | 100% | | 2 | 480 | 26/09/09 | 5280 |
| 218 | 100% | | 2 | 480 | 28/09/09 | |
| 219 | | 80% | 2.4 | 576 | 28/09/09 | |
| 220 | | 100% | 3 | 720 | 28/09/09 | |
| 221 | | 100% | 3 | 720 | 28/09/09 | 2496 |
| 222 | | 100% | 3 | 720 | 02/10/09 | |
| 223 | | 100% | 3 | 720 | 02/10/09 | |
| 224 | | 100% | 3 | 720 | 02/10/09 | |
| 225 | 100% | | 2 | 480 | 02/10/09 | |
| 226 | 100% | | 2 | 480 | 02/10/09 | |
| 227 | | 100% | 3 | 720 | 02/10/09 | |
| 228 | 100% | | 2 | 480 | 02/10/09 | |
| 229 | 100% | | 2 | 480 | 02/10/09 | 4800 |
| 230 | 100% | | 2 | 480 | 03/10/09 | |
| 231 | | 100% | 3 | 720 | 03/10/09 | |
| 232 | | 100% | 3 | 720 | 03/10/09 | |
| 233 | | 100% | 3 | 720 | 03/10/09 | |
| 234 | 100% | | 2 | 480 | 03/10/09 | |
| 235 | 100% | | 2 | 480 | 03/10/09 | |
| 236 | 95% | | 1.9 | 456 | 03/10/09 | |
| 237 | | 100% | 3 | 720 | 03/10/09 | |
| 238 | 100% | | 2 | 480 | 03/10/09 | |
| 239 | 100% | | 2 | 480 | 03/10/09 | |
| 240 | 100% | | 2 | 480 | 03/10/09 | |
| 241 | | 100% | 3 | 720 | 03/10/09 | |
| 242 | | 100% | 3 | 720 | 03/10/09 | |
| 243 | | 100% | 3 | 720 | 03/10/09 | 8376 |

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Table K.1 – Continued

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 244 | | 100% | | 3 | 720 | 04/10/09 | |
| 245 | 80% | | | 1.6 | 384 | 04/10/09 | |
| 246 | 100% | | | 2 | 480 | 04/10/09 | |
| 247 | | 100% | | 3 | 720 | 04/10/09 | |
| 248 | 100% | | | 2 | 480 | 04/10/09 | |
| 249 | | 100% | | 3 | 720 | 04/10/09 | |
| 250 | | 80% | | 2.4 | 576 | 04/10/09 | |
| 251 | | 100% | | 3 | 720 | 04/10/09 | |
| 252 | 100% | | | 2 | 480 | 04/10/09 | |
| 253 | | 100% | | 3 | 720 | 04/10/09 | |
| 254 | | 100% | | 3 | 720 | 04/10/09 | |
| 255 | | 100% | | 3 | 720 | 04/10/09 | |
| 256 | | 100% | | 3 | 720 | 04/10/09 | |
| 257 | 100% | | | 2 | 480 | 04/10/09 | |
| 258 | 100% | | | 2 | 480 | 04/10/09 | |
| 259 | | 100% | | 3 | 720 | 04/10/09 | |
| 260 | | 100% | | 3 | 720 | 04/10/09 | |
| 261 | | 50% | | 1.5 | 360 | 04/10/09 | |
| 262 | | 70% | | 2.1 | 504 | 04/10/09 | 11424 |
| 263 | | 90% | | 2.7 | 648 | 05/10/09 | |
| 264 | | 100% | | 3 | 720 | 05/10/09 | |
| 265 | | 100% | | 3 | 720 | 05/10/09 | 2088 |
| 266 | | 100% | | 3 | 720 | 09/10/09 | |
| 267 | | 100% | | 3 | 720 | 09/10/09 | |
| 268 | | 100% | | 3 | 720 | 09/10/09 | |
| 269 | | 100% | | 3 | 720 | 09/10/09 | |
| 270 | | 100% | | 3 | 720 | 09/10/09 | |
| 271 | | 100% | | 3 | 720 | 09/10/09 | 4320 |
| 272 | | 90% | | 2.7 | 648 | 10/10/09 | |
| 273 | | 80% | | 2.4 | 576 | 10/10/09 | |
| 274 | | 90% | | 2.7 | 648 | 10/10/09 | |
| 275 | | 100% | | 3 | 720 | 10/10/09 | |
| 276 | 100% | | | 2 | 480 | 10/10/09 | |
| 277 | 100% | | | 2 | 480 | 10/10/09 | 3552 |
| 278 | | 100% | | 3 | 720 | 11/10/09 | |
| 279 | 90% | | | 1.8 | 432 | 11/10/09 | |
| 280 | 90% | | | 1.8 | 432 | 11/10/09 | |
| 281 | | 100% | | 3 | 720 | 11/10/09 | |
| 282 | 100% | | | 2 | 480 | 11/10/09 | |
| 283 | | 100% | | 3 | 720 | 11/10/09 | |
| 284 | 80% | | | 1.6 | 384 | 11/10/09 | |
| 285 | 100% | | | 2 | 480 | 11/10/09 | |
| 286 | 100% | | | 2 | 480 | 11/10/09 | |
| 287 | | 100% | | 3 | 720 | 11/10/09 | |
| 288 | | | 100% | 0.5 | 120 | 11/10/09 | |
| 289 | 100% | | | 2 | 480 | 11/10/09 | |
| 290 | | | 100% | 0.5 | 120 | 11/10/09 | |
| 291 | | 100% | | 3 | 720 | 11/10/09 | 7008 |
| 292 | 95% | | | 1.9 | 456 | 12/10/09 | |
| 293 | 100% | | | 2 | 480 | 12/10/09 | |
| 294 | | 100% | | 3 | 720 | 12/10/09 | |
| 295 | 95% | | | 1.9 | 456 | 12/10/09 | |
| 296 | | 100% | | 3 | 720 | 12/10/09 | |
| 297 | 100% | | | 2 | 480 | 12/10/09 | |
| 298 | | 100% | | 3 | 720 | 12/10/09 | |

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Table K.1 – Continued

| | | | | | | |
|---|---|---|---|---|---|---|
| 299 | 100% | | 2 | 480 | 12/10/09 | |
| 300 | | 100% | 3 | 720 | 12/10/09 | |
| 301 | 95% | | 1.9 | 456 | 12/10/09 | |
| 302 | | 100% | 3 | 720 | 12/10/09 | |
| 303 | 100% | | 2 | 480 | 12/10/09 | 6888 |
| 304 | | 100% | 3 | 720 | 16/10/09 | |
| 305 | 100% | | 2 | 480 | 16/10/09 | |
| 306 | | 50% | 1.5 | 360 | 16/10/09 | |
| 307 | | 100% | 3 | 720 | 16/10/09 | |
| 308 | | 100% | 3 | 720 | 16/10/09 | |
| 309 | | 100% | 3 | 720 | 16/10/09 | |
| 310 | | 100% | 3 | 720 | 16/10/09 | 4440 |
| 311 | | 100% | 3 | 720 | 17/10/09 | |
| 312 | | 100% | 3 | 720 | 17/10/09 | |
| 313 | 100% | | 2 | 480 | 17/10/09 | |
| 314 | | 50% | 1.5 | 360 | 17/10/09 | |
| 315 | | 50% | 1.5 | 360 | 17/10/09 | |
| 316 | 100% | | 2 | 480 | 17/10/09 | |
| 317 | 100% | | 2 | 480 | 17/10/09 | |
| 318 | | 100% | 3 | 720 | 17/10/09 | |
| 319 | 100% | | 2 | 480 | 17/10/09 | |
| 320 | 100% | | 2 | 480 | 17/10/09 | |
| 321 | 100% | | 2 | 480 | 17/10/09 | |
| 322 | 100% | | 2 | 480 | 17/10/09 | 6240 |
| 323 | | 100% | 3 | 720 | 18/10/09 | |
| 324 | | 100% | 3 | 720 | 18/10/09 | |
| 325 | | 100% | 3 | 720 | 18/10/09 | |
| 326 | | 100% | 3 | 720 | 18/10/09 | |
| 327 | 100% | | 2 | 480 | 18/10/09 | |
| 328 | 100% | | 2 | 480 | 18/10/09 | |
| 329 | | 100% | 3 | 720 | 18/10/09 | |
| 330 | 100% | | 2 | 480 | 18/10/09 | |
| 331 | | 100% | 3 | 720 | 18/10/09 | |
| 332 | 100% | | 2 | 480 | 18/10/09 | |
| 333 | 100% | | 2 | 480 | 18/10/09 | |
| 334 | | 100% | 3 | 720 | 18/10/09 | |
| 335 | 100% | | 2 | 480 | 18/10/09 | 7920 |
| 336 | | 100% | 3 | 720 | 19/10/09 | |
| 337 | 100% | | 2 | 480 | 19/10/09 | |
| 338 | 100% | | 2 | 480 | 19/10/09 | |
| 339 | 100% | | 2 | 480 | 19/10/09 | |
| 340 | | 100% | 3 | 720 | 19/10/09 | |
| 341 | | 75% | 2.25 | 540 | 19/10/09 | |
| 342 | 100% | | 2 | 480 | 19/10/09 | 3900 |
| 343 | | 100% | 3 | 720 | 23/10/09 | |
| 344 | | 100% | 3 | 720 | 23/10/09 | |
| 345 | 100% | | 2 | 480 | 23/10/09 | |
| 346 | | 100% | 3 | 720 | 23/10/09 | |
| 347 | | 100% | 3 | 720 | 23/10/09 | |
| 348 | | 100% | 3 | 720 | 23/10/09 | |
| 349 | 100% | | 2 | 480 | 23/10/09 | |
| 350 | 100% | 100% | 5 | 1200 | 23/10/09 | |
| 351 | 100% | | 2 | 480 | 23/10/09 | |
| 352 | | 100% | 3 | 720 | 23/10/09 | 6960 |
| 353 | 100% | | 2 | 480 | 24/10/09 | |

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Table K.1 – Continued

| | | | | | | |
|---|---|---|---|---|---|---|
| 354 | | 100% | 3 | 720 | 24/10/09 | |
| 355 | | 100% | 3 | 720 | 24/10/09 | |
| 356 | | 100% | 3 | 720 | 24/10/09 | |
| 357 | 100% | | 2 | 480 | 24/10/09 | |
| 358 | | 100% | 3 | 720 | 24/10/09 | |
| 359 | 100% | | 2 | 480 | 24/10/09 | |
| 360 | 100% | | 2 | 480 | 24/10/09 | 4800 |
| 361 | | 100% | 3 | 720 | 25/10/09 | |
| 362 | 100% | | 2 | 480 | 25/10/09 | |
| 363 | 100% | | 2 | 480 | 25/10/09 | |
| 364 | | 100% | 3 | 720 | 25/10/09 | |
| 365 | | 100% | 3 | 720 | 25/10/09 | |
| 366 | | 100% | 3 | 720 | 25/10/09 | |
| 367 | 100% | | 2 | 480 | 25/10/09 | |
| 368 | 100% | | 2 | 480 | 25/10/09 | |
| 369 | 100% | | 2 | 480 | 25/10/09 | |
| 370 | 100% | | 2 | 480 | 25/10/09 | |
| 371 | 100% | | 2 | 480 | 25/10/09 | |
| 372 | | 100% | 3 | 720 | 25/10/09 | |
| 373 | 100% | | 2 | 480 | 25/10/09 | |
| 374 | 100% | | 2 | 480 | 25/10/09 | 7920 |
| 375 | 100% | | 2 | 480 | 26/10/09 | |
| 376 | 100% | 100% | 5 | 1200 | 26/10/09 | |
| 377 | | 100% | 3 | 720 | 26/10/09 | |
| 378 | | 100% | 3 | 720 | 26/10/09 | |
| 379 | | 100% | 3 | 720 | 26/10/09 | |
| 380 | | 100% | 3 | 720 | 26/10/09 | |
| 381 | 100% | | 2 | 480 | 26/10/09 | |
| 382 | 100% | | 2 | 480 | 26/10/09 | |
| 383 | | 100% | 3 | 720 | 26/10/09 | |
| 384 | | 100% | 3 | 720 | 26/10/09 | 6960 |
| 385 | | 100% | 3 | 720 | 30/10/09 | |
| 386 | | 100% | 3 | 720 | 30/10/09 | |
| 387 | 100% | | 2 | 480 | 30/10/09 | |
| 388 | 100% | | 2 | 480 | 30/10/09 | |
| 389 | 100% | | 2 | 480 | 30/10/09 | |
| 390 | | 100% | 3 | 720 | 30/10/09 | |
| 391 | 100% | | 2 | 480 | 30/10/09 | |
| 392 | | 100% | 3 | 720 | 30/10/09 | 4800 |
| 393 | | 100% | 3 | 720 | 31/10/09 | |
| 394 | 100% | | 2 | 480 | 31/10/09 | |
| 395 | | 100% | 3 | 720 | 31/10/09 | |
| 396 | 100% | | 2 | 480 | 31/10/09 | |
| 397 | | 80% | 2.4 | 576 | 31/10/09 | |
| 398 | 100% | | 2 | 480 | 31/10/09 | |
| 399 | | 100% | 3 | 720 | 31/10/09 | 4176 |
| 400 | 100% | | 2 | 480 | 01/11/09 | |
| 401 | 100% | | 2 | 480 | 01/11/09 | |
| 402 | | 100% | 3 | 720 | 01/11/09 | |
| 403 | | 100% | 3 | 720 | 01/11/09 | |
| 404 | | 100% | 3 | 720 | 01/11/09 | |
| 405 | 100% | | 2 | 480 | 01/11/09 | |
| 406 | | 100% | 3 | 720 | 01/11/09 | |
| 407 | 100% | | 2 | 480 | 01/11/09 | |
| 408 | 100% | | 2 | 480 | 01/11/09 | |

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Table K.1 – Continued

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 409 | | 100% | | 3 | 720 | 01/11/09 | |
| 410 | 100% | | | 2 | 480 | 01/11/09 | |
| 411 | | 100% | | 3 | 720 | 01/11/09 | |
| 412 | | 80% | | 2.4 | 576 | 01/11/09 | |
| 413 | 100% | | | 2 | 480 | 01/11/09 | |
| 414 | | 100% | | 3 | 720 | 01/11/09 | |
| 415 | 100% | | | 2 | 480 | 01/11/09 | |
| 416 | 100% | | | 2 | 480 | 01/11/09 | |
| 417 | 100% | | | 2 | 480 | 01/11/09 | 10416 |
| 418 | | 100% | | 3 | 720 | 02/11/09 | |
| 419 | | 100% | | 3 | 720 | 02/11/09 | |
| 420 | | 100% | | 3 | 720 | 02/11/09 | |
| 421 | 100% | | | 2 | 480 | 02/11/09 | |
| 422 | 100% | | | 2 | 480 | 02/11/09 | |
| 423 | 100% | | | 2 | 480 | 02/11/09 | |
| 424 | 100% | | | 2 | 480 | 02/11/09 | 4080 |
| 425 | 100% | | | 2 | 480 | 06/11/09 | |
| 426 | | 100% | | 3 | 720 | 06/11/09 | |
| 427 | 100% | | | 2 | 480 | 06/11/09 | |
| 428 | | 100% | | 3 | 720 | 06/11/09 | |
| 429 | 100% | | | 2 | 480 | 06/11/09 | |
| 430 | | 100% | | 3 | 720 | 06/11/09 | |
| 431 | | 100% | | 3 | 720 | 06/11/09 | |
| 432 | 100% | | | 2 | 480 | 06/11/09 | |
| 433 | | 100% | | 3 | 720 | 06/11/09 | |
| 434 | 80% | | | 1.6 | 384 | 06/11/09 | |
| 435 | 90% | | | 1.8 | 432 | 06/11/09 | 6336 |
| 436 | | 100% | | 3 | 720 | 07/11/09 | |
| 437 | | 100% | | 3 | 720 | 07/11/09 | |
| 438 | | 100% | | 3 | 720 | 07/11/09 | |
| 439 | | | 100% | 0.5 | 120 | 07/11/09 | |
| 440 | | 100% | | 3 | 720 | 07/11/09 | |
| 441 | | | 100% | 0.5 | 120 | 07/11/09 | |
| 442 | | | 100% | 0.5 | 120 | 07/11/09 | |
| 443 | | 100% | | 3 | 720 | 07/11/09 | |
| 444 | | 100% | | 3 | 720 | 07/11/09 | |
| 445 | | 100% | | 3 | 720 | 07/11/09 | |
| 446 | 100% | | | 2 | 480 | 07/11/09 | |
| 447 | 100% | | | 2 | 480 | 07/11/09 | 6360 |
| 448 | 100% | | | 2 | 480 | 08/11/09 | |
| 449 | | 100% | | 3 | 720 | 08/11/09 | |
| 450 | | 100% | | 3 | 720 | 08/11/09 | |
| 451 | 100% | | | 2 | 480 | 08/11/09 | |
| 452 | | 100% | | 3 | 720 | 08/11/09 | |
| 453 | 100% | | | 2 | 480 | 08/11/09 | |
| 454 | | 100% | | 3 | 720 | 08/11/09 | |
| 455 | 50% | | | 1 | 240 | 08/11/09 | |
| 456 | 90% | | | 1.8 | 432 | 08/11/09 | |
| 457 | 50% | | | 1 | 240 | 08/11/09 | |
| 458 | | | 90% | 0.45 | 108 | 08/11/09 | |
| 459 | 80% | | | 1.6 | 384 | 08/11/09 | |
| 460 | | 70% | | 2.1 | 504 | 08/11/09 | |
| 461 | | 100% | | 3 | 720 | 08/11/09 | |
| 462 | | 50% | | 1.5 | 360 | 08/11/09 | |
| 463 | | 50% | | 1.5 | 360 | 08/11/09 | |

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Table K.1 – Continued

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 464 | 80% | | | 1.6 | 384 | 08/11/09 | |
| 465 | 90% | | | 1.8 | 432 | 08/11/09 | |
| 466 | | | 100% | 0.5 | 120 | 08/11/09 | |
| 467 | 50% | | | 1 | 240 | 08/11/09 | |
| 468 | 95% | | | 1.9 | 456 | 08/11/09 | |
| 469 | 100% | | | 2 | 480 | 08/11/09 | |
| 470 | 100% | | | 2 | 480 | 08/11/09 | |
| 471 | 100% | | | 2 | 480 | 08/11/09 | |
| 472 | | 100% | | 3 | 720 | 08/11/09 | |
| 473 | 100% | | | 2 | 480 | 08/11/09 | |
| 474 | 100% | | | 2 | 480 | 08/11/09 | |
| 475 | | 100% | | 3 | 720 | 08/11/09 | |
| 476 | 100% | | | 2 | 480 | 08/11/09 | |
| 477 | | 100% | | 3 | 720 | 08/11/09 | |
| 478 | | 100% | | 3 | 720 | 08/11/09 | |
| 479 | 90% | | | 1.8 | 432 | 08/11/09 | |
| 480 | | | 100% | 0.5 | 120 | 08/11/09 | |
| 481 | | 100% | | 3 | 720 | 08/11/09 | |
| 482 | 80% | | | 1.6 | 384 | 08/11/09 | 16716 |
| 483 | 100% | | | 2 | 480 | 09/11/09 | |
| 484 | | 100% | | 3 | 720 | 09/11/09 | |
| 485 | | 80% | | 2.4 | 576 | 09/11/09 | |
| 486 | 100% | | | 2 | 480 | 09/11/09 | |
| 487 | | 100% | | 3 | 720 | 09/11/09 | |
| 488 | 100% | | | 2 | 480 | 09/11/09 | |
| 489 | | | 30% | 0.15 | 36 | 09/11/09 | |
| 490 | | 100% | | 3 | 720 | 09/11/09 | |
| 491 | 80% | | | 1.6 | 384 | 09/11/09 | |
| 492 | | 100% | | 3 | 720 | 09/11/09 | 5316 |
| 493 | 80% | | | 1.6 | 384 | 13/11/09 | |
| 494 | 100% | | | 2 | 480 | 13/11/09 | |
| 495 | | 100% | | 3 | 720 | 13/11/09 | |
| 496 | 100% | | | 2 | 480 | 13/11/09 | 2064 |
| 497 | 100% | | | 2 | 480 | 15/11/09 | |
| 498 | | 100% | | 3 | 720 | 15/11/09 | |
| 499 | | 100% | | 3 | 720 | 15/11/09 | |
| 500 | | 100% | | 3 | 720 | 15/11/09 | |
| 501 | 100% | | | 2 | 480 | 15/11/09 | |
| 502 | | 100% | | 3 | 720 | 15/11/09 | |
| 503 | 100% | | | 2 | 480 | 15/11/09 | |
| 504 | 100% | | | 2 | 480 | 15/11/09 | |
| 505 | | 80% | | 2.4 | 576 | 15/11/09 | |
| 506 | | 50% | | 1.5 | 360 | 15/11/09 | |
| 507 | 100% | | | 2 | 480 | 15/11/09 | |
| 508 | 100% | | | 2 | 480 | 15/11/09 | |
| 509 | | 100% | | 3 | 720 | 15/11/09 | |
| 510 | | 100% | | 3 | 720 | 15/11/09 | |
| 511 | 100% | | | 2 | 480 | 15/11/09 | |
| 512 | | 75% | | 2.25 | 540 | 15/11/09 | |
| 513 | 80% | | | 1.6 | 384 | 15/11/09 | 9540 |
| 514 | 100% | | | 2 | 480 | 16/11/09 | |
| 515 | | 100% | | 3 | 720 | 16/11/09 | |
| 516 | | 100% | | 3 | 720 | 16/11/09 | 1920 |
| 517 | | 100% | | 3 | 720 | 20/11/09 | |
| 518 | | 100% | | 3 | 720 | 20/11/09 | |

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Table K.1 – Continued

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 519 | 100% | | | 2 | 480 | 20/11/09 | 1920 |
| 520 | 100% | | | 2 | 480 | 21/11/09 | |
| 521 | | 100% | | 3 | 720 | 21/11/09 | |
| 522 | | 100% | | 3 | 720 | 21/11/09 | |
| 523 | 100% | | | 2 | 480 | 21/11/09 | |
| 524 | | 100% | | 3 | 720 | 21/11/09 | |
| 525 | 100% | | | 2 | 480 | 21/11/09 | |
| 526 | | 100% | | 3 | 720 | 21/11/09 | |
| 527 | 100% | | | 2 | 480 | 21/11/09 | 4800 |
| 528 | | 80% | | 2.4 | 576 | 22/11/09 | |
| 529 | | 100% | | 3 | 720 | 22/11/09 | |
| 530 | | 100% | | 3 | 720 | 22/11/09 | |
| 531 | | 100% | | 3 | 720 | 22/11/09 | |
| 532 | 100% | | | 2 | 480 | 22/11/09 | |
| 533 | 90% | | | 1.8 | 432 | 22/11/09 | |
| 534 | | 100% | | 3 | 720 | 22/11/09 | |
| 535 | | 100% | | 3 | 720 | 22/11/09 | 5088 |
| 536 | 100% | | | 2 | 480 | 27/11/09 | |
| 537 | | 100% | | 3 | 720 | 27/11/09 | |
| 538 | | 100% | | 3 | 720 | 27/11/09 | |
| 539 | | 100% | | 3 | 720 | 27/11/09 | |
| 540 | 80% | | | 1.6 | 384 | 27/11/09 | |
| 541 | 100% | | | 2 | 480 | 27/11/09 | |
| 542 | 80% | | | 1.6 | 384 | 27/11/09 | |
| 543 | | 100% | | 3 | 720 | 27/11/09 | |
| 544 | | 100% | | 3 | 720 | 27/11/09 | |
| 545 | | 100% | | 3 | 720 | 27/11/09 | |
| 546 | 100% | | | 2 | 480 | 27/11/09 | |
| 547 | 100% | | | 2 | 480 | 27/11/09 | |
| 548 | 80% | | | 1.6 | 384 | 27/11/09 | |
| 549 | | 100% | | 3 | 720 | 27/11/09 | |
| 550 | 80% | | | 1.6 | 384 | 27/11/09 | |
| 551 | 100% | | | 2 | 480 | 27/11/09 | 8976 |
| 552 | 100% | | | 2 | 480 | 30/11/09 | |
| 553 | | 100% | | 3 | 720 | 30/11/09 | |
| 554 | | 100% | | 3 | 720 | 30/11/09 | 1920 |
| 555 | 100% | | | 2 | 480 | 04/12/09 | |
| 556 | | 100% | | 3 | 720 | 04/12/09 | |
| 557 | 100% | | | 2 | 480 | 04/12/09 | |
| 558 | | 100% | | 3 | 720 | 04/12/09 | |
| 559 | 100% | | | 2 | 480 | 04/12/09 | |
| 560 | 100% | | | 2 | 480 | 04/12/09 | |
| 561 | | | 100% | 0.5 | 120 | 04/12/09 | |
| 562 | | 100% | | 3 | 720 | 04/12/09 | 4200 |
| 563 | 100% | | | 2 | 480 | 05/12/09 | |
| 564 | 100% | | | 2 | 480 | 05/12/09 | |
| 565 | | 100% | | 3 | 720 | 05/12/09 | |
| 566 | | 100% | | 3 | 720 | 05/12/09 | |
| 567 | 100% | | | 2 | 480 | 05/12/09 | |
| 568 | | | 100% | 0.5 | 120 | 05/12/09 | |
| 569 | | 100% | | 3 | 720 | 05/12/09 | |
| 570 | 100% | | | 2 | 480 | 05/12/09 | |
| 571 | | | 100% | 0.5 | 120 | 05/12/09 | 4320 |
| 572 | | 100% | | 3 | 720 | 06/12/09 | |
| 573 | | 100% | | 3 | 720 | 06/12/09 | |

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Table K.1 – Continued

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 574 | | | 100% | 0.5 | 120 | 06/12/09 | 1560 |
| 575 | | 100% | | 3 | 720 | 07/12/09 | |
| 576 | 100% | | | 2 | 480 | 07/12/09 | |
| 577 | | | 100% | 0.5 | 120 | 07/12/09 | 1320 |
| 578 | | 100% | | 3 | 720 | 12/12/09 | |
| 579 | 95% | | | 1.9 | 456 | 12/12/09 | |
| 580 | 100% | | | 2 | 480 | 12/12/09 | |
| 581 | | 100% | | 3 | 720 | 12/12/09 | |
| 582 | 100% | | | 2 | 480 | 12/12/09 | 2856 |
| 583 | | | 100% | 0.5 | 120 | 13/12/09 | |
| 584 | | 100% | | 3 | 720 | 13/12/09 | |
| 585 | | 100% | | 3 | 720 | 13/12/09 | |
| 586 | 100% | | | 2 | 480 | 13/12/09 | 2040 |
| 587 | | 100% | | 3 | 720 | 14/12/09 | |
| 588 | | 100% | | 3 | 720 | 14/12/09 | |
| 589 | | 100% | | 3 | 720 | 14/12/09 | |
| 590 | | 100% | | 3 | 720 | 14/12/09 | |
| 591 | | 100% | | 3 | 720 | 14/12/09 | |
| 592 | 100% | | | 2 | 480 | 14/12/09 | 4080 |
| 593 | | 100% | | 3 | 720 | 18/12/09 | |
| 594 | 100% | | | 2 | 480 | 18/12/09 | |
| 595 | 100% | | | 2 | 480 | 18/12/09 | |
| 596 | 95% | | | 1.9 | 456 | 18/12/09 | |
| 597 | | | 100% | 0.5 | 120 | 18/12/09 | |
| 598 | | 100% | | 3 | 720 | 18/12/09 | |
| 599 | | 100% | | 3 | 720 | 18/12/09 | |
| 600 | | | 100% | 0.5 | 120 | 18/12/09 | |
| 601 | | 70% | | 2.1 | 504 | 18/12/09 | |
| 602 | 50% | | | 1 | 240 | 18/12/09 | 4560 |
| 603 | 100% | | | 2 | 480 | 19/12/09 | |
| 604 | 100% | | | 2 | 480 | 19/12/09 | |
| 605 | | 100% | | 3 | 720 | 19/12/09 | |
| 606 | | | 80% | 0.4 | 96 | 19/12/09 | |
| 607 | | 95% | | 2.85 | 684 | 19/12/09 | |
| 608 | 90% | | | 1.8 | 432 | 19/12/09 | |
| 609 | 100% | | | 2 | 480 | 19/12/09 | |
| 610 | | | 100% | 0.5 | 120 | 19/12/09 | |
| 611 | | | 100% | 0.5 | 120 | 19/12/09 | 3612 |
| 612 | | 100% | | 3 | 720 | 20/12/09 | |
| 613 | | 100% | | 3 | 720 | 20/12/09 | |
| 614 | | 100% | | 3 | 720 | 20/12/09 | |
| 615 | 100% | 100% | | 5 | 1200 | 20/12/09 | |
| 616 | 100% | | | 2 | 480 | 20/12/09 | |
| 617 | | 100% | | 3 | 720 | 20/12/09 | |
| 618 | | 100% | | 3 | 720 | 20/12/09 | 5280 |
| 619 | | 100% | | 3 | 720 | 26/12/09 | |
| 620 | | 100% | | 3 | 720 | 26/12/09 | |
| 621 | 100% | | | 2 | 480 | 26/12/09 | |
| 622 | | 100% | | 3 | 720 | 26/12/09 | |
| 623 | 100% | | | 2 | 480 | 26/12/09 | 3120 |
| 624 | | 100% | | 3 | 720 | 27/12/09 | |
| 625 | | 100% | | 3 | 720 | 27/12/09 | |
| 626 | | 100% | | 3 | 720 | 27/12/09 | |
| 627 | | 100% | | 3 | 720 | 27/12/09 | |
| 628 | | 100% | | 3 | 720 | 27/12/09 | |

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Table K.1 – Continued

| | | | | | | |
|---|---|---|---|---|---|---|
| 629 | | 100% | 3 | 720 | 27/12/09 | |
| 630 | | 100% | 3 | 720 | 27/12/09 | |
| 631 | 100% | | 2 | 480 | 27/12/09 | |
| 632 | 100% | | 2 | 480 | 27/12/09 | |
| 633 | | 100% | 3 | 720 | 27/12/09 | 6720 |
| 634 | | 100% | 3 | 720 | 28/12/09 | |
| 635 | | 100% | 3 | 720 | 28/12/09 | |
| 636 | | 100% | 3 | 720 | 28/12/09 | |
| 637 | | 100% | 3 | 720 | 28/12/09 | |
| 638 | | 100% | 3 | 720 | 28/12/09 | 3600 |
| 639 | | 100% | 3 | 720 | 01/01/10 | |
| 640 | | 100% | 3 | 720 | 01/01/10 | |
| 641 | 100% | | 2 | 480 | 01/01/10 | 1920 |
| 642 | | 100% | 3 | 720 | 02/01/10 | |
| 643 | | 100% | 3 | 720 | 02/01/10 | |
| 644 | | 100% | 3 | 720 | 02/01/10 | |
| 645 | | 100% | 3 | 720 | 02/01/10 | |
| 646 | 100% | | 2 | 480 | 02/01/10 | |
| 647 | 100% | | 2 | 480 | 02/01/10 | 3840 |
| 648 | | 100% | 3 | 720 | 03/01/10 | |
| 649 | | 100% | 3 | 720 | 03/01/10 | |
| 650 | 100% | | 2 | 480 | 03/01/10 | |
| 651 | 100% | | 2 | 480 | 03/01/10 | |
| 652 | | 100% | 3 | 720 | 03/01/10 | |
| 653 | | 100% | 3 | 720 | 03/01/10 | |
| 654 | | 100% | 3 | 720 | 03/01/10 | 4560 |
| 655 | | 100% | 3 | 720 | 04/01/10 | |
| 656 | 100% | | 2 | 480 | 04/01/10 | |
| 657 | | 100% | 3 | 720 | 04/01/10 | |
| 658 | 100% | | 2 | 480 | 04/01/10 | |
| 659 | 100% | | 2 | 480 | 04/01/10 | 2880 |
| 660 | | 100% | 3 | 720 | 08/01/10 | |
| 661 | | 100% | 3 | 720 | 08/01/10 | |
| 662 | | 100% | 3 | 720 | 08/01/10 | |
| 663 | | 100% | 3 | 720 | 08/01/10 | |
| 664 | 100% | | 2 | 480 | 08/01/10 | |
| 665 | 100% | | 2 | 480 | 08/01/10 | |
| 666 | | 100% | 3 | 720 | 08/01/10 | |
| 667 | 100% | | 2 | 480 | 08/01/10 | |
| 668 | 100% | | 2 | 480 | 08/01/10 | |
| 669 | 100% | | 2 | 480 | 08/01/10 | |
| 670 | | 100% | 3 | 720 | 08/01/10 | |
| 671 | | 100% | 3 | 720 | 08/01/10 | |
| 672 | | 100% | 3 | 720 | 08/01/10 | 8160 |
| 673 | | 100% | 3 | 720 | 09/01/10 | |
| 674 | | 100% | 3 | 720 | 09/01/10 | |
| 675 | | 100% | 3 | 720 | 09/01/10 | |
| 676 | | 100% | 3 | 720 | 09/01/10 | |
| 677 | | 100% | 3 | 720 | 09/01/10 | |
| 678 | 100% | | 2 | 480 | 09/01/10 | |
| 679 | 100% | | 2 | 480 | 09/01/10 | |
| 680 | | 100% | 3 | 720 | 09/01/10 | |
| 681 | 100% | | 2 | 480 | 09/01/10 | |
| 682 | 100% | | 2 | 480 | 09/01/10 | |
| 683 | | 100% | 3 | 720 | 09/01/10 | |

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Table K.1 – Continued

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|---|---|---|---|---|---|---|---|
| 684 | | 100% | | 3 | 720 | 09/01/10 | |
| 685 | | 100% | | 3 | 720 | 09/01/10 | |
| 686 | | 100% | | 3 | 720 | 09/01/10 | 9120 |
| 687 | | 100% | | 3 | 720 | 10/01/10 | |
| 688 | | 100% | | 3 | 720 | 10/01/10 | |
| 689 | 100% | | | 2 | 480 | 10/01/10 | |
| 690 | | 100% | | 3 | 720 | 10/01/10 | |
| 691 | | 100% | | 3 | 720 | 10/01/10 | |
| 692 | | 100% | | 3 | 720 | 10/01/10 | |
| 693 | 100% | | | 2 | 480 | 10/01/10 | |
| 694 | | 100% | | 3 | 720 | 10/01/10 | |
| 695 | | 100% | | 3 | 720 | 10/01/10 | |
| 696 | 100% | | | 2 | 480 | 10/01/10 | |
| 697 | | 100% | | 3 | 720 | 10/01/10 | 7200 |
| 698 | | 100% | | 3 | 720 | 11/01/10 | |
| 699 | | 100% | | 3 | 720 | 11/01/10 | |
| 700 | | 100% | | 3 | 720 | 11/01/10 | |
| 701 | | 100% | | 3 | 720 | 11/01/10 | |
| 702 | | 100% | | 3 | 720 | 11/01/10 | |
| 703 | | 100% | | 3 | 720 | 11/01/10 | |
| 704 | | 100% | | 3 | 720 | 11/01/10 | |
| 705 | | 100% | | 3 | 720 | 11/01/10 | |
| 706 | | 100% | | 3 | 720 | 11/01/10 | |
| 707 | | 100% | | 3 | 720 | 11/01/10 | |
| 708 | | 100% | | 3 | 720 | 11/01/10 | |
| 709 | | 100% | | 3 | 720 | 11/01/10 | 8640 |
| 710 | | | 100% | 0.5 | 120 | 15/01/10 | |
| 711 | | 100% | | 3 | 720 | 15/01/10 | |
| 712 | | 100% | | 3 | 720 | 15/01/10 | |
| 713 | 100% | | | 2 | 480 | 15/01/10 | |
| 714 | 100% | | | 2 | 480 | 15/01/10 | |
| 715 | 100% | | | 2 | 480 | 15/01/10 | |
| 716 | | 100% | | 3 | 720 | 15/01/10 | |
| 717 | | 100% | | 3 | 720 | 15/01/10 | |
| 718 | | | 100% | 0.5 | 120 | 15/01/10 | |
| 719 | | 100% | | 3 | 720 | 15/01/10 | |
| 720 | 100% | | | 2 | 480 | 15/01/10 | |
| 721 | 100% | | | 2 | 480 | 15/01/10 | |
| 722 | | 100% | | 3 | 720 | 15/01/10 | |
| 723 | | 100% | | 3 | 720 | 15/01/10 | 7680 |
| 724 | | 100% | | 3 | 720 | 16/01/10 | |
| 725 | | 100% | | 3 | 720 | 16/01/10 | |
| 726 | 100% | | | 2 | 480 | 16/01/10 | |
| 727 | 100% | | | 2 | 480 | 16/01/10 | |
| 728 | 100% | | | 2 | 480 | 16/01/10 | |
| 729 | 100% | | | 2 | 480 | 16/01/10 | |
| 730 | | | 100% | 0.5 | 120 | 16/01/10 | |
| 731 | | 100% | | 3 | 720 | 16/01/10 | |
| 732 | | 100% | | 3 | 720 | 16/01/10 | |
| 733 | 100% | | | 2 | 480 | 16/01/10 | |
| 734 | | 100% | | 3 | 720 | 16/01/10 | |
| 735 | | | 100% | 0.5 | 120 | 16/01/10 | |
| 736 | | 100% | | 3 | 720 | 16/01/10 | |
| 737 | | 100% | | 3 | 720 | 16/01/10 | 7680 |
| 738 | | 100% | | 3 | 720 | 17/01/10 | |

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Table K.1 – Continued

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 739 | | 100% | | 3 | 720 | 17/01/10 | |
| 740 | | 100% | | 3 | 720 | 17/01/10 | |
| 741 | 100% | | | 2 | 480 | 17/01/10 | |
| 742 | 100% | | | 2 | 480 | 17/01/10 | |
| 743 | | 100% | | 3 | 720 | 17/01/10 | |
| 744 | 100% | | | 2 | 480 | 17/01/10 | |
| 745 | | 100% | | 3 | 720 | 17/01/10 | |
| 746 | 100% | | | 2 | 480 | 17/01/10 | |
| 747 | 100% | | | 2 | 480 | 17/01/10 | |
| 748 | 100% | | | 2 | 480 | 17/01/10 | |
| 749 | | 100% | | 3 | 720 | 17/01/10 | |
| 750 | | 100% | | 3 | 720 | 17/01/10 | 7920 |
| 751 | 100% | | | 2 | 480 | 18/01/10 | |
| 752 | 100% | | | 2 | 480 | 18/01/10 | 960 |
| 753 | 100% | | | 2 | 480 | 22/01/10 | |
| 754 | 100% | | | 2 | 480 | 22/01/10 | |
| 755 | | 100% | | 3 | 720 | 22/01/10 | |
| 756 | | 100% | | 3 | 720 | 22/01/10 | |
| 757 | | 100% | | 3 | 720 | 22/01/10 | |
| 758 | | 100% | | 3 | 720 | 22/01/10 | |
| 759 | | 100% | | 3 | 720 | 22/01/10 | |
| 760 | | 100% | | 3 | 720 | 22/01/10 | |
| 761 | | | 100% | 0.5 | 120 | 22/01/10 | |
| 762 | | 100% | | 3 | 720 | 22/01/10 | |
| 763 | 100% | | | 2 | 480 | 22/01/10 | |
| 764 | 100% | | | 2 | 480 | 22/01/10 | 7080 |
| 765 | | 100% | | 3 | 720 | 23/01/10 | |
| 766 | | 100% | | 3 | 720 | 23/01/10 | |
| 767 | 100% | | | 2 | 480 | 23/01/10 | |
| 768 | | 100% | | 3 | 720 | 23/01/10 | |
| 769 | 100% | | | 2 | 480 | 23/01/10 | |
| 770 | 100% | | | 2 | 480 | 23/01/10 | |
| 771 | 100% | | | 2 | 480 | 23/01/10 | |
| 772 | | 100% | | 3 | 720 | 23/01/10 | |
| 773 | | 100% | | 3 | 720 | 23/01/10 | |
| 774 | 100% | | | 2 | 480 | 23/01/10 | |
| 775 | 100% | | | 2 | 480 | 23/01/10 | |
| 776 | 100% | | | 2 | 480 | 23/01/10 | |
| 777 | 100% | | | 2 | 480 | 23/01/10 | |
| 778 | 100% | | | 2 | 480 | 23/01/10 | |
| 779 | 100% | | | 2 | 480 | 23/01/10 | |
| 780 | 100% | | | 2 | 480 | 23/01/10 | |
| 781 | | 100% | | 3 | 720 | 23/01/10 | |
| 782 | | 100% | | 3 | 720 | 23/01/10 | |
| 783 | 100% | | | 2 | 480 | 23/01/10 | |
| 784 | | 100% | | 3 | 720 | 23/01/10 | |
| 785 | | 100% | | 3 | 720 | 23/01/10 | |
| 786 | | 100% | | 3 | 720 | 23/01/10 | |
| 787 | | 100% | | 3 | 720 | 23/01/10 | 13680 |
| 788 | 100% | | | 2 | 480 | 24/01/10 | |
| 789 | 100% | | | 2 | 480 | 24/01/10 | |
| 790 | | 100% | | 3 | 720 | 24/01/10 | |
| 791 | | 100% | | 3 | 720 | 24/01/10 | |
| 792 | | 100% | | 3 | 720 | 24/01/10 | |
| 793 | 100% | | | 2 | 480 | 24/01/10 | |

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Table K.1 – Continued

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 794 | 100% | | | 2 | 480 | 24/01/10 | |
| 795 | 100% | | | 2 | 480 | 24/01/10 | |
| 796 | | | 100% | 0.5 | 120 | 24/01/10 | |
| 797 | | 100% | | 3 | 720 | 24/01/10 | |
| 798 | | 100% | | 3 | 720 | 24/01/10 | |
| 799 | 100% | | | 2 | 480 | 24/01/10 | |
| 800 | 100% | | | 2 | 480 | 24/01/10 | |
| 801 | 100% | | | 2 | 480 | 24/01/10 | |
| 802 | 100% | | | 2 | 480 | 24/01/10 | |
| 803 | 100% | | | 2 | 480 | 24/01/10 | |
| 804 | 100% | | | 2 | 480 | 24/01/10 | |
| 805 | | 100% | | 3 | 720 | 24/01/10 | |
| 806 | | 100% | | 3 | 720 | 24/01/10 | |
| 807 | | | 100% | 0.5 | 120 | 24/01/10 | |
| 808 | 100% | | | 2 | 480 | 24/01/10 | 11040 |
| 809 | | 100% | | 3 | 720 | 25/01/10 | |
| 810 | | 100% | | 3 | 720 | 25/01/10 | |
| 811 | 100% | | | 2 | 480 | 25/01/10 | |
| 812 | 100% | | | 2 | 480 | 25/01/10 | |
| 813 | | 100% | | 3 | 720 | 25/01/10 | |
| 814 | | 100% | | 3 | 720 | 25/01/10 | |
| 815 | | 100% | | 3 | 720 | 25/01/10 | |
| 816 | | 100% | | 3 | 720 | 25/01/10 | |
| 817 | | 100% | | 3 | 720 | 25/01/10 | |
| 818 | 100% | | | 2 | 480 | 25/01/10 | |
| 819 | | | 100% | 0.5 | 120 | 25/01/10 | |
| 820 | | 100% | | 3 | 720 | 25/01/10 | |
| 821 | | 100% | | 3 | 720 | 25/01/10 | |
| 822 | 100% | | | 2 | 480 | 25/01/10 | |
| 823 | | 100% | | 3 | 720 | 25/01/10 | |
| 824 | | 100% | | 3 | 720 | 25/01/10 | |
| 825 | | 100% | | 3 | 720 | 25/01/10 | 10680 |
| 826 | 100% | | | 2 | 480 | 29/01/10 | |
| 827 | 100% | 100% | | 5 | 1200 | 29/01/10 | |
| 828 | 100% | 100% | | 5 | 1200 | 29/01/10 | |
| 829 | 100% | 100% | | 5 | 1200 | 29/01/10 | |
| 830 | 100% | 100% | | 5 | 1200 | 29/01/10 | |
| 831 | 100% | | | 2 | 480 | 29/01/10 | |
| 832 | | | 100% | 0.5 | 120 | 29/01/10 | |
| 833 | | | 100% | 0.5 | 120 | 29/01/10 | |
| 834 | | 100% | | 3 | 720 | 29/01/10 | |
| 835 | | 100% | | 3 | 720 | 29/01/10 | |
| 836 | | 100% | | 3 | 720 | 29/01/10 | |
| 837 | | 100% | | 3 | 720 | 29/01/10 | |
| 838 | 100% | | | 2 | 480 | 29/01/10 | |
| 839 | | | 100% | 0.5 | 120 | 29/01/10 | |
| 840 | | 100% | | 3 | 720 | 29/01/10 | |
| 841 | 100% | | | 2 | 480 | 29/01/10 | 10680 |
| 842 | | 100% | | 3 | 720 | 30/01/10 | |
| 843 | | 100% | | 3 | 720 | 30/01/10 | |
| 844 | 100% | | | 2 | 480 | 30/01/10 | |
| 845 | 100% | | | 2 | 480 | 30/01/10 | |
| 846 | 100% | | | 2 | 480 | 30/01/10 | |
| 847 | 100% | 100% | | 5 | 1200 | 30/01/10 | |
| 848 | 100% | | | 2 | 480 | 30/01/10 | |

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Table K.1 – Continued

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 849 | | 100% | | 3 | 720 | 30/01/10 | |
| 850 | 100% | | | 2 | 480 | 30/01/10 | |
| 851 | 100% | | | 2 | 480 | 30/01/10 | |
| 852 | 100% | | | 2 | 480 | 30/01/10 | 6720 |
| 853 | | | 100% | 0.5 | 120 | 31/01/10 | |
| 854 | | 100% | | 3 | 720 | 31/01/10 | |
| 855 | | 100% | | 3 | 720 | 31/01/10 | |
| 856 | | 100% | | 3 | 720 | 31/01/10 | |
| 857 | 100% | | | 2 | 480 | 31/01/10 | |
| 858 | 100% | | | 2 | 480 | 31/01/10 | |
| 859 | 100% | 100% | | 5 | 1200 | 31/01/10 | |
| 860 | 100% | | | 2 | 480 | 31/01/10 | |
| 861 | 100% | | | 2 | 480 | 31/01/10 | 5400 |
| 862 | 100% | 100% | | 5 | 1200 | 01/02/10 | |
| 863 | | | 100% | 0.5 | 120 | 01/02/10 | |
| 864 | | 100% | | 3 | 720 | 01/02/10 | |
| 865 | 100% | | | 2 | 480 | 01/02/10 | |
| 866 | | 100% | | 3 | 720 | 01/02/10 | |
| 867 | | 100% | | 3 | 720 | 01/02/10 | |
| 868 | | 100% | | 3 | 720 | 01/02/10 | |
| 869 | | 100% | | 3 | 720 | 01/02/10 | |
| 870 | | 100% | | 3 | 720 | 01/02/10 | |
| 871 | | 100% | | 3 | 720 | 01/02/10 | 6840 |
| 872 | 100% | | | 2 | 480 | 05/02/10 | |
| 873 | 100% | 100% | | 5 | 1200 | 05/02/10 | |
| 874 | | | 100% | 0.5 | 120 | 05/02/10 | |
| 875 | | 100% | | 3 | 720 | 05/02/10 | |
| 876 | | 100% | | 3 | 720 | 05/02/10 | |
| 877 | | 100% | | 3 | 720 | 05/02/10 | |
| 878 | 100% | | | 2 | 480 | 05/02/10 | |
| 879 | 100% | | | 2 | 480 | 05/02/10 | |
| 880 | | 100% | | 3 | 720 | 05/02/10 | |
| 881 | | 100% | | 3 | 720 | 05/02/10 | |
| 882 | | 100% | | 3 | 720 | 05/02/10 | |
| 883 | | | 100% | 0.5 | 120 | 05/02/10 | |
| 884 | 100% | | | 2 | 480 | 05/02/10 | |
| 885 | 100% | | | 2 | 480 | 05/02/10 | 8160 |
| 886 | | 100% | | 3 | 720 | 06/02/10 | |
| 887 | | 100% | | 3 | 720 | 06/02/10 | |
| 888 | | 100% | | 3 | 720 | 06/02/10 | |
| 889 | | 100% | | 3 | 720 | 06/02/10 | |
| 890 | 100% | 100% | | 5 | 1200 | 06/02/10 | |
| 891 | 100% | 100% | | 5 | 1200 | 06/02/10 | |
| 892 | | | 100% | 0.5 | 120 | 06/02/10 | |
| 893 | | 100% | | 3 | 720 | 06/02/10 | |
| 894 | | 100% | | 3 | 720 | 06/02/10 | |
| 895 | | 100% | | 3 | 720 | 06/02/10 | |
| 896 | 100% | | | 2 | 480 | 06/02/10 | |
| 897 | 100% | | | 2 | 480 | 06/02/10 | |
| 898 | | 100% | | 3 | 720 | 06/02/10 | |
| 899 | | 100% | | 3 | 720 | 06/02/10 | |
| 900 | 100% | | | 2 | 480 | 06/02/10 | |
| 901 | | 100% | | 3 | 720 | 06/02/10 | |
| 902 | 100% | | | 2 | 480 | 06/02/10 | 11640 |
| 903 | | 100% | | 3 | 720 | 07/02/10 | |

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Table K.1 – Continued

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|---|---|---|---|---|---|---|---|
| 904 | | 100% | | 3 | 720 | 07/02/10 | |
| 905 | | 100% | | 3 | 720 | 07/02/10 | |
| 906 | | 100% | | 3 | 720 | 07/02/10 | |
| 907 | | 100% | | 3 | 720 | 07/02/10 | |
| 908 | | 100% | | 3 | 720 | 07/02/10 | |
| 909 | | 100% | | 3 | 720 | 07/02/10 | |
| 910 | | 100% | | 3 | 720 | 07/02/10 | |
| 911 | | 100% | | 3 | 720 | 07/02/10 | |
| 912 | 100% | | | 2 | 480 | 07/02/10 | |
| 913 | 100% | | | 2 | 480 | 07/02/10 | |
| 914 | | | 100% | 0.5 | 120 | 07/02/10 | |
| 915 | | 100% | | 3 | 720 | 07/02/10 | |
| 916 | | 100% | | 3 | 720 | 07/02/10 | |
| 917 | | 100% | | 3 | 720 | 07/02/10 | |
| 918 | | 100% | | 3 | 720 | 07/02/10 | |
| 919 | | 100% | | 3 | 720 | 07/02/10 | |
| 920 | 100% | 100% | | 5 | 1200 | 07/02/10 | |
| 921 | | 100% | | 3 | 720 | 07/02/10 | |
| 922 | | 100% | | 3 | 720 | 07/02/10 | |
| 923 | | 100% | | 3 | 720 | 07/02/10 | 14520 |
| 924 | | 100% | | 3 | 720 | 08/02/10 | |
| 925 | | 100% | | 3 | 720 | 08/02/10 | |
| 926 | | 100% | | 3 | 720 | 08/02/10 | |
| 927 | | 100% | | 3 | 720 | 08/02/10 | |
| 928 | | 100% | | 3 | 720 | 08/02/10 | |
| 929 | 100% | | | 2 | 480 | 08/02/10 | |
| 930 | | 100% | | 3 | 720 | 08/02/10 | |
| 931 | | 100% | | 3 | 720 | 08/02/10 | |
| 932 | | 100% | | 3 | 720 | 08/02/10 | |
| 933 | | 100% | | 3 | 720 | 08/02/10 | |
| 934 | | 100% | | 3 | 720 | 08/02/10 | |
| 935 | | 100% | | 3 | 720 | 08/02/10 | |
| 936 | | | 100% | 0.5 | 120 | 08/02/10 | |
| 937 | | 100% | | 3 | 720 | 08/02/10 | |
| 938 | | 100% | | 3 | 720 | 08/02/10 | |
| 939 | | 100% | | 3 | 720 | 08/02/10 | |
| 940 | | 100% | | 3 | 720 | 08/02/10 | |
| 941 | | 100% | | 3 | 720 | 08/02/10 | |
| 942 | | 100% | | 3 | 720 | 08/02/10 | |
| 943 | 100% | | | 2 | 480 | 08/02/10 | |
| 944 | 100% | | | 2 | 480 | 08/02/10 | |
| 945 | 100% | | | 2 | 480 | 08/02/10 | |
| 946 | | 100% | | 3 | 720 | 08/02/10 | |
| 947 | | 100% | | 3 | 720 | 08/02/10 | |
| 948 | 100% | 100% | | 5 | 1200 | 08/02/10 | 16920 |
| 949 | | 100% | | 3 | 720 | 12/02/10 | |
| 950 | | 100% | | 3 | 720 | 12/02/10 | |
| 951 | | 100% | | 3 | 720 | 12/02/10 | |
| 952 | | 100% | | 3 | 720 | 12/02/10 | |
| 953 | | 100% | | 3 | 720 | 12/02/10 | |
| 954 | | 100% | | 3 | 720 | 12/02/10 | |
| 955 | 100% | | | 2 | 480 | 12/02/10 | |
| 956 | 100% | | | 2 | 480 | 12/02/10 | |
| 957 | 100% | | | 2 | 480 | 12/02/10 | |
| 958 | | 100% | | 3 | 720 | 12/02/10 | |

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Table K.1 – Continued

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|---|---|---|---|---|---|---|---|
| 959 | | 100% | | 3 | 720 | 12/02/10 | 7200 |
| 960 | 100% | | | 2 | 480 | 13/02/10 | |
| 961 | 100% | | | 2 | 480 | 13/02/10 | |
| 962 | 100% | | | 2 | 480 | 13/02/10 | |
| 963 | 100% | | | 2 | 480 | 13/02/10 | |
| 964 | 100% | | | 2 | 480 | 13/02/10 | |
| 965 | | 100% | | 3 | 720 | 13/02/10 | |
| 966 | | 100% | | 3 | 720 | 13/02/10 | |
| 967 | | 100% | | 3 | 720 | 13/02/10 | |
| 968 | | 100% | | 3 | 720 | 13/02/10 | |
| 969 | | | 100% | 0.5 | 120 | 13/02/10 | |
| 970 | | | 100% | 0.5 | 120 | 13/02/10 | |
| 971 | 100% | | | 2 | 480 | 13/02/10 | |
| 972 | | 100% | | 3 | 720 | 13/02/10 | |
| 973 | 100% | | | 2 | 480 | 13/02/10 | |
| 974 | 100% | | | 2 | 480 | 13/02/10 | |
| 975 | | 100% | | 3 | 720 | 13/02/10 | |
| 976 | | 100% | | 3 | 720 | 13/02/10 | |
| 977 | 100% | | | 2 | 480 | 13/02/10 | |
| 978 | 100% | | | 2 | 480 | 13/02/10 | 10080 |
| 979 | | 100% | | 3 | 720 | 14/02/10 | |
| 980 | | 100% | | 3 | 720 | 14/02/10 | |
| 981 | | 100% | | 3 | 720 | 14/02/10 | |
| 982 | 100% | | | 2 | 480 | 14/02/10 | |
| 983 | | 100% | | 3 | 720 | 14/02/10 | |
| 984 | | 100% | | 3 | 720 | 14/02/10 | |
| 985 | | 100% | | 3 | 720 | 14/02/10 | |
| 986 | | 100% | | 3 | 720 | 14/02/10 | |
| 987 | | 100% | | 3 | 720 | 14/02/10 | |
| 988 | | 100% | | 3 | 720 | 14/02/10 | |
| 989 | | 100% | | 3 | 720 | 14/02/10 | |
| 990 | | 100% | | 3 | 720 | 14/02/10 | |
| 991 | | 100% | | 3 | 720 | 14/02/10 | |
| 992 | 100% | | | 2 | 480 | 14/02/10 | |
| 993 | 100% | | | 2 | 480 | 14/02/10 | |
| 994 | | 100% | | 3 | 720 | 14/02/10 | 10800 |
| 995 | 100% | | | 2 | 480 | 15/02/10 | |
| 996 | 100% | | | 2 | 480 | 15/02/10 | |
| 997 | 100% | | | 2 | 480 | 15/02/10 | |
| 998 | | 100% | | 3 | 720 | 15/02/10 | |
| 999 | | 100% | | 3 | 720 | 15/02/10 | |
| 1000 | | 100% | | 3 | 720 | 15/02/10 | |
| 1001 | | 100% | | 3 | 720 | 15/02/10 | |
| 1002 | | 100% | | 3 | 720 | 15/02/10 | |
| 1003 | | 100% | | 3 | 720 | 15/02/10 | |
| 1004 | 100% | | | 2 | 480 | 15/02/10 | |
| 1005 | 100% | | | 2 | 480 | 15/02/10 | |
| 1006 | 100% | | | 2 | 480 | 15/02/10 | |
| 1007 | 100% | | | 2 | 480 | 15/02/10 | 7680 |
| 1008 | | 100% | | 3 | 720 | 19/02/10 | |
| 1009 | 100% | | | 2 | 480 | 19/02/10 | |
| 1010 | | | 100% | 0.5 | 120 | 19/02/10 | |
| 1011 | 100% | | | 2 | 480 | 19/02/10 | |
| 1012 | 100% | | | 2 | 480 | 19/02/10 | |
| 1013 | 100% | | | 2 | 480 | 19/02/10 | |

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Table K.1 – Continued

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1014 | 100% | | | 2 | 480 | 19/02/10 | |
| 1015 | | 100% | | 3 | 720 | 19/02/10 | |
| 1016 | | 100% | | 3 | 720 | 19/02/10 | |
| 1017 | | 100% | | 3 | 720 | 19/02/10 | |
| 1018 | 100% | | | 2 | 480 | 19/02/10 | |
| 1019 | 100% | | | 2 | 480 | 19/02/10 | |
| 1020 | 100% | | | 2 | 480 | 19/02/10 | |
| 1021 | | 100% | | 3 | 720 | 19/02/10 | |
| 1022 | 100% | | | 2 | 480 | 19/02/10 | |
| 1023 | | 100% | | 3 | 720 | 19/02/10 | |
| 1024 | 100% | | | 2 | 480 | 19/02/10 | |
| 1025 | 100% | | | 2 | 480 | 19/02/10 | 9720 |
| 1026 | | 100% | | 3 | 720 | 20/02/10 | |
| 1027 | | 100% | | 3 | 720 | 20/02/10 | |
| 1028 | | 100% | | 3 | 720 | 20/02/10 | |
| 1029 | | 100% | | 3 | 720 | 20/02/10 | |
| 1030 | 100% | | | 2 | 480 | 20/02/10 | |
| 1031 | | 100% | | 3 | 720 | 20/02/10 | |
| 1032 | 100% | | | 2 | 480 | 20/02/10 | |
| 1033 | | 100% | | 3 | 720 | 20/02/10 | |
| 1034 | | 100% | | 3 | 720 | 20/02/10 | |
| 1035 | | 100% | | 3 | 720 | 20/02/10 | |
| 1036 | | 100% | | 3 | 720 | 20/02/10 | |
| 1037 | 100% | | | 2 | 480 | 20/02/10 | |
| 1038 | 100% | | | 2 | 480 | 20/02/10 | |
| 1039 | 100% | | | 2 | 480 | 20/02/10 | |
| 1040 | | 100% | | 3 | 720 | 20/02/10 | |
| 1041 | | 100% | | 3 | 720 | 20/02/10 | |
| 1042 | 100% | | | 2 | 480 | 20/02/10 | |
| 1043 | 100% | | | 2 | 480 | 20/02/10 | |
| 1044 | | 100% | | 3 | 720 | 20/02/10 | |
| 1045 | | | 100% | 0.5 | 120 | 20/02/10 | 12120 |
| 1046 | | 100% | | 3 | 720 | 21/02/10 | |
| 1047 | | 100% | | 3 | 720 | 21/02/10 | |
| 1048 | 100% | | | 2 | 480 | 21/02/10 | |
| 1049 | 100% | | | 2 | 480 | 21/02/10 | |
| 1050 | | 100% | | 3 | 720 | 21/02/10 | |
| 1051 | | 100% | | 3 | 720 | 21/02/10 | |
| 1052 | | 100% | | 3 | 720 | 21/02/10 | |
| 1053 | 100% | | | 2 | 480 | 21/02/10 | |
| 1054 | 100% | | | 2 | 480 | 21/02/10 | |
| 1055 | | 100% | | 3 | 720 | 21/02/10 | |
| 1056 | | 100% | | 3 | 720 | 21/02/10 | |
| 1057 | | 100% | | 3 | 720 | 21/02/10 | |
| 1058 | 100% | | | 2 | 480 | 21/02/10 | |
| 1059 | 100% | | | 2 | 480 | 21/02/10 | |
| 1060 | 100% | | | 2 | 480 | 21/02/10 | |
| 1061 | | 100% | | 3 | 720 | 21/02/10 | |
| 1062 | | 100% | | 3 | 720 | 21/02/10 | |
| 1063 | 100% | | | 2 | 480 | 21/02/10 | |
| 1064 | 100% | | | 2 | 480 | 21/02/10 | |
| 1065 | 100% | | | 2 | 480 | 21/02/10 | |
| 1066 | | | 100% | 0.5 | 120 | 21/02/10 | |
| 1067 | | 100% | | 3 | 720 | 21/02/10 | |
| 1068 | 100% | | | 2 | 480 | 21/02/10 | 13320 |

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Table K.1 – Continued

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|---|---|---|---|---|---|---|---|
| 1069 | 100% | | | 2 | 480 | 22/02/10 | |
| 1070 | 100% | | | 2 | 480 | 22/02/10 | |
| 1071 | | 100% | | 3 | 720 | 22/02/10 | |
| 1072 | | 100% | | 3 | 720 | 22/02/10 | |
| 1073 | | 100% | | 3 | 720 | 22/02/10 | |
| 1074 | | 100% | | 3 | 720 | 22/02/10 | |
| 1075 | 100% | | | 2 | 480 | 22/02/10 | |
| 1076 | | | 100% | 0.5 | 120 | 22/02/10 | |
| 1077 | 100% | | | 2 | 480 | 22/02/10 | |
| 1078 | | 100% | | 3 | 720 | 22/02/10 | |
| 1079 | | 100% | | 3 | 720 | 22/02/10 | |
| 1080 | | 100% | | 3 | 720 | 22/02/10 | |
| 1081 | | 100% | | 3 | 720 | 22/02/10 | 7800 |
| 1082 | 100% | | | 2 | 480 | 26/02/10 | |
| 1083 | | 100% | | 3 | 720 | 26/02/10 | |
| 1084 | | 100% | | 3 | 720 | 26/02/10 | |
| 1085 | | 100% | | 3 | 720 | 26/02/10 | |
| 1086 | | 100% | | 3 | 720 | 26/02/10 | |
| 1087 | 100% | | | 2 | 480 | 26/02/10 | |
| 1088 | 100% | | | 2 | 480 | 26/02/10 | |
| 1089 | 100% | | | 2 | 480 | 26/02/10 | |
| 1090 | 100% | | | 2 | 480 | 26/02/10 | |
| 1091 | 100% | | | 2 | 480 | 26/02/10 | |
| 1092 | | 100% | | 3 | 720 | 26/02/10 | |
| 1093 | 100% | | | 2 | 480 | 26/02/10 | |
| 1094 | 100% | | | 2 | 480 | 26/02/10 | |
| 1095 | 100% | | | 2 | 480 | 26/02/10 | |
| 1096 | 100% | | | 2 | 480 | 26/02/10 | |
| 1097 | 100% | | | 2 | 480 | 26/02/10 | |
| 1098 | 100% | | | 2 | 480 | 26/02/10 | |
| 1099 | | 100% | | 3 | 720 | 26/02/10 | |
| 1100 | 100% | | | 2 | 480 | 26/02/10 | |
| 1101 | 100% | | | 2 | 480 | 26/02/10 | |
| 1102 | 100% | | | 2 | 480 | 26/02/10 | 11520 |
| 1103 | 100% | | | 2 | 480 | 27/02/10 | |
| 1104 | | 100% | | 3 | 720 | 27/02/10 | |
| 1105 | | 100% | | 3 | 720 | 27/02/10 | |
| 1106 | | 100% | | 3 | 720 | 27/02/10 | |
| 1107 | | 100% | | 3 | 720 | 27/02/10 | |
| 1108 | 100% | | | 2 | 480 | 27/02/10 | |
| 1109 | 100% | | | 2 | 480 | 27/02/10 | |
| 1110 | | | 100% | 0.5 | 120 | 27/02/10 | |
| 1111 | | 100% | | 3 | 720 | 27/02/10 | |
| 1112 | | 100% | | 3 | 720 | 27/02/10 | |
| 1113 | | 100% | | 3 | 720 | 27/02/10 | |
| 1114 | 100% | | | 2 | 480 | 27/02/10 | |
| 1115 | 100% | | | 2 | 480 | 27/02/10 | |
| 1116 | 100% | | | 2 | 480 | 27/02/10 | |
| 1117 | | 100% | | 3 | 720 | 27/02/10 | |
| 1118 | 100% | 100% | | 5 | 1200 | 27/02/10 | |
| 1119 | | 100% | | 3 | 720 | 27/02/10 | |
| 1120 | | 100% | | 3 | 720 | 27/02/10 | |
| 1121 | 100% | | | 2 | 480 | 27/02/10 | |
| 1122 | 100% | | | 2 | 480 | 27/02/10 | 12360 |
| 1123 | | 100% | | 3 | 720 | 28/02/10 | |

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Table K.1 – Continued

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|---|---|---|---|---|---|---|---|
| 1124 | | 100% | | 3 | 720 | 28/02/10 | |
| 1125 | | 100% | | 3 | 720 | 28/02/10 | |
| 1126 | | | 100% | 0.5 | 120 | 28/02/10 | |
| 1127 | | | 100% | 0.5 | 120 | 28/02/10 | |
| 1128 | | 100% | | 3 | 720 | 28/02/10 | |
| 1129 | 100% | | | 2 | 480 | 28/02/10 | |
| 1130 | | 100% | | 3 | 720 | 28/02/10 | |
| 1131 | | 100% | | 3 | 720 | 28/02/10 | |
| 1132 | | 100% | | 3 | 720 | 28/02/10 | |
| 1133 | | 100% | | 3 | 720 | 28/02/10 | |
| 1134 | 100% | | | 2 | 480 | 28/02/10 | |
| 1135 | | 100% | | 3 | 720 | 28/02/10 | |
| 1136 | 100% | | | 2 | 480 | 28/02/10 | |
| 1137 | 100% | | | 2 | 480 | 28/02/10 | |
| 1138 | 100% | | | 2 | 480 | 28/02/10 | |
| 1139 | | 100% | | 3 | 720 | 28/02/10 | |
| 1140 | | 100% | | 3 | 720 | 28/02/10 | |
| 1141 | 100% | | | 2 | 480 | 28/02/10 | |
| 1142 | 100% | | | 2 | 480 | 28/02/10 | |
| 1143 | | 100% | | 3 | 720 | 28/02/10 | 12240 |
| 1144 | 100% | | | 2 | 480 | 01/03/10 | |
| 1145 | 100% | | | 2 | 480 | 01/03/10 | |
| 1146 | | 100% | | 3 | 720 | 01/03/10 | |
| 1147 | | 100% | | 3 | 720 | 01/03/10 | |
| 1148 | | 100% | | 3 | 720 | 01/03/10 | |
| 1149 | | 100% | | 3 | 720 | 01/03/10 | |
| 1150 | | 100% | | 3 | 720 | 01/03/10 | |
| 1151 | | 100% | | 3 | 720 | 01/03/10 | |
| 1152 | | 100% | | 3 | 720 | 01/03/10 | 6000 |

# Appendix L

# Strategy Document for Brighton Council

Brighton Council

# Climate Change Mitigation

## Research Overview and Recommendations

Oliver Heyward
August 2010

Figure L.1: Overview and Recommendations (Report to Brighton Council)

Figure L.1 – Continued



## CONTENTS



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Figure L.1 – Continued



## INTRODUCTION

Climate change and its impact on our society is commonly considered from two perspectives, both requiring separate but complementary action.

- Climate change 'mitigation' describes the measures we take to reduce future greenhouse gas emissions and thus minimise its impact.
- Climate change 'adaptation' describes the measures we take to adjust to its impacts, for example, sea level rise or more severe storms, which may result from a warming climate. This aspect of climate change is not the focus of the present report and is discussed for Brighton Council, in detail, in the accompanying paper 'Climate Change Adaptation Discussion Paper'.

This report follows from a research project undertaken at the University of Tasmania, School of Engineering, into climate change mitigation, where Brighton Council was adopted as a case study.

The purpose of this report is to present the findings of the research in a concise and summarised format and to provide recommendations on climate change mitigation strategy for Brighton Council.

## BACKGROUND

Brighton Council made formal recognition of the potential significance of climate change for the first time in 2002, with commencement of the Cities for Climate Protection program (CCP). The Council then resolved to target greenhouse gas emission reductions of 20% by 2010 for both the community and the corporate sectors. The final report[1] for this program however revealed significant divergence from these emission reduction trajectories for a number of reasons.

The key outcomes of the CCP program were a number of low cost initiatives, many consisting of building retrofit measures such as timers on lights or upgrades to more efficient computing equipment. Funding for the program was ceased in 2009.

Since 2009, Brighton Council has been involved in Planet Footprint. Planet Footprint is an environmental 'scorekeeping' organisation that continuously measures an organisation's energy and greenhouse performance, consumption, costs and emissions. Through the program Brighton Council is able to generate up to date reports on energy and greenhouse gas status. This tool enables Council to compare

[1] CCP Plus Planning and Review Report, 2009

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Figure L.1 – Continued



its performance against other similar organisations. It can also be used to assess the impact of an initiative on Council's emission profile.

In 2007, Brighton Council became the focus of a research project based at the School of Engineering, University of Tasmania. The objective of the research was to assess the technology options available to Brighton Council, for the purpose of mitigating climate change. A methodology was developed and applied to Brighton Council from which localised strategies were identified using local resources and initiatives. The methodology employed a triple bottom line approach to the assessment of options, with the intention of identifying options that provided good economic returns, as well as net emission reductions. From this perspective, the methodology did not attempt to set targets for emission reductions, rather, it aimed to find practical and economically sustainable initiatives that would also deliver substantial net emission savings.

The primary objective of this report is to present the research findings and to put them in the context of climate change mitigation strategy for Brighton Council. Full documentation of the research is available in a thesis held at the School of Engineering, UTAS, or alternatively by contacting Council's project engineer, Oliver Heyward.

## RESEARCH METHODOLOGY

The methodology adopted by the research project employed the following three stage procedure in order to strategically assess the technology options.

1. Development of a greenhouse gas emission inventory model for the Council's community and corporate emission profiles.
2. Desktop, triple bottom line assessment of the various technology options based on literature and the baseline inventory data sets.
3. Identification of an initiative that demonstrated the best potential from the desktop assessment. Development of a system model for the initiative, for the purpose of providing input for a preliminary business case.

The triple bottom line perspective is assumed best practice for Council decision making and is therefore the basis for justified strategy. The assessment thus attempts to give equal weight to the social and economic impact, as is given to the environment and emission reduction capacity. It should be noted also that any technology option not sufficiently discussed in the literature was neglected since there was not sufficient basis for comparison.

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Figure L.1 – Continued



While the approach was purely technology focused, it is recognised that significant opportunity for achieving community emission reductions exists from the social awareness and Council planning perspectives. The objective of the study however was to identify initiatives that could make significant cuts in emissions, as well as provide a reasonable return on investment for Council.

The present report aims to summarise the technology review and discuss the options that were identified as having the best potential, when compared to the base line inventory datasets.

## KEY RESEARCH FINDINGS

There are a range of technologies that provide the opportunity for both Brighton Council and the community to reduce greenhouse gas emissions. These technology options come at varying costs and levels of effectiveness. The technology review undertaken in the research focused on three primary emission sources: fuel usage and transport, electricity and waste. With reference to the emission inventory, the technology options were discussed for each of these emission sources, the objective being to discuss the associated issues and identify opportunity for Council, without compromising Council's ability to perform its function in anyway.

The following summarises the research findings.

### FUEL USAGE & TRANSPORT

- The potential for emission savings in this area are only as great as the emissions that are generated by Council's vehicle fleet. That is, by employing the use of technologies to directly reduce vehicle fleet emissions, there is only opportunity to reduce Council's net emissions by 51.5% or 60.3% if staff commute was included. Council should only explore the alternative fuel options that provide minimal impact on Council's vehicle fleet budget.

- A review of the literature demonstrates that most alternative fuel options require significant capital investment for conversion of current fleet or the purchase of new and already converted vehicles.

- There is little opportunity for a return on investment and it is likely that these options would simply be investment from the point of view of reducing emissions.

- Biodiesel offered opportunity to reduce Council's vehicle fleet emission profile without significant cost. Trials of biodiesel however identified that its use

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Figure L.1 – Continued



impacted too greatly on Councils ability to perform its function. Council vehicles were underpowered as a result of biodiesel use.

- It is noted that with Council's three year vehicle turnover policy, approximately 12 vehicles per year are sold on to the public. As with all fleet managers, Council's choice of vehicle therefore has an impact on the types of vehicles the community own in the future and therefore the emission profile of the community.

- Regional modeling of the transport system would provide strategic direction for Council's transport network, improve public transport and minimise community vehicle mileage. This could be considered the responsibility of the state government but should be and encouraged supported by Council.

### ELECTRICITY

- It is identified that improved efficiency is likely to be the most cost effective option for reducing emissions since this approach is directly reducing energy costs at the same time. Organisations should explore options to improve their usage of electricity as a first step to reducing electricity associated greenhouse gas emissions. Council has largely addressed this in implementation of the CCP program.

- While electricity usage contributes only 20.6% to Council's emission profile, it is noted that in generating renewable energy, Council and other community members have the opportunity to not only offset usage, but to sell excess electricity to the grid for greater economic and environmental returns.

- A range of renewable energy technologies have been compared. It is identified that for organisations with an organic waste stream, waste to energy technologies provide the greatest potential for achieving greenhouse gas emission reductions.

- Green waste to energy technologies demonstrate good economics when compared to small scale wind and solar, particularly when considering capacity factor for the Brighton locality.

- Brighton Council should assess the uptake of organic or green waste to energy both individually and in terms of the economies of agglomeration.

- For community members that do not have an organic waste stream, it is suggested that the capacity factor of both wind and solar be assessed at the location of their largest energy usage point, in order to maximise the return on

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Figure L.1 – Continued



investment by offsetting their electricity tariff costs. Council has undertaken wind and solar modeling at the Council chambers (its greatest electricity usage site) which has demonstrated an insufficient resource to be economically justified.

## WASTE

- Brighton Council is in the unique position of managing the bulk waste stream throughout the municipality.
- The green waste component should be considered a resource from which value added products can be derived.
- It is demonstrated that production of electricity and biochar from Council's green waste stream have the potential to offset Council's entire emission profile or more and produce substantial revenue for Council. This should be considered a key strategic objective for Brighton Council in its efforts to mitigate climate change.

## RECOMMENDATIONS

The following is a list of specific actions that Council should consider for its climate change mitigation strategy. These actions predominantly have minimal financial implication to Council, with the exception of item 5 that involves a technology investment. The economics of this item are discussed in the subsequent section.

1. Reinforce Council's vehicle purchase policy to ensure Council only accepts vehicles of high efficiency and low emissions.
2. Encourage and support regional modeling of the transport network in order to improve public transport and minimise community vehicle mileage. Work has already been undertaken in this area by the Department of Infrastructure and Energy Resources. Council should review the work in light of its own future planning.
3. Facilitate the uptake of renewable energy and other sustainability initiatives through Council planning processes. Current regional planning initiatives may make consideration for this.
4. Assess the capacity factor for wind and solar at the Brighton Council Chambers and other points of significant electricity usage. This information

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should be made available to ratepayers to ensure they are well informed for making decisions about small scale renewable energy.

5. Seek funding to support a green waste gasification and biochar facility, sized to match Council's green waste stream. There may be a role for the other levels of government in supporting such an initiative financially. There may also be a role for the University in terms of biochar promotion and biochar characterisation, in order to aid in the establishment of a new biochar market. Collaboration with these institutions should be actively sort by Council.

6. Once the establishment of a biochar production facility has been realized, Council should seek collaborate with other biochar stakeholders, including other Councils and the agricultural industry, to develop long term strategy for the uptake of biochar in the region. Council should not expect to see a return on investment from the biochar perspective in the first instance but should consider the development of a new biochar market, including the establishment of a biochar price, a sensible long term investment. An appropriate forum to support a regional biochar strategy maybe the Regional Climate Change Initiative, part of the Southern Tasmanian Council's Authority.

Based on the technology review, the most economically justified investment for Brighton Council to reduce corporate greenhouse gas emissions is through green waste gasification. It is also identified that biochar maybe produced through a similar process. Council may therefore consider the establishment of a facility that has the capacity to produce either electricity or biochar. A system should be integrated such that it monitors the spot price of electricity and that of biochar and automates the process for maximum returns.

## PRELIMINARY ECONOMIC FEASIBILITY MODELING

As discussed in the previous section, the key investment recommendation of this report is for the establishment of a green waste gasification and biochar production facility, to be housed at Council's waste transfer station.

The process from which each of these products is derived is similar and is known as pyrolysis. It is simply an adjustment of conditions under which pyrolysis occurs that determines which product is under production. Further to this there are some materials handling, peripheral infrastructure and some additional automation

Continued on Next Page. . .

Figure L.1 – Continued



equipment that is required to combine gasification and biochar production into one facility.

It is likely that a combination of the two strategies will provide the best outcome and it is thus recommended that a system be designed that has the capacity to produce either product. The economics of this strategy are most easily discussed in two parts. Firstly, considering a facility that is purely setup for gasification and therefore electricity production; secondly, for a similar system, setup for biochar production.

A definitive economic analysis of a facility would require detailed design of the combined system which would require engagement of a engineering commercial operator and would therefore require a financial investment by Council.

The following tables provide indicative costing of each strategy, sized to process Council's entire green waste stream and located at Council's waste transfer station.

## GREEN WASTE GASIFICATION – ELECTRICITY GENERATION

### ANNUAL EXPENDITURE

| | | |
|---|---|---|
| **Maintenance** | **$20,000** | **(5% of capital)** |
| **Labour for Operation** | **$12,500** | **(25% of a wage, where wage = $50k)** |
| **Decommissioning** | **$0.00** | |
| **Feedstock Transportation** | **$0.00** | |

### ANNUAL REVENUE

| | | |
|---|---|---|
| **Energy** | **$28,732** | |
| **RECs** | **$6,177** | |
| *Cost per tonne to Glenorchy Landfill* | *$27* | **(as at July 2007)** |
| **Glenorchy Landfill Offset** | **$33,743** | |
| *Cost per tonne to transport to Glenorchy* | *$18* | **(as at July 2007)** |
| **Transport to Glenorchy Offset** | **$22,379** | |
| *Gate fee, per tonne* | *$5* | **(assuming one load = one tonne)** |
| **Gate Fee** | **$6,217** | |

### CASH FLOW

| | |
|---|---|
| **Gross Revenue** | **$97,248** |
| **Net Revenue** | **$64,748** |

### LOAN

| | | |
|---|---|---|
| **Loan Interest Rate** | **6.32%** | **(Indicative 10yr rate – Tas Corp)** |
| **Annual Loan Repayment** | **$64,748** | |
| **Gasification System** | **$400,000** | **(Estimated Cost of Facility)** |
| **Payback Period (Years)** | **8.08** | |

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Figure L.1 – Continued



Modeling undertaken as part of the research suggests that this initiative would offset approximately 200% of Council's corporate emissions as a result of avoided landfill emissions and offset of non renewable energy.

This analysis is based on the current Tasmanian electricity feed in tariff of $0.2 per kWhr. This value is very low in comparison to other states in Australia and thus there is potential for a higher feed in tariff to be introduced. This would significantly improve energy revenue and thus the economics of the initiative.

## GREEN WASTE TO BIOCHAR

### ANNUAL EXPENDITURE

| | | |
|---|---|---|
| **Maintenance** | **$10,000** | **(5% of capital)** |
| **Labour for Operation** | **$12,500** | **(25% of a wage, where wage = $50k)** |
| **Decommissioning** | **$0** | |
| **Feedstock Transportation** | **$0** | |

### ANNUAL REVENUE

| | | |
|---|---|---|
| *Biochar (approx. tonnes per year)* | *248.66* | **(assuming 20% conversion)** |
| *Revenue per tonne biochar* | *$100* | **(TIAR, 2010)** |
| **Annual Biochar Revenue** | **$24,866** | |
| **Glenorchy Landfill Offset** | **$33,743** | |
| *Cost per tonne to transport to Glenorchy* | *$18* | **(as at July 2007)** |
| **Transport to Glenorchy Offset** | **$22,379** | |
| *Gate fee, per tonne* | *$5* | **(assuming one load = one tonne)** |
| **Gate Fee** | **$6,217** | |

### CASH FLOW

| | |
|---|---|
| **Gross Revenue** | **$87,205** |
| **Net Revenue** | **$64,705** |

### LOAN

| | | |
|---|---|---|
| **Loan Interest Rate** | **6.32%** | **(Indicative 10yr rate – Tas Corp)** |
| **Annual Loan Repayment** | **$64,705** | |
| **Biochar System** | **$200,000** | **(Estimated Cost of Facility)** |
| **Payback Period (Years)** | **3.55** | |

Modeling of this strategy, undertaken as part of the research, suggests that Council's corporate emissions would be reduced by approximately 123%, as a result of avoided landfill emissions and sequestered carbon in biochar.

Continued on Next Page. . .

Figure L.1 – Continued



A figure of $100 per tonne of biochar has been used in this analysis. This could be considered a conservative figure. Australian owned company Renewable Carbon Resources Australia (RCRA) is currently able to sell biochar for approximately $1000 per tonne in small quantities.

It should be reiterated however that presently there is no biochar market in Tasmania. Council cannot therefore expect to achieve a significant return on investment through biochar until future market is established.

Neither scenario has considered the potential for carbon credits. Political negotiations regarding a price of carbon have not at the present time been resolved. If however in the future a price is set, the emission reduction capacity of this initiative could lead to a significantly improved payback period.

It should also be noted that the capital investment estimates in the above tables are conservative and for budget purposes only. They may in fact be brought down when a design is refined.

## CONCLUSIONS

This report has presented the findings of a research project, undertaken at the University of Tasmania, School of Engineering, investigating climate change mitigation for Brighton Council.

The study has been highly summarised here in order to convey the key findings of the research to Brighton Council and other interested community members, in a concise manner.

Key recommendations have been provided in order to establish climate change mitigation direction for Brighton Council.

# Appendix M

# Research Emission Offset Estimation

The table below provides a conservative calculation of the emissions associated with the present research and thesis. It is estimated that this work has resulted in 2 tonnes of $CO_2e$ as a result of electricity and paper usage. A financial contribution for the offset of an equivalent amount is therefore made to the not-for-profit company 'Carbon Neutral', certified under 'The Greenhouse Friendly$^{TM}$' initiative. This contribution offsets all scope 1 & 2 emissions associated with the project. Figure M.1 verifies this contribution.

| **Electricity** | | |
|---|---|---|
| Approximate Office Time | 2080 | Hours |
| | | |
| Computer Power Consumption | 240 | Watts |
| Usage as a Percentage of Office Time | 100% | |
| Energy Usage | 499.20 | kWhrs |
| | | |
| Monitor Power Consumption | 65 | Watts |
| Usage as a Percentage of Office Time | 100% | |
| Energy Usage | 135.20 | kWhrs |
| | | |
| Lighting Power Consumption | 144 | Watts |
| Usage as a Percentage of Office Time | 80% | |
| Energy Usage | 239.62 | kWhrs |
| | | |
| Heater Power Consumption | 2000 | Watts |
| Usage as a Percentage of Office Time | 10% | |
| Energy Usage | 416.00 | kWhrs |
| | | |
| Total Energy Usage | 1290.02 | kWrs |
| Conversion Factor [Department of Climate Change, 2008a] | 1.3 | kg$CO_2e/kWhr$ |
| **Emissions from Electricity** | **1.68** | **Tonnes** $CO_2e$ |

| **Paper** | | |
|---|---|---|
| Reams of Paper (500 sheets per ream) | 4 | |
| Mass of One Ream | 2.6 | kg |
| Mass of Paper used | 10.4 | kg |
| Emissions due to Production [Carbon Neutral, 2010] | 0.02 | Tonnes $CO_2e$ |
| Emissions due to Waste [Carbon Neutral, 2010] | 0.03 | Tonnes $CO_2e$ |
| **Emissions from Paper** | **0.05** | **Tonnes** $CO_2e$ |
| | | |
| **Total Emissions** | **1.73** | **Tonnes** $CO_2e$ |

Table M.1: Research Emission Offset Calculations


2010

This is to certify that

Oliver Heyward

Carbon Neutral's mission is to reduce carbon emissions through education and revegetation.

Has cumulatively contributed to : Offsetting an estimated 2 tonnes of carbon emissions by the planting of native trees.

We are a not for profit company working with hundreds of organisations and thousands of individuals to measure, reduce and offset carbon emissions and support revegetation projects.

Ray Wilson
Chief Executive Officer

Carbon Neutral partners with Men of the Trees in Western Australia, Trees for Life in South Australia, and Landscapes for Life in Victoria. Together these organisations have contributed over 39 million native trees to the Australian landscape over the past 30 years.

Carbon Neutral Ltd.
Telephone 1300 851 211
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Figure M.1: Certificate for Carbon Offset