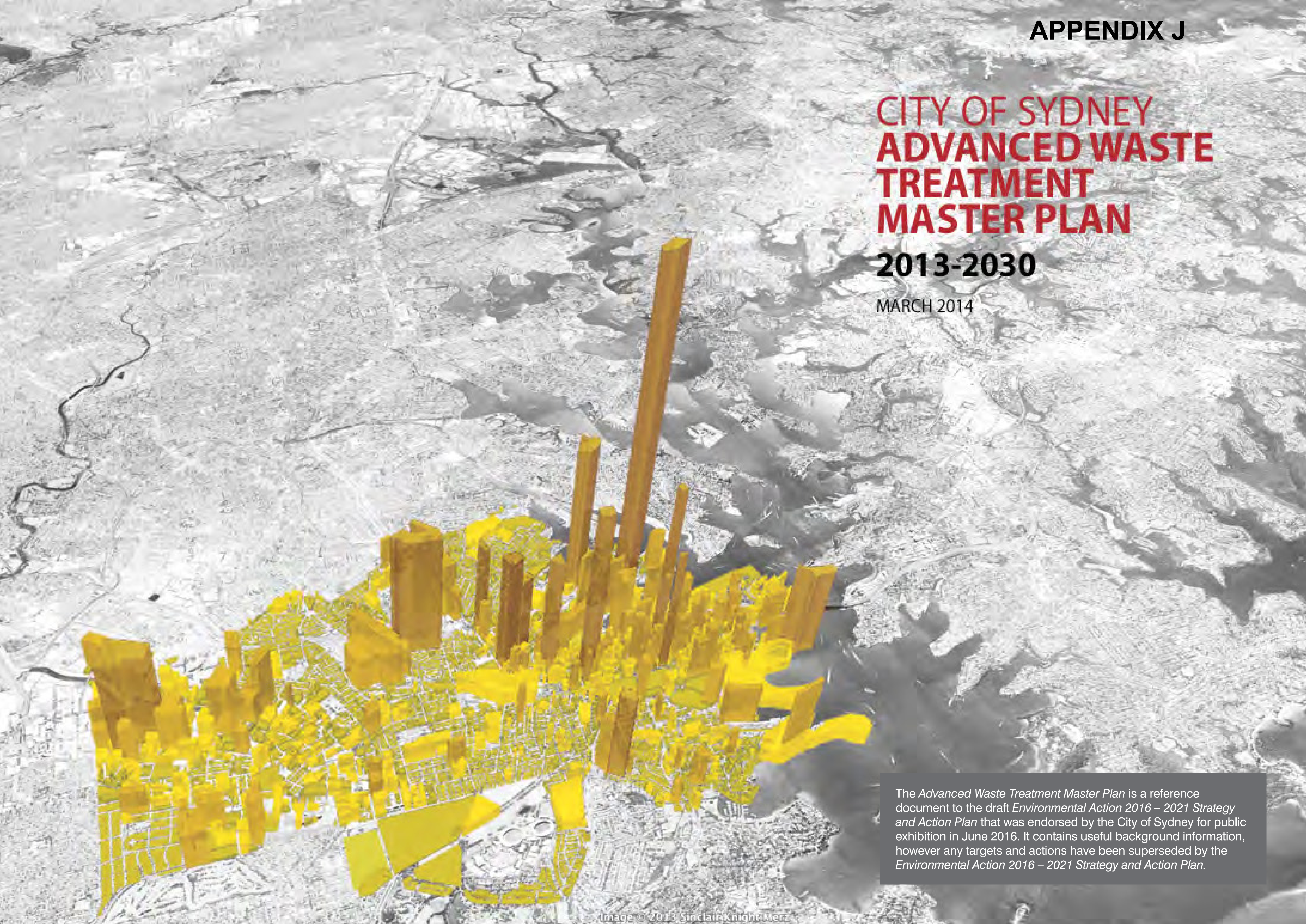
APPENDIX J

CITY OF SYDNEY ADVANCED WASTE TREATMENT MASTER PLAN

2013-2030

MARCH 2014



The *Advanced Waste Treatment Master Plan* is a reference document to the draft *Environmental Action 2016 – 2021 Strategy and Action Plan* that was endorsed by the City of Sydney for public exhibition in June 2016. It contains useful background information, however any targets and actions have been superseded by the *Environmental Action 2016 – 2021 Strategy and Action Plan.*

ACKNOWLEDGEMENTS

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This Master Plan has been prepared by the City of Sydney

February 2014

CONTENTS

FOREWORD

In 2008 the City of Sydney launched Sustainable Sydney 2030 and committed Sydney to becoming a green, global and connected city.

The City has become a leader and innovator in waste management.

The City increased the resource recovery rate from the domestic waste we collect from 27% to 66% between 2006 and 2011/12, two years ahead of the state-wide target set by the NSW Government. We focus on separating valuable recyclables, composting the organic fraction, with the remaining 34% of the waste stream going to landfill.

Waste minimisation and recycling will continue to be a priority for the City and we are looking for a more efficient solution that will maximise the recovery of waste and treat waste as a valuable resource. Even though recycling rates are increasing, population growth is forecast to increase the amount of waste being sent to landfill.

Landfill costs have increased 300% in the past decade and landfill sites near the city are rapidly running out of space. Most of Sydney's future waste will be landfilled at the Woodlawn facility near Goulburn, and a new landfill site will be needed before 2030. Landfill sites generate methane which is a very powerful greenhouse gas. It makes environmental as well as economic sense to seek a new solution.

This Advanced Waste Treatment Master Plan (the Master Plan) outlines a solution where waste is treated as a valuable resource. Non-recyclable waste contains valuable resources that are lost if buried in landfill.

The Master Plan examines a range of technologies that are in use elsewhere, and finds the best solution is to use a high-temperature gasifier to convert solid waste into a gas. Together with recycling, gasification of non-recyclable waste can avoid up to 95% of waste going to landfill, and the gas can be injected into the gas grid to fuel local energy generation or transport networks.

The City has a responsibility to collect residential waste, but businesses are responsible for arranging collection of their own waste. However, this Master Plan also demonstrates the opportunity for commercial and industrial businesses to save money and greenhouse gas emissions by using a waste-to-gas facility instead of landfill.

The waste to gas solution proposed in this Master Plan, if fully implemented, could avoid around 180,000 tonnes of domestic, commercial and industrial waste generated by the City's LGA from going to landfill by 2030. This avoided landfilling cost and levy could be used to fund this new and innovative waste to gas technology. The City's LGA greenhouse gas emissions would be reduced by more than 196,000 tonnes a year through avoided landfill emissions by 2030.

Sustainable Sydney 2030 set a target to reduce greenhouse gas emissions across the entire local government area (LGA) by 70% below 2006 levels by 2030. This Master Plan demonstrates waste can be converted to renewable gas to supply 100% of gas demand for Council operations and planned trigeneration systems, and still have gas available for other uses. The combination of the Advanced Waste Treatment, Renewables Energy, and Trigeneration Master Plans, if implemented, could reduce the City's LGA greenhouse gas emissions by 70% against 2030 business as usual emissions.

The impact of the City's Decentralised Energy Master Plans goes well beyond the City's LGA; creating a market for renewable gas grid injection could provide both councils and businesses within 250km of the City's LGA with the opportunity to avoid around 4.6 million tonnes of waste going to landfill. This could collectively save councils and businesses around $429 million a year in NSW waste levy payments alone and reduce the area's greenhouse gas emissions by around 5.2 million tonnes a year through avoided landfill emissions by 2030.

As a City government responsible for managing residential waste, we can drive forward this advanced waste solution, but we can't deliver this vision alone. It will require the support of Sydney's residents and businesses and a modern regulatory environment that allows 21st century methods to treat waste as a resource and provide a long term solution for the future.

For the City to go much further will require a step change in how waste is managed in Sydney. Using non-recyclable waste as a resource is the way of the future.

Allan Jones MBE
Chief Development Officer, Energy and Climate Change

Clover Moore
Lord Mayor
City of Sydney

UNLOCKING THE MASTER PLAN

1. By 2030, advanced waste treatment can avoid 95% of the City of Sydney local government area domestic, commercial and industrial waste from going to landfill by a combination of recycling and converting non-recyclable waste into renewable gas.
2. Replace 100% of the City of Sydney's own fossil fuel natural gas consumption, including the City's planned trigeneration systems supplying the City's own buildings, with renewable gas derived from non-recyclable domestic waste.
3. Reduce greenhouse gas emissions across the City of Sydney local government area by 7% from avoided landfill gas emissions and conversion of non-recyclable waste into renewable gas.
4. Supply between 6% and 9.5% of the City's planned trigeneration network from gases derived from non-recyclable waste from the City of Sydney local government area.
5. Together with the Energy Efficiency, Trigeneration and Renewable Energy Master Plans, the Advanced Waste Treatment Master Plan can reduce greenhouse gas emissions across the City of Sydney local government area by 70%.

The combination of this Master Plan and the Renewable Energy and Trigeneration Energy Master Plans could deliver the Sustainable Sydney 2030 target to reduce greenhouse gas emissions by 70% below 2006 levels by 2030.

INTEGRATING WASTE AND ENERGY SOLUTIONS

The City of Sydney's vision for 2030 is a sustainable City delivering global best practice services for its residents and businesses. This Advanced Waste Treatment Master Plan details technical solutions for the City to deliver a long-term sustainable waste and energy solution of international standard, providing many benefits at affordable cost.

The City of Sydney is growing. From 2006 to 2030 the population will grow from 166,000 to 246,000, and jobs from 368,000 jobs to 465,000. As the City grows, so will the levels of waste produced.

On projected trends, the City's residential annual waste will increase from 54,000 tonnes in 2006 to 80,000 tonnes in 2030. Business waste will increase from 248,000 tonnes to 307,000 tonnes a year across the same period.

Waste minimisation and recycling will continue to be a priority for the City to manage this expected increase.

The City is an innovator in waste management. Since 2011, kerbside bin waste has been sent to treatment facilities sorting waste to recover materials, and produce a compost-like material. This has diverted over 66% of waste from landfill. However, the City can still do more to ensure virtually no waste goes to landfill and waste produces a more useful product than low grade compost for mine-site rehabilitation.

Sydney's existing waste infrastructure has not kept pace pace with this population and economic growth. For the Sydney metro region no new landfill has been introduced since 2003. There will be no local landfill capacity remaining after 2021. No new waste treatment facilities have been constructed since 2009. Every cubic metre of landfill being used up by the City today will be a cost on its next generation to replace.

The City's Renewable Energy Master Plan shows the most effective way to reduce greenhouse gas emissions is by using local renewable energy. It proposes using renewable gas fuels from waste for the city's energy needs, since conventional renewable energy was limited by the City's high density urban form.

The City has researched international Advanced Waste Treatment technologies, which can treat waste that would otherwise go to landfill. These technologies are proven to reduce material going to landfill by 95% and can generate energy from that waste. Available technologies were evaluated on maturity, risk, and performance. The preferred waste treatment technology is "gasification".

Gasification, or thermal conversion technology, uses heat in a low-oxygen environment to convert solid waste into a gas. This gas can be used to generate electricity, converted into a range of renewable fuels, or rendered to a product similar to natural gas. The substitute natural gas can be delivered by existing gas pipelines, and using City waste will be two-thirds renewable energy content.

By producing energy from waste, the City will reduce greenhouse gas emissions, reduce waste going to landfill and provide renewable energy to fuel our city. As identified in the Trigeneration Master Plan, this renewable gas also provides a hydrogen source for fuel cell technology to further reduce emissions.

Advanced waste treatment costs are competitive for each tonne of waste diverted. The City has analysed potential costs and benefits, including avoiding landfill costs, waste levies and treatment expenses.

While current regulations do not prevent the City from delivering this Master Plan, they do however increase project risk and uncertainty and hence the cost of any potential project. In particular, to allow a level playing field for renewable gas, some market rules need updating. These changes will clarify the sustainability value of renewable energy from waste set out in this master plan.

Chapter 1 reviews the City of Sydney local government area waste, the complex issues and increasing costs impacting current treatment and disposal methods, the evaluation of the various waste treatment options and advanced gasification solutions which could provide a long-term solution for treating the City's waste.

Chapter 2 re-thinks the city's waste as an energy resource and sets out the useful outputs from advanced gasification technologies.

Chapter 3 sets out the proposed advanced waste treatment for the City of Sydney, the environmental and economic benefits of reducing waste to landfill, and the benefits of using substitute natural gas to supply the city's energy demands in the city through the existing gas grid.

Chapter 4 details the performance of the selected advanced waste treatment and gasification solutions and potential costs, savings and benefits.

Chapter 5 sets out the actions necessary to deliver the full potential of this master plan.

Chapter 6 sets out nine overseas case studies covering each type of advanced waste treatment technology referred to in the plan.

OBJECTIVES OF THIS MASTER PLAN

As part of its Green Infrastructure Plan and associated Master Plans, the City is seeking a technical solution for waste treatment that can:

- Generate a long term sustainable waste solution.
- Significantly divert waste from landfill.
- Significantly reduce greenhouse gas emissions arising from waste.
- Handle the complexity and changing levels of city-generated waste over time.
- Provide a renewable energy positive alternative energy resource for the city, that integrates with the Trigeneration and Renewable Energy Master Plans.
- Encourage improved outcomes for the local commercial sector and the surrounding region.
- Deliver value for money in meeting the City's waste obligations at the highest environmental benefit.
- Identify the suitability of sites in close proximity to the City of Sydney with optimal transport and energy delivery connections.

There is a range of advanced waste treatments that can achieve all of these objectives in use internationally. The provision of a renewable and non-fossil energy source moves waste management beyond the existing practice of the City which currently uses a composting solution for waste treatment.

WASTE HIERARCHY

The waste hierarchy offers a simple proxy of best environmental outcomes in the management of waste.

This Master Plan outlines solutions that address existing levels of the waste hierarchy, and provide the means to include the missing level of energy recovery.

Since energy recovery is a resource recovery step of a higher order than landfill, its use in waste management should be encouraged as vigorously as encouraging avoidance before recycling.

The City has identified commercially available energy recovery technologies in this Master Plan that not only achieve higher results if avoidance and recycling are maximised before treatment, but recover additional materials as a by-product during the process of energy recovery, such as metals, chemicals, construction materials and water.

The principle opportunity in the future for near complete resource recovery lies in the ability to convert waste materials by advanced thermal treatment technologies into a renewable gas.

FIGURE 1: THE WASTE HIERACHY (SOURCE: CITY OF SYDNEY)

DOMESTIC WASTE

In 2006, the residential population of the City of Sydney local government area (LGA) was 165,596 which had grown to 191,091 by 2013. With an annual increase of about 1.5%, the City's residential population is forecast to reach approximately 246,000 by 2030.

Collection of domestic or municipal solid waste is the responsibility of the City of Sydney. In 2006, the City collected 53,990 tonnes of domestic waste of which 27% was recycled. In 2012, the City collected 62,598 tonnes of domestic waste of which 66% was diverted from landfill, two years ahead of the state-wide target set by NSW Government. By 2030, domestic waste is forecast to grow to nearly 80,000 tonnes a year of which about 27,000 tonnes of non-recyclable waste would otherwise be expected to go to landfill on a 'business as usual' basis.

The advantage of renewable gas grid injection plants being developed for the City's domestic waste is the virtual elimination of non-recyclable waste going to landfill and the avoidance of the NSW waste levy. If all of the residual domestic waste within the City's LGA was diverted from landfill by advanced waste treatment and renewable gas grid injection this could reduce greenhouse gas emissions by 0.035 $MtCO_{2-e}$ a year in avoided landfill gas emissions and avoid around $3.9 million a year in NSW waste levy payments by 2030.

COMMERCIAL AND INDUSTRIAL WASTE

Collection of commercial and industrial waste is the responsibility of the businesses that generate the waste. In 2006, it is estimated that 248,000 tonnes of commercial and industrial waste was collected of which 35% was recycled. In 2012, it is estimated that 267,000 tonnes of commercial and industrial waste was collected of which 51% was recycled. By 2030, commercial and industrial waste is forecast to grow to 307,000 tonnes a year of which 150,000 tonnes of non-recyclable waste would otherwise be expected to go to landfill on a 'business as usual' basis.

If all of the residual commercial and industrial waste within the City's LGA was diverted from landfill by advanced waste treatment and renewable gas grid injection this could reduce greenhouse gas emissions by 0.15 $MtCO_{2-e}$ a year in avoided landfill gas emissions and avoid around $18 million a year in NSW waste levy payments by 2030.

In addition, the City and businesses must handle waste from those visiting Sydney. In 2006, the numbers of workers and visitors in the City of Sydney LGA was 377,000 and 475,000 per day, respectively, which had grown to 442,256 and 510,000 per day, respectively by 2013. In addition, more than 2 million international visitors come to Sydney every year.

COMBINED DOMESTIC, COMMERCIAL AND INDUSTRIAL WASTE

Utilising advanced waste treatment with renewable gas grid injection for the City's combined domestic, commercial and industrial waste would see the virtual elimination of non-recyclable waste going to landfill and the avoidance of the NSW waste levy. If all of the residual domestic, commercial and industrial waste within the City's LGA was diverted from landfill by advanced waste treatment and renewable gas grid injection this could reduce greenhouse gas emissions by 0.20 $MtCO_{2-e}$ a year in avoided landfill gas emissions and avoid around $17 million a year in NSW waste levy payments by 2030.

LANDFILL: RISING COSTS AND FALLING CAPACITY

Landfill remains the default solution for most waste in NSW, with over half the waste generated from the Sydney Metropolitan Area households ending up in landfill, despite recycling.

The City avoids landfill dependency as far as practicable. City waste treatment relies on recycling and waste sorting to minimise the levels of waste that go to landfill. Even with significant recovery, around one-third of the waste from households will eventually be disposed to a landfill. Existing waste treatment systems have greatly reduced the City's dependence on landfill, but the residues must still be disposed of to landfill.

The City does not own or control its own landfill. Landfills in the Sydney Metropolitan Area are almost fully privatised.

Together with the larger Sydney Metropolitan region, the City is dependent on these limited landfill sites for the final disposal of waste. Existing advanced waste solutions within the Sydney area for waste treatment are limited to around 300,000 tonnes capacity. This compares with the Sydney Metropolitan Area annual waste streams of more than 2,500,000 tonnes, or eight times this waste processing capacity.

Underlying costs in the past 10 years for operating landfill passed through to Councils have risen by more than 300%, with headline costs for waste disposal now at $269-$300 per tonne of waste.

Projections are that landfill costs will continue to rise, and will conservatively exceed $400 per tonne of waste by 2030.

The NSW waste levy has risen by nearly 500% since 2001 to $107.80 per tonne of waste in 2013/14, with further rises legislated until 2016, after which it will adjust annually in line with the Consumer Price Index. The cost of waste disposal to landfill is therefore becoming expensive with no useful outputs arising in addition to the very powerful greenhouse gas emissions in the form of methane emissions into the atmosphere contributing towards climate change.

USING ORGANIC RESOURCES IN WASTE

The organic content of waste might potentially be separated for recovery of its nutrient value. There are a number of reasons why this is not viable for the City of Sydney LGA as recovering the renewable energy content of that waste.

The levels of food waste available in the City's residential waste means that a separate capture of organics would render the remaining waste unsuitable for processing at the existing waste treatment plant. This could lead to an undesirable increase in waste sent to landfill.

Councils that have opted to recover organics rely on co-collecting food with their garden waste service. Due to the high rise development nature of the city the City's garden organics service covers only 4% of the City's LGA households. A co-collected option is simply not possible for the City's households.

This Master Plan identifies treatment options that can process a wide range of levels of organic content in waste. Should future waste avoidance programs reduce levels this will not negatively impact on the treatment technology.

Commercial waste is overall much lower in organic content than household, so variations in this level are not deemed a pressing issue for waste treatment. Existing and future collections of separated organic waste will only be viable for business sectors generating high levels of this type of waste, and should continue to be encouraged where it is economically viable for the business.

EVALUATING THE TREATMENT OPTIONS

The treatment technologies considered in this Advanced Waste Treatment Master Plan were subject to successive levels of analysis to evaluate their suitability to meet the City's key requirements. The evaluations included:

- High level risk evaluation;
- Multi-criteria analysis;
- Life Cycle analysis; and
- Gasification technology review.

HIGH LEVEL RISK ANALYSIS

This evaluation of a broad range of possible technologies was intended to filter out at a high level those technologies at risk of not meeting key requirements. Those not eliminated would be moved forward to greater analysis. At this level a pass-fail approach was adopted against the following key requirements:

- Divert waste from landfill;
- Reduce greenhouse gas emissions; and
- Deliver a renewable/non-fossil fuel gas suitable for renewable gas grid injection for end use in the city, particularly for supplying the planned trigeneration network.

To evaluate against future best practice landfill options, the City included a "bioreactor" landfill in the analysis as a default for the "business as usual" model.

FIGURE 2: HIGH LEVEL RISK EVALUATION OF WASTE TREATMENT PROCESSES (SOURCE: ARUP)

Initial Assessment	Mechanical Biological Treatment	Bioreactor Landfill	Anaerobic Digestion	Grate Incineration	Fluidised Bed Incineration	Gasification (two stage)	Pyrolysis	Plasma Arc Gasification
Significantly reduces GHG emissions	✔	✘	✔	?	?	✔	✔	✔
Generates renewable/ non-fossil fuel gas for end use energy supply	✔	✔	✔	✘	✘	✔	✔	✔
Waste diversion target	✔	✘	✔	✘	✔	✔	✔	✔

MULTI-CRITERIA ANALYSIS

After eliminating bioreactor landfill and thermal combustion or incineration approaches, the City then carried out two detailed ranking evaluations on the remaining technology types.

The multi-criteria analysis assessed the technologies against key elements of four key objective areas:

- Technical performance;
- Financial impacts;
- Environmental impacts; and
- Social impacts.

The evaluation of each technology type within the four objective areas was weighted. A technology might be a midrange performer in one area but a good performer in another and its ranking shift according to the weighting of the overall objective.

The multi-criteria analysis concluded that all of the technologies assessed could provide the performance in the key objective areas sought by the City, subject to performing in accordance with expectations of available research. However, pyrolysis was more suited for separated organic material than more mixed waste.

Gasification technologies ranked first in evaluation for highest weighted technical and environmental performance categories. These technologies ranked higher than biological treatments because of superior energy, carbon reduction and waste diversion outcomes.

LIFE CYCLE ASSESSMENT

The second ranking evaluation used was a Life Cycle Assessment, using an industry standard assessment tool to predict values. The tool used best estimates from operational facilities to represent each treatment process, rather than a particular proprietary technology. This assessment reviewed the totality of environmental impacts and analyses and any offsets each process could accumulate across its lifetime. If an operational impact is a cost, the potential resource recovery offsets are like a credit.

The aim of the Life Cycle Assessment was to produce a theoretical model of the environmental impacts of a technological process across time.

The process reviewed (with abbreviations):

BRL – Bioreactor Landfill

AD – Mechanical Biological Treatment (Anaerobic Digestion)

GAS – Gasification

Gas + PLASMA – Very high temperature gasification and secondary indirect processing with Plasma Gasification

PLASMA – Direct Plasma Gasification

AD + GAS – Waste is sorted and separately biologically treated and gasified

PYR – Pyrolysis

MBT – Estimates for existing mechanical-biological treatment of waste

To effectively rank the processes the life cycle methodology set a boundary common to all. The impacts for energy and waste disposal were assessed across five stages of process:

- Waste pre-treatment;
- Waste treatment (including treatment facility and conventional recycling);
- Residual waste disposal;
- Treatment and transportation of gas generated; and
- Electricity and heat generation.

The results presented in this Master Plan are based on the City's existing waste management system which offers kerbside recycling and waste separately. The total tonnages assessed using the tool are made up of the residential and commercial loads combined.

FIGURE 3: GREENHOUSE GAS REDUCTION BY PROCESS (SOURCE: ARUP)

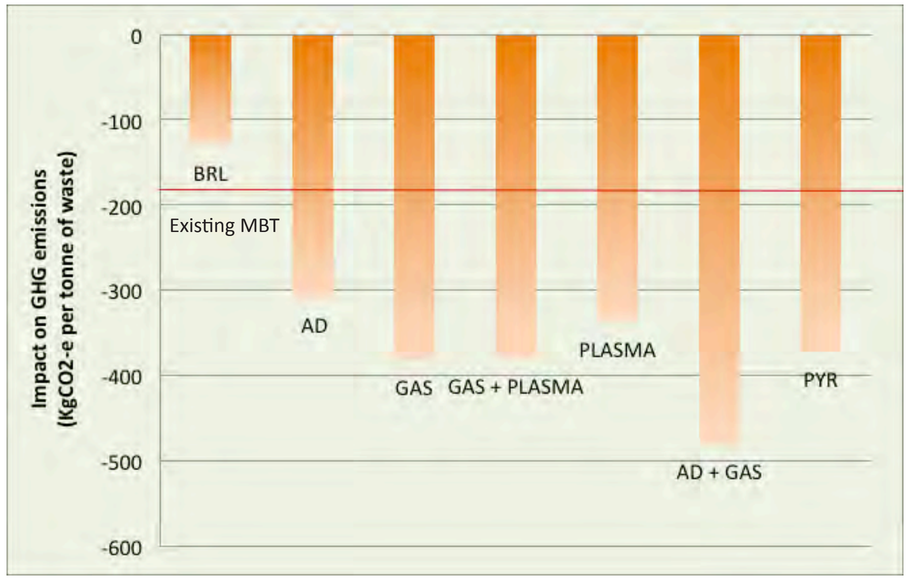
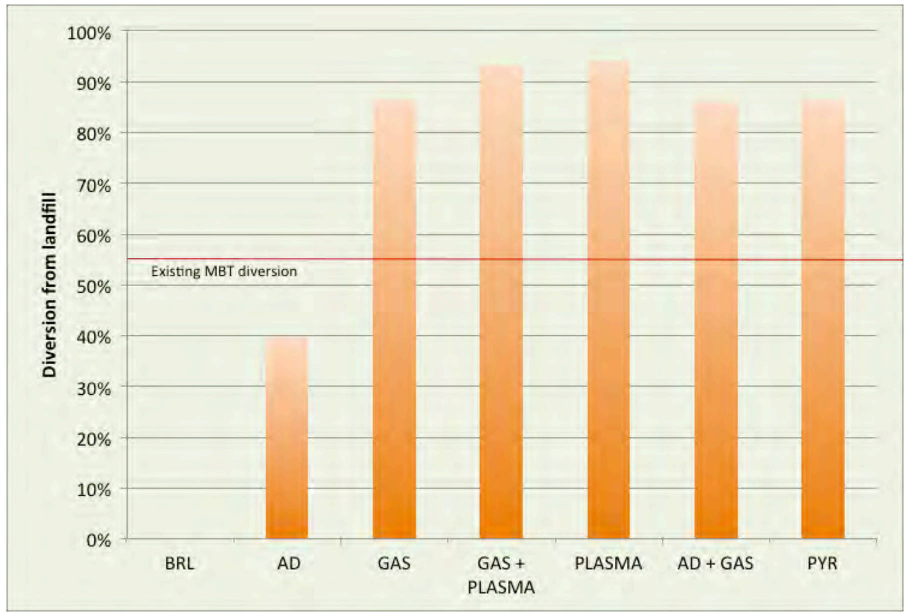


FIGURE 4: WASTE DIVERSION RATE BY PROCESS (SOURCE: ARUP)



Key offsets used to determine the life cycle assessment include:

- Avoided use of grid electricity or fossil fuel mains gas consumption as a result of renewable gas generation and use;
- Avoided paper, plastics, glass and metals production as a result of recycling;
- Avoided fertiliser production as a result of compost/soil conditioner use; and
- Avoided gravel extraction as a result of use of slag by-products from the process.

The City has used the Life Cycle Assessment to review the greenhouse gas and waste diversion impacts of each approach modelled on projected 2030 waste levels.

The reduction in greenhouse gas emissions for each major technology shows that the thermal gasification technologies perform significantly above the other available advanced waste treatment options. The higher the negative number the greater the impact reduction.

In terms of reducing the City's dependence on landfill, only the thermal conversion (gasification) processes offer the required diversion rates, eliminating over 90% of non-recycled waste input to the technology. This would achieve the level sought by the City's Interim Waste Strategy 2012.

Because of the low level of waste diverted from landfill for the AD process, it remains significantly exposed to the risk from rising landfill prices and landfill scarcity.

In terms of economics and cost of carbon abatement the AD + GAS process would require two conversion technologies to convert the renewable gases into substitute natural gas, upgrading for the biogas output from anaerobic digestion and the methanation process (see Chapter 2) for the gas product output from gasification. In addition, the AD process is sensitive to the quality of source separated organics as AD requires homogeneous organic materials which lead to further cost imposts for source separated organics which is impractical for a city like the City of Sydney.

All scenarios offer a significant improvement over BAU. Thermal conversion (gasification) approaches also offer the highest diversion of waste from landfill with corresponding reductions in greenhouse gas emissions.

REVIEW OF GASIFICATION TECHNOLOGIES

The outcome of the Life Cycle Assessment identified the gasification technologies as providing the highest rates for diversion of waste from landfill and reductions in greenhouse gas emissions. However, both the Multi-criteria Analysis and Life Cycle Assessment relied on theoretical modelling of the processes evaluated. To determine the ideal type or class of gasification technology to treat the City's non-recycled waste, the City commissioned a gasification Technologies Review which forms the Technical Appendix to this Advanced Waste Treatment Master Plan.

Five key selection criteria were needed to be met for inclusion of suitable reference technologies to assess the likely performance, costs and benefits of gasification:

1) Commercial Maturity

To ensure consistent performance data, each technology had to be either

- **Demonstrated** – at least one reference facility operating successfully at a commercial-scale.
- **Proven** – at least one reference facility in continued, full-commercial operation.
- **Commercial** – several reference facilities in continued, full commercial operation.

2) Plant Throughput

Based on the City's waste levels technologies needed to process between 40,000 to 150,000 tonnes per year with high diversion levels.

3) Feedstock

Technologies needed to be capable of treating municipal solid waste (MSW), and commercial and industrial (C&I) waste in the city, and potentially one or more Council's waste within the vicinity of the advanced waste treatment plant.

4) Syngas Generation

The gas product output from gasification processes is known as synthesis gas, or syngas, as it is synthesised from the chemical components of the waste and treatment additives (see Chapter 2). Technologies needed to be capable of generating a syngas that could be converted into substitute natural gas via the methanation process for injection into the gas grid.

5) Best Available Standard Emissions Performance

Technologies had to meet or be better than international emissions standards, including the European Union Waste Incineration Directive.

SHORTLISTED REFERENCE TECHNOLOGIES

A shortlist of 16 gasification technologies met the selection criteria which are detailed in Chapter 1. The technologies can be organised into three broad categories or classes of gasification depending on their thermal conversion temperatures:

Low Temperature Conversion: based on technologies operating up to 750°C

High Temperature Conversion: based on technologies operating at or over 750°C

High Temperature + Ash Melting: based on technologies incorporating a melting zone (over 1,500°C) to melt out ash and impurities.

The high temperature + ash melting gasification technologies had the highest waste feedstocks to renewable energy content and levels of waste diversion as detailed in Chapter 2.

WHAT IS THE MASTER PLAN PROPOSING?

This Advanced Waste Treatment Master Plan sets out the options for the City of Sydney to improve the long term sustainability of its waste management needs, while providing a renewable energy recovery solution integrated with the targets of the Renewable Energy and Trigeneration Master Plans.

Any of the high temperature plus ash melting gasification technologies would meet the City's objectives for waste diversion and syngas generation for energy recovery, with plasma gasification offering the highest outcomes in this category.

The clean-up and methanation of syngas into a substitute natural gas for injection into the gas grid has the highest end use efficiency, greatest reduction in greenhouse gas emissions, greater economic value as a renewable gas than as renewable electricity and provides the pathway for the City's own contribution of renewable gas to supply all of the City of Sydney's gas demands, including the City's own planned trigeneration systems, as well as domestic gas demands in the City of Sydney LGA.

RENEWABLE ENERGY

Almost 90% of electricity currently used in the City of Sydney LGA comes from coal fired power stations. These are responsible for 80% of greenhouse gas emissions for the City of Sydney LGA. Renewable energy technologies currently produce about 10% of Australia's electricity, largely from hydro and wind power, which is set to grow to 20% of Australia's electricity supply by 2020 under the current Renewable Energy Target.

This Advanced Waste Treatment Master Plan contributes toward the Sustainable Sydney 2030 target to reduce greenhouse gas emissions by 70% from 2006 levels by 2030. Since 80% of the City of Sydney LGA emissions come from centralised power generation, primarily coal, Sustainable Sydney 2030 also set a target for the City of Sydney LGA to have capacity to meet up to 100% of electricity demand by local generation by 2030. Of this local electricity demand, renewable electricity generation was expected to supply 30% and trigeneration 70% by 2030.

In developing the Renewable Energy Master Plan detailed research was undertaken into non-recyclable waste resources inside and in proximity to the City's LGA, particularly how domestic, commercial and industrial waste could contribute towards the renewable gas resources to replace 100% of the gas needed to fuel the City's planned trigeneration network. This Advanced Waste Treatment Master Plan identifies the waste resources, policies and technologies needed to maximise the City's LGA own non-recyclable waste to contribute towards the renewable gas and reduction in greenhouse gas emissions targets.

RENEWABLE GASES FROM WASTE

This Master Plan identifies the potential of renewable gases that can be recovered from the City of Sydney LGA own domestic, commercial and industrial waste that is not otherwise recycled. Beyond the city, renewable gases can also be sourced from domestic, commercial and industrial waste in the Sydney Metropolitan and Extended Areas and from livestock manure, agricultural stubble and husks from crops or non-native forestry off-cut waste.

The Renewable Energy Master Plan identified renewable gas feedstocks from waste both inside the City of Sydney LGA and up to 250km from the City of Sydney LGA. This Advanced Waste Treatment Master Plan details the renewable gas feedstocks available from the City's LGA own waste and how this resource can be used to generate renewable gases and further significantly reduce waste going to landfill. Both the gases from these wastes can be converted into a substitute natural gas (SNG) and brought to the city within the existing natural gas pipe network or by liquefaction and transport to the nearest natural gas pipe network. This provides a common carrier of energy recovered from waste suitable for delivery to the City.

The trigeneration decentralised energy network operating 24 hours a day at 372 megawatt electrical (MWe) capacity could use the renewable gases recovered from waste. Natural gas fuelled trigeneration provides low carbon electricity and zero carbon heating and cooling. This reduces greenhouse gases being emitted from connected buildings by up to 60%.

The renewable gas energy potential and associated reduction in greenhouse gas emissions for the City's LGA own waste was included in the Renewable Energy Master Plan but the reduction in waste going to landfill and associated avoided landfill methane emissions was excluded from the Renewable Energy Master Plan. Both of these are included in this Advanced Waste Treatment Master Plan.

Using renewable gases instead of natural gas would effectively deliver a 100% renewable energy system and produce virtually zero net greenhouse gas emissions. Renewable gases are currently the least developed form of renewable energy in Australia so further work was undertaken in the Renewable Energy Master Plan to determine the actual potential renewable gas feedstock resource and the economics of renewable gas technologies which are included in that Master Plan.

Using renewable gases from waste in the City's trigeneration network will also overcome the problem of ensuring the reliable and consistent supply of local energy into the future without the need to rely on fossil fuel spinning reserve.

Further energy can be harnessed by converting inorganic waste into syngas. However, for the purposes of the Renewable Energy Master Plan organic waste only was taken into account for the supply of renewable gases to the City's trigeneration network. Gas derived from inorganic waste represents an additional, virtually zero carbon, unconventional non-fossil fuel resource. Both types of gases are included in this Advanced Waste Treatment Master Plan.

Of the total renewable gas resource identified in the Renewable Energy Master Plan the City's LGA own domestic, commercial and industrial waste could contribute 1.62PJ/year of renewable and non-fossil fuel gas towards displacing fossil fuel natural gas supplying the City's planned trigeneration network. This represents between 9.5% and 6% of the gas needed to fuel the trigeneration network in the four low carbon zones for 7am–10pm and 24 hours a day, respectively. In other words, enough renewable and non-fossil fuel gas to supply between 35.5MWe and 22.3MWe of trigeneration, respectively.

Not only would renewable gas injected into the fossil fuel gas grid recover up to three times the primary renewable energy resource than renewable electricity generation only it would also reduce greenhouse gas emissions by up to four times as much as renewable electricity generation only as well as producing a non-intermittent form of renewable energy from a resource that would otherwise be disposed of in landfill where it would take up land and generate methane emissions.

Europe is currently the global leader and far ahead of Australia in terms of advanced waste treatment, renewable energy targets, and the delivery of both by smart and integrated regulatory approaches.

Converting waste into a renewable gas would also reduce pressure on Sydney landfill sites which are estimated to reach capacity by 2021.

Trigeneration supplied by renewable gas derived from domestic, commercial and industrial waste converted to substitute natural gas (SNG) and injected into the gas grid has the lowest marginal social cost of abatement than any renewable electricity technology, with the exception of micro wind energy on buildings, and could potentially have negative marginal social cost of abatement by 2020.

Renewable gas/substitute natural gas derived from the City's LGA own waste will potentially be cheaper than fossil fuel natural gas in the immediate future and significantly cheaper than fossil fuel natural gas by 2030. See 'Cost of Renewable Gas' in Chapter 4. In order to capture the benefits of this low cost form renewable energy a new regulatory regime a Government led market development approach will need to be adopted similar to the German model to maximise the efficiency and emissions reduction of renewable gases and to prevent 'price gouging'. See 'Establish Renewable Gas Target and Develop Regulatory Regime for Renewable Gases' in Chapter 5.

The City's plans for precinct trigeneration will create a market for renewable gases which would otherwise not exist, thereby improving the commercial viability of energy from waste projects as well as contributing towards the economy.

FIGURE 5: GREENHOUSE GAS EMISSION SAVINGS FOR RENEWABLE GAS GRID INJECTION (SOURCE: CITY OF SYDNEY)

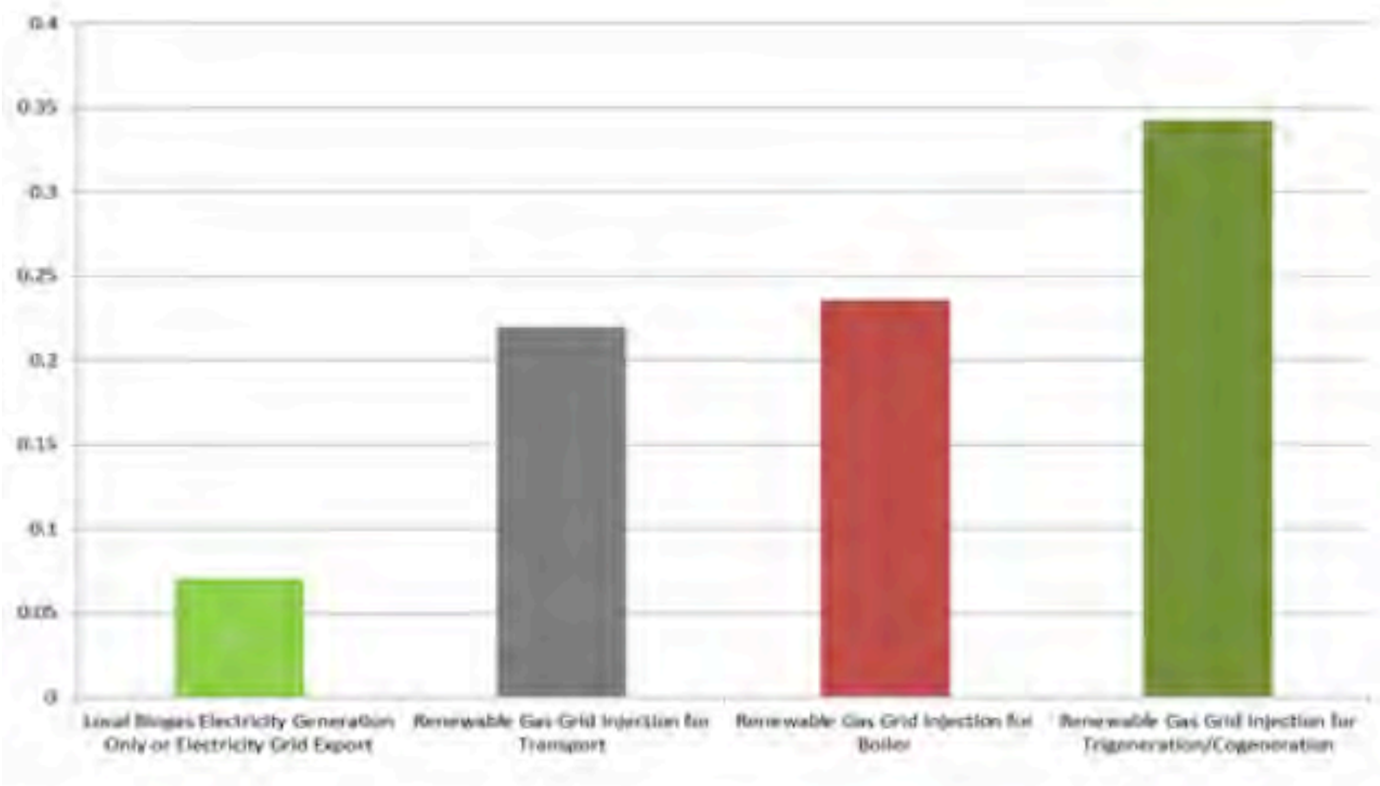
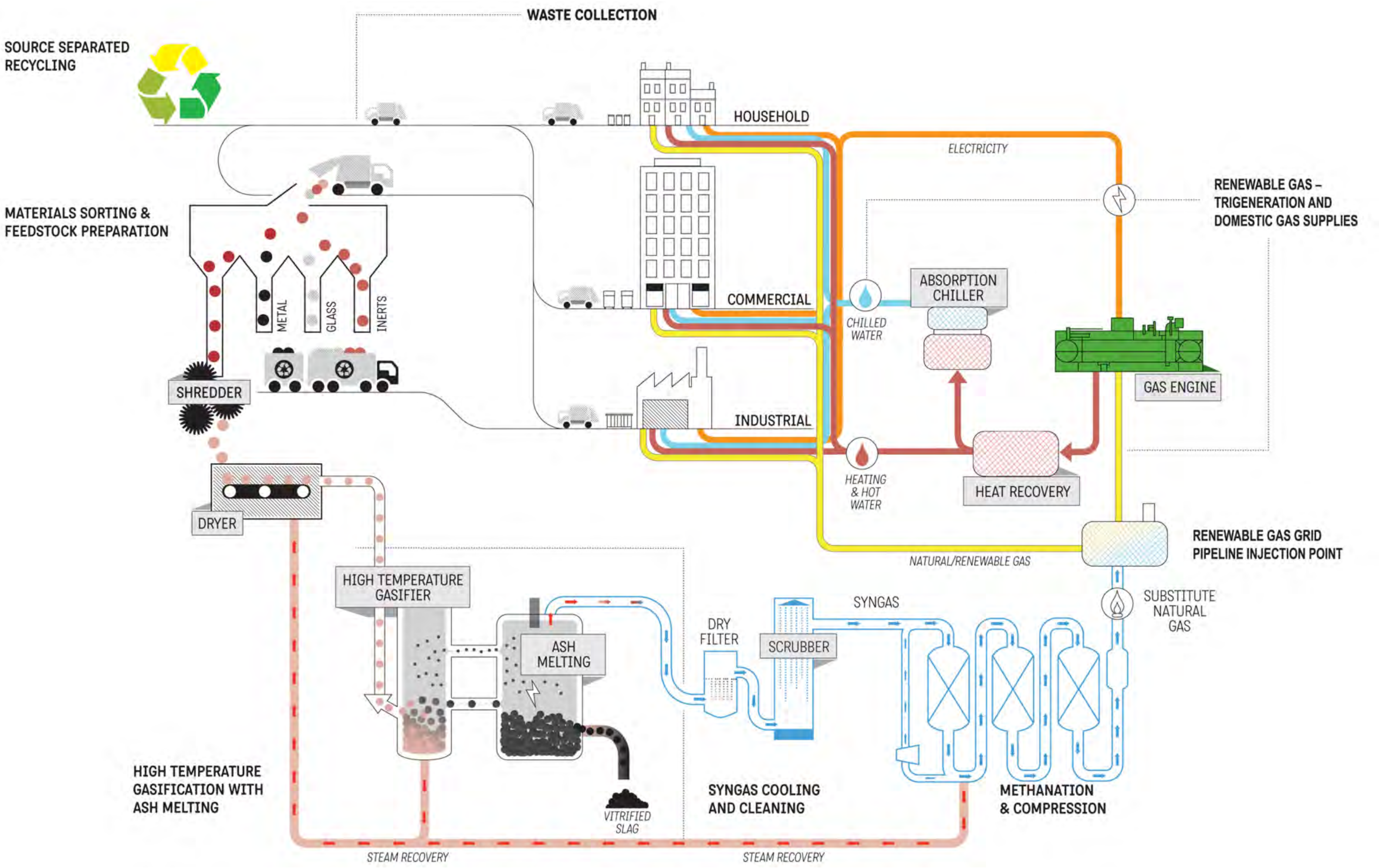


FIGURE 6: ADVANCED WASTE TREATMENT – RENEWABLE GAS GRID INJECTION
(SOURCE: CITY OF SYDNEY)



TRACKING 2030 TARGETS

Figure 7 shows the renewable gas generation contribution to the 100% renewable gas target by 2030 and Figure 8 shows the reduction in greenhouse gas emissions from renewable energy proposed by this Advanced Waste Treatment Master Plan, as well as from other green infrastructure by 2030.

The reduction in greenhouse gas emissions brought about by renewable gas derived from waste replacing natural gas supplying the City's trigeneration network are accounted for in the Renewable Energy Master Plan but the reduction in greenhouse gas emissions brought about by avoided methane emissions at landfill sites through diverting waste away from landfill to renewable gas generation is accounted for in this Advanced Waste Treatment Master Plan.

The Advanced Waste Treatment Master Plan shows that the City's LGA domestic, commercial and industrial non-recyclable waste going to landfill could:

- Supply 100% of the City's own gas demands, including the City's own planned trigeneration systems, estimated to be 0.2PJ/year from the 0.25PJ/year renewable gas (0.63PJ/year including non-fossil fuel gas) gasified from the City's collection of non-recyclable domestic or municipal solid waste.
- Reduce greenhouse gas emissions from waste recycled or recovered by treatment since 2006 across the City's LGA by 0.135 $MtCO_{2\text{-}e}$ a year (2.1%) through avoided landfill gas emissions below 2006 levels by 2030 (not included in the Renewable Energy Master Plan).
- Reduce greenhouse gas emissions from waste sent to landfill across the City's LGA by 0.196 $MtCO_{2\text{-}e}$ a year (3.1%) through avoided landfill gas emissions below 2006 levels by 2030 (not included in the Renewable Energy Master Plan).
- Reduce greenhouse gas emissions across the City's LGA by 0.106 $MtCO_{2\text{-}e}$ a year (1.7%) through conversion of non-recyclable waste into renewable gas for the trigeneration network below 2006 levels by 2030 (included in the Renewable Energy Master Plan).
- Together with avoided landfill gas emissions and conversion of non-recyclable waste into renewable gas for the trigeneration network reduce greenhouse gas emissions across the City of Sydney LGA by 0.437 $MtCO_{2\text{-}e}$ a year (6.9%) below 2006 levels by 2030.
- Supply between 9.5% (35.5MWe) and 6% (22.3 MWe) of the planned City's LGA trigeneration network for 7am–10pm and 24 hours a day, respectively, from renewable and non-fossil fuel gases derived from the non-recyclable waste feedstocks available within the City's LGA by 2030.

FIGURE 7: CITY OF SYDNEY LGA RENEWABLE GAS CONTRIBUTION TO 100% RENEWABLE ENERGY TARGET FOR 2030 (SOURCE: CITY OF SYDNEY)

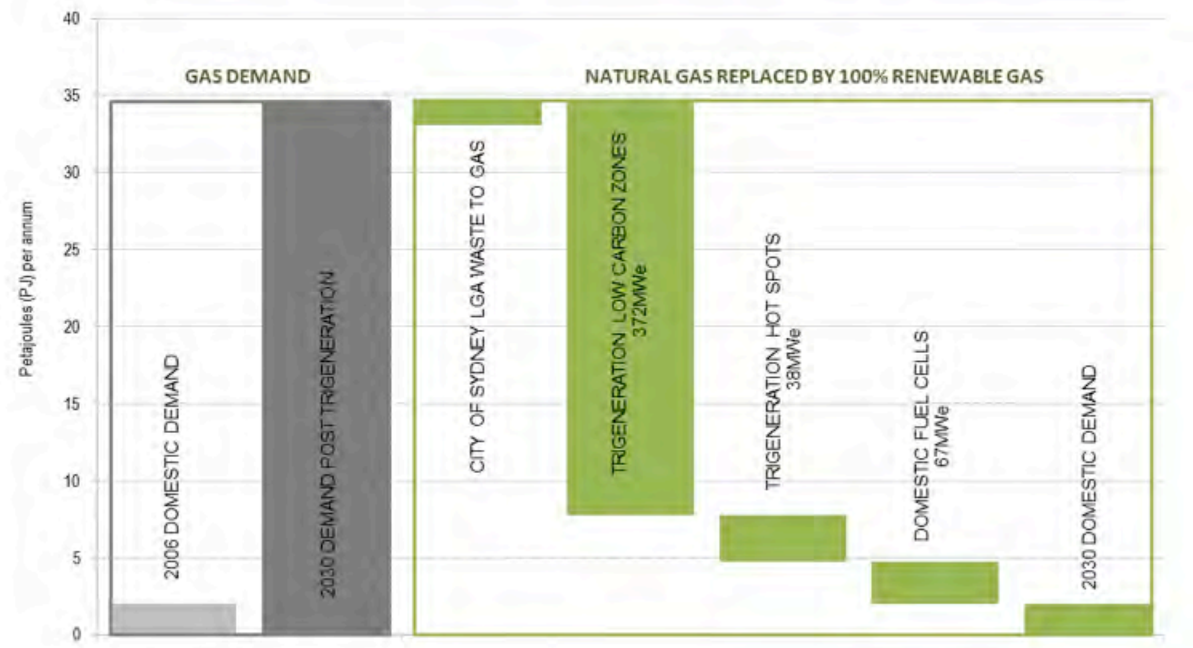
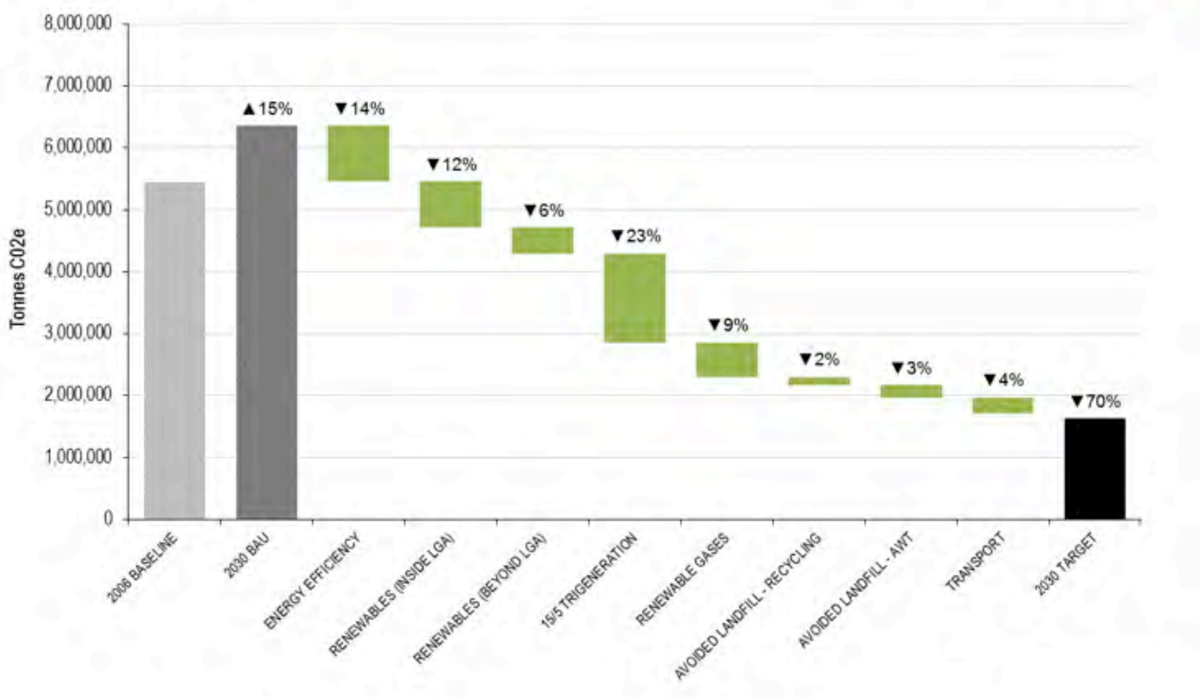


FIGURE 8: CITY OF SYDNEY LGA ADVANCED WASTE TREATMENT CONTRIBUTION TO 70% GREENHOUSE GAS EMISSION REDUCTION TARGET FOR 2030 (SOURCE: CITY OF SYDNEY)



ADVANCED WASTE TREATMENT

ADVANCED WASTE TREATMENT

This Master Plan proposes to utilise waste resources in a way that represents a radical departure from current practice.

The proposed use of advanced waste treatment technologies to convert solid waste into a renewable gas will provide immediate and significant reductions in waste disposal to landfill.

This Master Plan identifies thermal conversion treatment technologies that will reduce the City's reliance on fossil fuel natural gas and provide an integrated waste recycling and renewable energy solution that reduce greenhouse gas emissions by avoiding or displacing current sources of emissions.

WHY THINGS HAVE TO CHANGE

The case for seeking an alternative solution to improve current waste practice is stark; growth in City waste levels; rising landfill prices, greenhouse gas emissions loads; upstream impacts relating to how waste is managed, improved treatment opportunities, reduced landfill capacity and anticipated more extensive waste transport demands make for a compelling social, environmental and economic case.

GROWTH LEVELS OF WASTE

Total waste generation within the City's local government area (LGA) is projected to continue to rise with increases in population and business growth. In the year 2012–13, the City's residents disposed of 329 Kg per capita of mixed waste after recycling. This per capita rate has shown some signs of levelling out in recent years, but the additional population forecast for 2030 will see an increase in absolute levels of waste.

The characteristics of this waste are described further in Chapter 2.

RESIDENTIAL WASTE LEVELS TO 2030

Figure 9 is for municipal solid waste until 2030, showing waste levels without including waste treatment. Based on current trends, the City's residential waste load (the combined total for recycling and garbage) will reach 80,000 tonnes per year by 2030.

FIGURE 9: RESIDENTIAL WASTE LEVELS TO 2030 (SOURCE: TALENT WITH ENERGY)

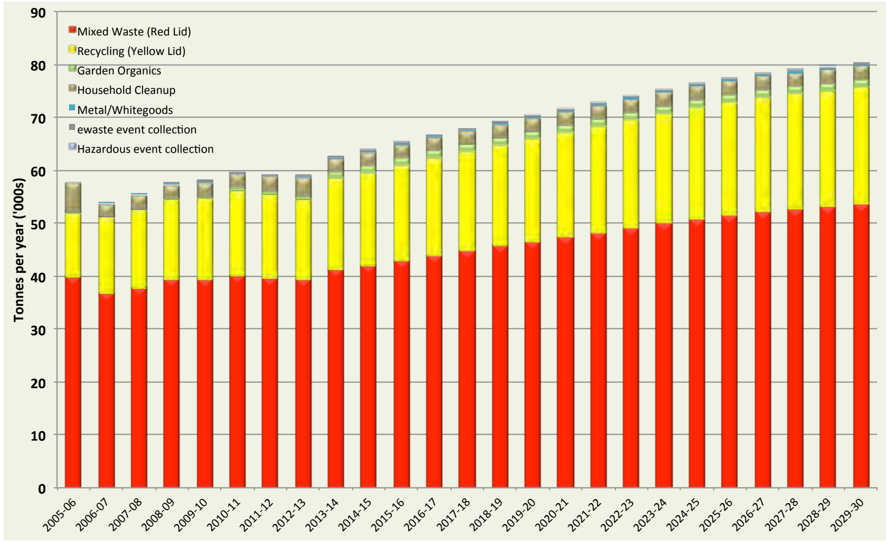
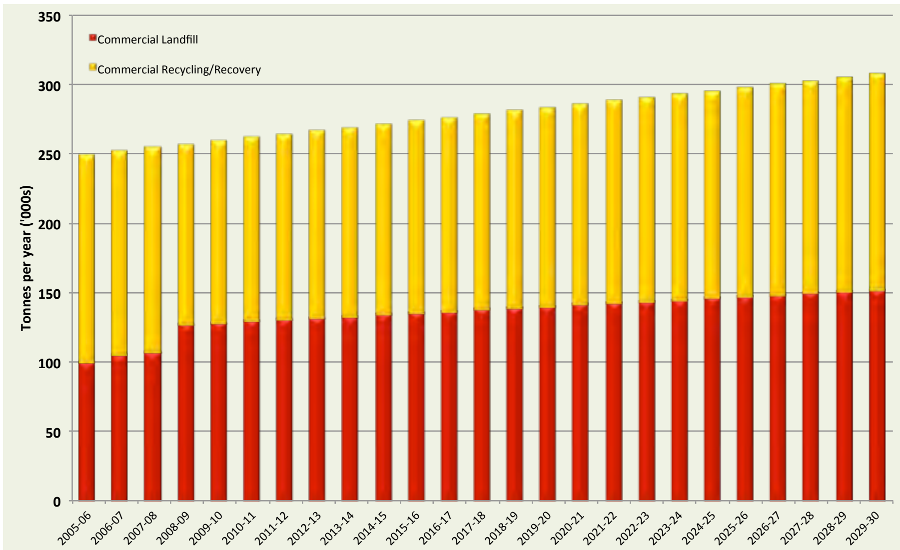


FIGURE 10: COMMERCIAL AND INDUSTRIAL WASTE LEVELS TO 2030 (SOURCE: TALENT WITH ENERGY)



COMMERCIAL AND INDUSTRIAL WASTE LEVELS TO 2030

Increases in commercial waste are projected to continue in line with business growth. Commercial waste generated in the City LGA is currently around five times the level of residential waste. On these trends it is projected that the commercial waste load in the City of Sydney LGA will exceed 300,000 tonnes per year by 2030.

LANDFILL: RISING COSTS AND FALLING CAPACITY

Landfill remains the default solution for most waste in NSW, with over half of the waste generated from Sydney Metropolitan Area households ending up in landfill, despite recycling.

The City avoids landfill dependency as far as practicable. Existing City waste treatment relies first on recycling and waste sorting to minimise the levels of waste that go to landfill. Even with significant recovery, around one-third of the waste from households will eventually be disposed to a landfill. Existing waste treatment systems have greatly reduced the City's dependence on landfill, but the residues from these treatments must still be disposed of to landfill.

The City does not own or control its own landfill. Landfills in the Sydney Metropolitan Area are almost fully privatised.

Together with the larger Sydney Metropolitan region, the City is dependent on these limited landfill sites for the final disposal of waste.

Increasing regulatory compliance and operating costs, together with a levy on waste disposed to landfill, continue to force up costs associated with any landfill disposal.

Underlying costs in the past 10 years for operating landfill passed through to Councils have risen by more than 300%, with headline costs for waste now at $269–$300 per tonne of waste.

Projections are that landfill costs will continue to rise to 2030, and will conservatively exceed $400 per tonne on present value by that time.

The NSW government has imposed a levy since 1971 on all waste tipped into landfills, and this charge has been rising steeply in the past decade. The levy rises aim to make waste treatment and recycling infrastructure more viable when compared with direct-to-landfill options.

Recently reviewed for the first time, the waste levy has risen almost fivefold since 2001 to $107.80 per tonne in 2013–14, with further rises legislated until 2016, after which it will adjust annually in line with the Consumer Price Index. This levy is also applied in full to waste disposed even after processing in advanced waste treatment facilities.

FIGURE 11: HISTORIC LANDFILL COSTS IN SYDNEY (SOURCE: CITY OF SYDNEY, WSN ENVIRONMENTAL SOLUTIONS, SITA ENVIRONMENTAL SOLUTIONS)

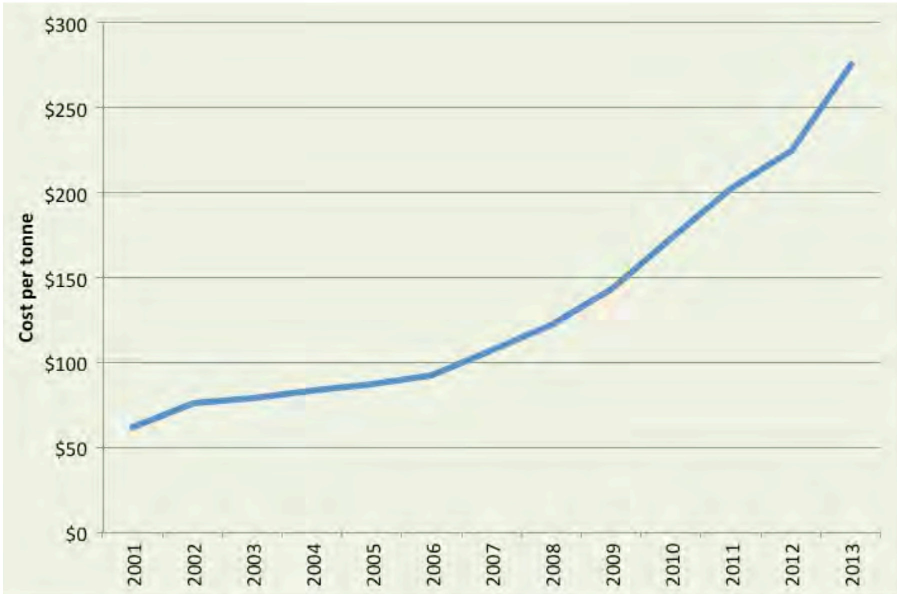
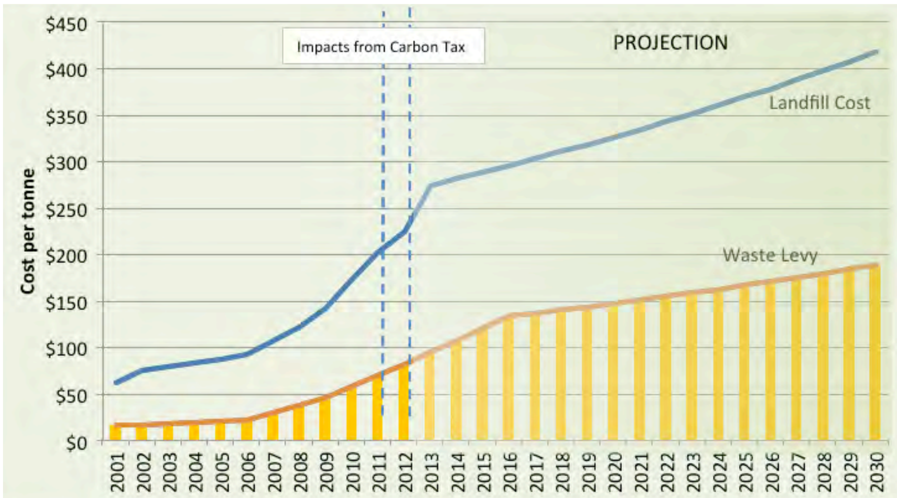


FIGURE 12: PROJECTED LANDFILL COSTS IN SYDNEY (SOURCE: CITY OF SYDNEY)

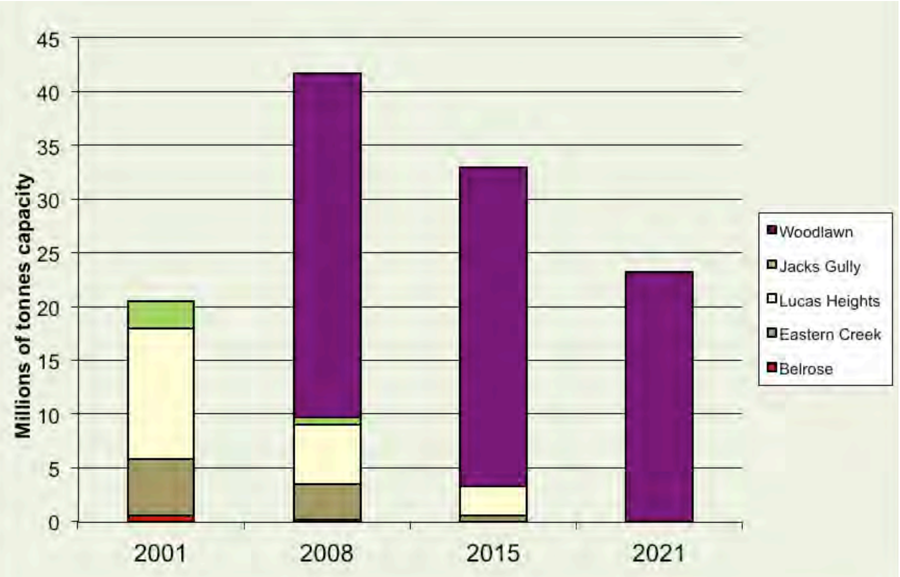


Other significant impacts on waste costs have been for regulatory compliance, such as costs of landfill construction and extension, licencing obligations and even the price on carbon.

Despite increasing costs, landfill sites accepting mixed waste within Sydney have been filling up quickly over the past decade. Of four major landfills available two years ago, only Eastern Creek, Belrose and Lucas Heights landfills now remain available for waste within the Sydney region. Eastern Creek and Belrose are scheduled to close within the next one to three years, and depending on extension approvals, Lucas Heights will follow soon after. It is expected that Sydney's landfill demand will be largely met in the future by the Woodlawn facility near Goulburn, 250 kilometres distance from Sydney, serviced by a rail link.

It is apparent that within the timeframe of the Sustainable Sydney 2030 plan there will be a need to find yet another landfill site for Sydney's waste. No new landfills are yet in planning for the local area. Any new landfill proposal is likely to be divisive for the community identified to host the facility. Adequate compensation for the area selected to host a landfill for other region's waste will drive up the cost of disposal.

FIGURE 13: PROJECTED LANDFILL CAPACITY FOR SYDNEY METROPOLITAN AREA WASTE (SOURCE: CITY OF SYDNEY)



The City of Sydney's use of existing waste treatment substantially lowers the levels that it contributes to landfill. That facility also handles waste from other councils and commercial users. The landfill capacity currently set aside for the output from the treatment facility will not last beyond 2030, and may fill earlier.

REPEAL OF A PRICE ON CARBON FROM WASTE

The price on carbon that had been imposed on Australia's 500 largest carbon polluters has been repealed. The City's Master Plan had modelled its proposals on the cost of abatement of carbon rather than rely on the ongoing carbon tax to incentivise its planning.

The City continues to audit the levels of carbon arising from its activities to ensure it maintains its status as a "carbon neutral" city. The audit of carbon arising from waste excludes emissions from the combustion of biomass, biofuels and biogas and therefore encourages solutions using renewable gases derived from waste.

The City focuses on abatement measures to reduce any contribution from its waste to carbon pollution.

The repeal of the carbon pricing mechanism by Federal Parliament will have little impact on the cost of waste disposal compared with the NSW Waste Levy and other costs of disposal. New opportunities to reduce carbon pollution under the Emissions Reduction Fund program using Advanced Waste Treatment are being investigated.

LIMITED PROCESSING CAPACITY FOR TREATING WASTE

There is limited existing or proposed options for treating waste in the Sydney region. Treating waste is important in the final recovery of resources before disposal.

Current processing capacity for treatment of waste using mechanical biological material facilities is limited to around 305,000 tonnes per year. The combined waste generated in the Sydney Metropolitan Area suitable for treatment is over 2,500,000 tonnes per year. Publicly announced facilities in planning only nominate an additional 200,000 tonnes of processing capacity to 2017.

There is an increasing driver to include more treatment options in the Sydney region to ensure the maximum recovery of resources from waste. The options that can recover those resources to an extent that minimises reliance on landfill while generating energy are of highest importance.

LANDFILL GREENHOUSE GAS EMISSIONS

When waste such as household waste with its high moisture level, is buried and decomposes over time it emits greenhouse gases, principally methane. These greenhouse gases are creating global warming leading to climate change on Earth. Methane is 25 times more powerful as a greenhouse gas than carbon dioxide and levels are growing with increased methane emissions from landfill and other forms of waste.

Landfill methane emissions currently contribute about 3% of Sydney's total greenhouse gas emissions. The greenhouse gas emissions from domestic waste sent to landfill in 2012/13, not including recycling, was estimated to be equivalent to 25,510 tonnes of carbon dioxide equivalent ($CO_{2\text{-}e}$). Emissions arising from commercial waste generated in the city are even higher. In response, the City moved to end direct landfill disposal and sought processing options for its waste.

Under current national greenhouse gas accounting, the output from the existing advanced waste treatment facility into landfill still contributes to carbon pollution with a factor equivalent to unprocessed waste.

To help meet the City's carbon reduction targets, this waste to landfill needs first to be minimised as far as possible. By also utilising the energy in waste and returning it for use in the City, additional emissions currently from remote fossil fuel power generation can be reduced. The net effect will be for the City to reduce greenhouse gas emissions from waste by using waste as a renewable gas resource by 8%.

In the absence of a government-imposed price on carbon as a means of assigning value, the cost efficiency of greenhouse abatement actions are less certain. However, the advantages offered by avoiding emissions from landfill and displacing fossil-fuel generated power makes investment in converting waste to gas for energy use an efficient direct action.

USING ORGANIC RESOURCES IN WASTE

The organic content of waste might potentially be separated for recovery of its nutrient value. There are a number of reasons why this is not as viable for the City of Sydney LGA as recovering the renewable energy content of that waste.

Separating the organics at source is a means to recover this fraction from mixed waste. A Federal Government analysis of existing separate food collections indicated that only 33% of the food waste will be captured.

The levels of food waste available in the City's residential waste means that a separate capture of organics would render the remaining waste unsuitable for processing at the existing waste treatment plant. This could lead to an undesirable increase in waste sent to landfill.

Councils that have opted to recover food organics rely on co-collecting food with their garden waste service. Due to the high rise development nature of the city the City's garden organics service covers only 4% of the City's LGA households. A co-collected option is simply not possible for the City's households.

The City currently uses a processing facility to separate some organics from residential waste. This provides a partial recovery solution. However the City's level of organic waste is low (see Chapter 2) and any further reduction in the organic content would mean the sorting process is no longer financially viable. An energy recovery option can process the existing level of organics in waste and yet still allow flexibility for any future organics waste avoidance programs to reduce that level while remaining viable.

The City utilises the Waste Management Hierarchy as a simple guide to the best available management level to recover resources from waste. A simple version of the hierarchy is to Reduce, Recycle, and only then Disposal. Internationally, the recovery of energy resources is a level just before Disposal, but the Waste Hierarchy is only a proxy in the absence of data to achieve the best environmental outcomes. Any scientific study that shows an environmental improvement should be considered in determining the best option. A 2011 UK study by the Department for the Environment, Food and Rural Affairs determined that in most instances recovery of energy from food in mixed waste is better for the environment than recovery for low grade applications that do not return nutrients into the food production cycle.

The Interim Waste Strategy indicated that the avoidance of food waste may prove a more useful approach to reducing the wastage of food organics. Such an approach avoids the need for additional bin storage, treatment facilities and the additional fleet of vehicles needed for collection.

TRANSPORT IMPACTS FROM WASTE

To dispose of waste within the Sydney Metropolitan Area, around 400,000 truck movements are required each and every year. Each movement contributes to the greenhouse gas and noxious pollutant emissions load associated with waste as well as the congestion of roadways.

The landfills and existing advanced waste treatment used by the City of Sydney are located at some distance on the periphery of the metropolitan area. To access these, the City must depend upon a network of transfer stations to aggregate waste from smaller collection vehicles and then transport to the landfill or treatment locations.

Since the transfer stations were set up to support landfill operations, relying on those transfer stations is not an approach optimised for the efficient delivery of materials to advanced waste treatment.

Commercial waste from the City is also hauled to various waste facilities at a distance. The economic cost of this transport forms a major factor of waste disposal costs for businesses.

More recently waste movements in Sydney have been extended to include a rail link to Woodlawn, hauling over 1,000 tonnes per day. This transport level is likely to triple within a few years. While rail transport can be as little as 40–50% of the greenhouse gas emissions of road transport per tonne kilometre, this waste is travelling over four times the distance to landfill than current local waste options.

Without the timely development of nearby advanced waste treatment facilities with energy recovery, the Sydney region faces a future similar to that recently facing international cities such as New York, where long haul of waste by rail has become entrenched, expensive to operate and environmentally costly. New York is now seeking proposals to implement its own waste to energy network to avoid this haulage.

These emissions from landfill and its associated transport can be avoided. The solution lies in a treatment for waste that recovers both material and energy from waste, leaving minimal residues to be further transported for disposal.

ASH WASTE FROM COAL-FIRED POWER STATIONS

The City of Sydney LGA currently relies principally on coal-fired power stations to provide electricity for homes and businesses. These power stations are responsible for around 80% of the City's LGA greenhouse gas emissions.

A report by Hyder Consulting commissioned by the City of Sydney determined that the centralised electricity grid relying on coal fired power stations generated approximately 87 tonnes of coal ash from for every 1GWh of electricity supplied

The impact of displacing centralised fossil-fuel power generation with the proposed decentralised energy network established that the original 360MWe of trigeneration in the four low carbon zones in the Trigeneration Master Plan would be to reduce that level of ash waste for every 1GWh of centralised grid electricity that is displaced or avoided as a result of the planned trigeneration network.

Because this coal ash waste is generated as a consequence of the City's energy demand, avoiding this level of coal ash waste would result in a huge reduction in the total waste disposal arising from the City's activities.

From an environmental perspective, the gain can be significant. Coal ash contains varying degrees of hazardous elements and heavy metals such as arsenic, chromium, copper, nickel, lead, mercury and zinc. The average levels of these elements vary depending upon the source of coal. Dust from wind blown ash can disperse particulate matter over a wide area.

The eight coal fired power stations in NSW will dispose more than 6,000,000 tonnes of coal ash waste a year. At those levels, thousands of tonnes of these elements are stored in landfills, also known as 'ash dams'. Unlike other forms of landfill waste, this material is granted an exemption from the NSW landfill waste levy, representing a hidden subsidy of nearly $650 million a year for coal fired power generation.

An integrated waste to renewable gas approach will provide the means for the City to displace its share of coal ash waste disposal. Ash dams in other developed countries including the United States have failed, releasing the ash and contaminated water leading to significant environmental damage.

FIGURE 14: BAYSWATER POWER STATION AND ASSOCIATED ASH DAM (FOREGROUND) (SOURCE: GOOGLE EARTH)

FIGURE 15: NSW COAL ASH TRACE ELEMENTS CONCENTRATIONS (PARTS PER MILLION) (SOURCE: HYDER CONSULTING)

Element	Coal Ash average (2006 data)	Coal Ash Exemption 2011 absolute maximum
Arsenic	15.72	20
Chromium (total)	44.96	50
Copper	65.62	40
Nickel	35.26	50
Lead	56.60	50
Mercury	0.11	1
Zinc	105.44	70

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WHY TREAT WASTE?

Advanced Waste Treatment refers to a number of technologies that process waste previously disposed to landfill and recover resources in the form of recyclable materials and/or energy.

Increasing levels of waste needing collection and disposal are driven by increasing population and economic growth in the City. This growth is driving up waste levels across both the residential and commercial sectors.

The City is responding with programs to lower the generation of waste overall, and by maximising recycling. Since early 2011, the City has also sent all of its solid residential waste to a Mechanical Biological Waste Treatment facility which relies on mechanical sorting and then treatment of a separated organic fraction of waste.

The City's use of recycling in combination with existing mechanical biological waste treatment has enabled the City to reach its 66% diversion of residential waste from landfill target in the City's Environmental Management Plan 2007. Even with this achievement, population and economic growth will continue to drive the absolute tonnage of waste landfilled back closer to current levels over time.

The City remains fully committed to improving its recycling levels above current levels. The City will continue its programs and strategies to improve waste avoidance, reuse and recycling first, then seek the best treatment and recovery option for non-recycled waste that achieves multiple sustainability objectives.

Further detail is provided in the City's Interim Waste Management Strategy that is soon to be updated.

Sustainable Sydney 2030 calculated that at least 50% of the City's waste (both residential and commercial) should be treated to recover the energy content of that material, in order to meet the City's carbon reduction target of 70%. The City's Interim Waste Strategy also called for reviewing Advanced Waste Treatment technologies with a requirement that they reduce by 90% its resident's waste to landfill.

Technologies now exist that can convert the City's waste into a synthesis gas to recover energy resources, and significantly increase diversion of waste from landfill to well over 90%. The use of renewable and non-fossil fuel gases for the City's planned trigeneration network would also improve energy security and significantly reduce greenhouse gas emissions from energy production. For the purposes of this Master Plan, gas produced from the organic fraction of waste is defined as renewable gas and gas produced from the inorganic fraction of waste is defined as non-fossil fuel gas. Based on the level of organic materials (including rubber, leather, textiles, unrecycled paper products, nappy contents, oils and food scraps) in the City's waste stream, around 65% of the gas produced will therefore be renewable gas and count as a renewable energy source.

Together, this Master Plan and the City's Renewable Energy Master Plan set out the resources and technical options for energy recovery from waste as a further step in managing waste as a resource. Using waste generated within the city as an energy resource will help meet the Sustainable Sydney 2030 target for 100% of local electricity generation.

Managing the residential waste stream is the City's legal obligation, but the advanced waste treatment solution can also be used for commercial and industrial waste. Recovering renewable energy from both waste streams via advanced waste treatment is important to deliver the Sustainable Sydney 2030 target for the reduction in greenhouse gas emissions arising from the City's overall waste. It also reduces landfill greenhouse gas emissions and the City's dependency on remote landfill sites for the final disposal of waste.

Even the best landfills present an environmental burden, emitting very powerful greenhouse gas emissions in the form of methane and threatening both groundwater with contamination and the atmosphere with other compounds. Of even a greater burden is the loss of all the resources and the economic investment embodied in the city's waste as worthless refuse entombed within a landfill.

WHAT IS ADVANCED WASTE TREATMENT?

Advanced Waste Treatment is the collective name for a range of technological solutions for managing waste after higher order activities such as avoidance, re-use and recycling have first separated useful materials out of the waste disposal stream and returned them to the economic cycle.

Advanced Waste Treatment solutions intercept the waste that would otherwise be disposed to landfill and treats the waste as a resource, by using mechanical, biological or thermal processes to harvest metals, recyclables, organics and renewable energy. This is why the City has since 2009 sought increasing levels of waste treatment rather than direct landfill disposal as its waste solution.

However, the existing advanced waste treatment used by the City to achieve its recovery target diverts mostly the organic fraction of the City's residential waste. After processing, this organic material is used for mine site rehabilitation. Other wastes remaining after processing must still be sent to landfill as there are no energy recovery options available.

The proposed Advanced Waste Treatment in this Master Plan overcomes the inadequacy of the existing advanced waste treatment facility by significantly increasing the recovery of resources locally and converting non-recycled waste into renewable gas for injection into the gas grid to help power the city.

By intercepting and recovering both the materials and energy resources within waste before final disposal to landfill, the City is positively managing the environmental, economic and social impacts of waste on itself and other communities.

EXPANDING RESOURCE RECOVERY FROM WASTE

The City's investigation of international best practice waste treatment solutions established that the City can exceed the environmental outcomes from existing advanced waste treatment plants in the Sydney region.

Australia currently has one of the highest rates of waste generation per capita in the world. In 2009/10, there were 21.6 million tonnes of waste received at an estimated 918 landfills. A further 17.6 million tonnes was received at facilities other than landfill, of which 13.6 million tonnes was recovered or reprocessed and 4 million tonnes was disposed to landfill or other final destination.

There are 10 existing advanced waste treatment (AWT) plants in Australia, processing a total of just under 1 million tonnes each year. Almost entirely, these facilities are aimed at mechanically sorting waste in order to recover some of the organic material in waste and produce a compost-like material. Small amounts of recyclable material such as steel and aluminium cans are also recovered during the process.

The development of MBT plants has slowed significantly in Australia. In NSW no new facilities have opened since 2009, despite substantial increases to the waste levy for disposal at landfill. In 2014, a new contract for construction of a facility at Woodlawn taking around 100,000 tonnes of Sydney waste was announced.

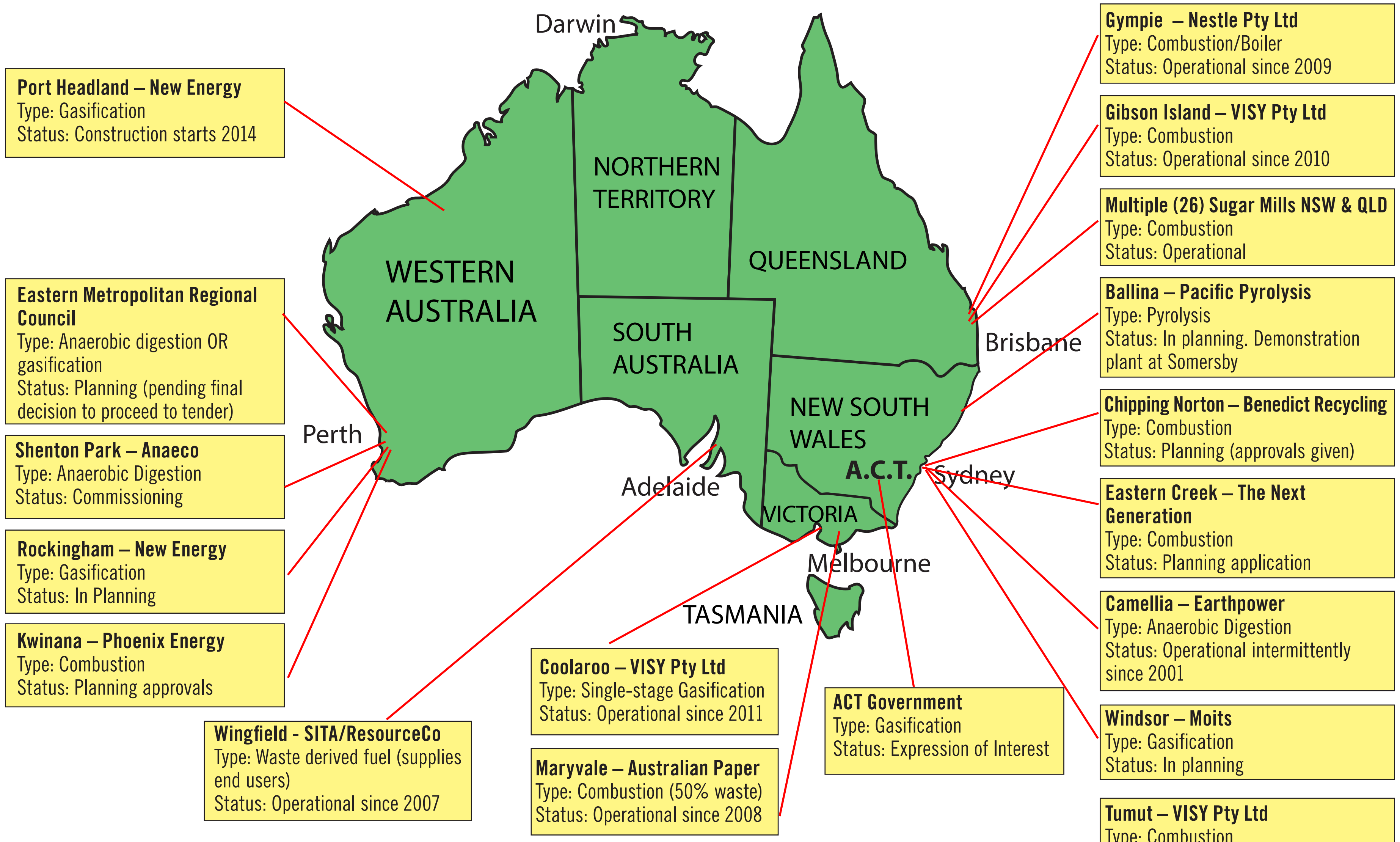
Internationally, the additional processing of waste to extract an energy resource is well established, and in NSW energy recovery from waste is written into the waste management hierarchy within key waste legislation on the same level as recycling and processing of waste. Hundreds of facilities converting waste to energy have been operating globally for decades and many other countries regard this as a legitimate means of maximising resource recovery in line with the Waste Hierarchy which sees energy from waste as a higher order use for waste than landfill.

In Australia, advanced waste treatment to recover energy from waste has been operating in some cases for over a decade. There is a surge of new energy from waste projects in the pipeline. The treatment facilities operating or planned adopt a wide range of energy from waste approaches:

- Biomass waste for energy (Gibson Island, Gympie, Ballina, multiple sugar mills in NSW and Queensland)
- Recycling operations waste or rejects (Tumut, Coolaroo)
- Commercial food waste (Camellia)
- Construction and demolition waste (Chipping Norton, Eastern Creek)
- Residential and commercial waste (ACT government, Wingfield (produces fuel only), Port Headland, Eastern Metropolitan Regional Council, Rockingham, Kwinana).

In December 2013, Kwinana Council signed an agreement with Phoenix Energy to supply residential waste as a feedstock for a twenty year term when the facility is constructed.

FIGURE 16: THE EMERGING AUSTRALIAN ENERGY FROM WASTE SECTOR (SOURCE: CITY OF SYDNEY)



Existing AWTs do have a significant impact on reducing materials lost into landfill, and greatly reduce greenhouse gas emissions for the materials that they receive. However, around half the waste being treated will still end up in a landfill, with a loss of any potential environmental benefit or economic resources remaining in that waste.

After viable recycling and processing of waste there remains a waste fraction high in plastics and other high energy materials. Extending resource recovery to the development of an advanced waste treatment facility that can recover the renewable gas from waste is a necessary additional step in sustainably managing waste, maximising useful resources and reducing greenhouse gas emissions from waste.

AVAILABLE TREATMENT TECHNOLOGY OPTIONS

As part of its Green Infrastructure Plan and associated Master Plans, the City is seeking a technical solution for waste treatment that can:

- Generate a long term sustainable waste solution.
- Significantly divert waste from landfill.
- Significantly reduce greenhouse gas emissions arising from waste.
- Handle the complexity and changing levels of city-generated waste over time.
- Provide a renewable energy positive alternative energy resource for the city, that integrates with the Trigeneration and Renewable Energy Master Plans.
- Encourage improved outcomes for the local commercial sector and the surrounding region.
- Deliver value for money in meeting the City's waste obligations at the highest environmental benefit.
- Identify the suitability of sites in close proximity to the City of Sydney with optimal transport and energy delivery connections.

There are a range of waste treatments that can achieve all these objectives in use internationally. The provision for a renewable and non-fossil fuel energy source moves waste management beyond the existing practice of the City which currently uses a composting solution for waste treatment.

ADVANCED WASTE TREATMENT EXPLAINED

Advanced Waste Treatments are technologies designed to take the complex and varying mix of materials that make up what we know as waste and do three things:

1) Recover useful products from the waste.
2) Stabilise the waste to minimise environmental impacts.
3) Reduce material to landfill.

The reasons for these objectives of advanced waste treatment are to:

1) Reduce the need for a large volume of land to be given over simply for long term storing of waste.
2) Remove the elements in waste that might cause environmental harm and pollution.
3) Eliminate the loss to the economy of the materials, nutrients and energy sealed within a landfill.

Advanced waste treatments have some common stages in the treatment.

SORTING: All treatment processes start with some preliminary sorting to remove oversized materials, or readily identified hazards such as car batteries or medical waste.

PRE-PROCESSING: Most technologies then rely on a "pre-processing" stage to sort any metals for recycling, and to shred or re-size remaining waste for consistent handling.

TREATMENT: Treatments will then be based around recovering only the organic component of waste and turning that into a compost-like material, or using the waste or by-products from waste as a fuel for energy generation. Each additional process usually means more material or energy is recycled, and less needs to be landfilled.

RECOVERY: Treatment technologies aimed at recovering nutrients from the waste will need to mature and decontaminate the organic fraction before it can be reused. Those treatment technologies aiming to recover energy from waste, release the heating value within waste materials, by either burning directly or extracting a renewable or non-fossil fuel gas that can be later combusted locally to generate power or combined heat and power or converted into a substitute natural gas, injected into the gas grid and used to generate renewable energy at end use such as, trigeneration, district heating and/or transport fuels. This gas will be cleaned of any remaining ash particles and acids. The application of heat may allow some metals to be refined out of the waste.

DISPOSAL: Unused material sorted at the first stage and waste remaining after treatment must be disposed or sent for other uses.

OVERVIEW OF TREATMENT TECHNOLOGIES

Advanced waste treatment processes that may include an energy recovery step are broadly classed as:

- mechanical and biological treatment;
- thermal combustion; and/or
- thermal conversion treatment.

These processes can be used separately, or in conjunction with one another.

1. Mechanical and Biological Treatment

Mechanical and biological treatment combines two processes together. Current technologies focus on separating out the organic material in waste, as it can be further refined.

Suitable waste streams for mechanical biological treatment can include household waste, sewage sludge, agriculture crops, forestry waste, horticulture residue and livestock manure.

The **mechanical treatment** dries and physically separates out the organic waste from recoverable recyclables such as plastics, glass, metals and unusable waste.

The **biological treatment** degrades the waste in two ways: by composting, or by using microorganisms in an oxygen-free environment to break down or digest the organic material.

Composting is a biological process that produces a by-product that is used for such activities as mining site rehabilitation. As a treatment it does not recover energy from the waste.

Anaerobic Digestion

A second biological process is also known as "anaerobic digestion". It aims to generate a biogas as a by-product of treating the organic component. Anaerobic refers to the low oxygen conditions that allow specific micro-organisms to dominate the decomposition. The biogas is cleaned and is commonly burned to directly heat water in a boiler to drive a steam turbine, or used as fuel in a specially converted electricity generating gas engine. Anaerobic digestion is used as a treatment after organics are sorted and separated, and is more commonly used for single-stream organics such as agricultural wastes.

Mechanical-biological treatment is limited in application to various waste types, as it requires a consistent level of organics to make the process viable. Household waste commonly contains organics at around that level, but mixed waste from commercial sources typically does not. Materials such as glass or plastic present in the mixed waste will also cause contamination of any by-product.

This treatment therefore still leaves a high level of residual waste, close to half the input, needing to be landfilled.

2. Thermal Combustion

Thermal combustion (commonly referred to as "incineration") technologies aim to use the waste directly as a fuel to heat water to raise steam to drive an electricity generating turbine. This process is similar to electricity generation from coal, merely substituting the fuel type. Thermal combustion is often used in Australia to process biomass waste, such as waste sugar cane (called "bagasse") from sugar mills.

Other suitable waste streams for thermal combustion technologies include household or commercial and industrial waste. Waste streams with high moisture content such as sewage sludge or separately collected food are not suitable for combustion.

Direct thermal combustion of mixed waste is most commonly seen in a "mass burn" incinerator. Waste is burned with sufficiently large quantities of air added to allow near complete combustion. The process is destructive, so only materials recycled prior to the combustion stage are recovered.

Electricity generation only is inefficient with efficiencies as little as 15%. The efficiency can be increased by recovering the waste heat usually distributed to districts local to the thermal combustion plant. Heating and cooling (via decentralised thermal chillers) can be provided and is relatively common in countries in Europe, Asia and America.

Advances in combustion air pollution control have meant facilities internationally meet regulated air emissions standards. Meeting those emissions standards requires an extensive regime of pollution control and monitoring equipment.

Both the ash from the exhaust stack (fly ash) and ash from the combustion chamber (bottom ash) need to be disposed to landfill. Some of the ash can be used as an additive to concrete or in other construction materials. Should the levels of heavy metals exceed regulated thresholds, the ash may be deemed hazardous, requiring special disposal.

3. Thermal Conversion Treatment

Thermal conversion treatments are a class of technologies that use chemical reactions and heat to break down waste in an oxygen-starved environment. The treatment decomposes the waste into its basic molecules converting it into a flammable gas, mostly carbon and hydrogen. The treatment does not work by combustion, just as in a kettle you don't "burn" water to turn it into steam.

The flammable gas derived from converting waste into gas is an alternative fuel called synthesis gas, abbreviated to syngas. The gas product output from gasification processes is known as synthesis gas, or syngas, as it is synthesised from the chemical components of the waste and treatment additives (see Chapter 2). This is a high energy gas suitable for a range of fuel uses or chemical manufacture.

There is a significant difference between thermal conversion and thermal combustion treatments. By "decomposing" the waste without bringing in oxygen there are less chemical reactions that generate pollutants, and a greatly reduced volume of exhaust needing air pollution controls.

Various by-products can also be recovered at different stages of the conversion process. These can include various metals, chemicals and melted slag. Some processes can even generate water as a by-product.

Thermal conversion technologies result in very low levels of residual material that need to be landfilled (usually less than 20%).

Emissions from thermal conversion treatment are generated only where the gas is used on-site as a fuel to generate electricity, rather than from the conversion process itself. However, these emissions are significantly less than thermal combustion emissions and can be treated.

There are several classess of thermal conversion treatment technologies suited for different feedstocks and delivering different outputs. Because these technologies deliver high waste diversion levels together with a multi-use transportable gas, the available thermal conversion treatments are explained in the next section.

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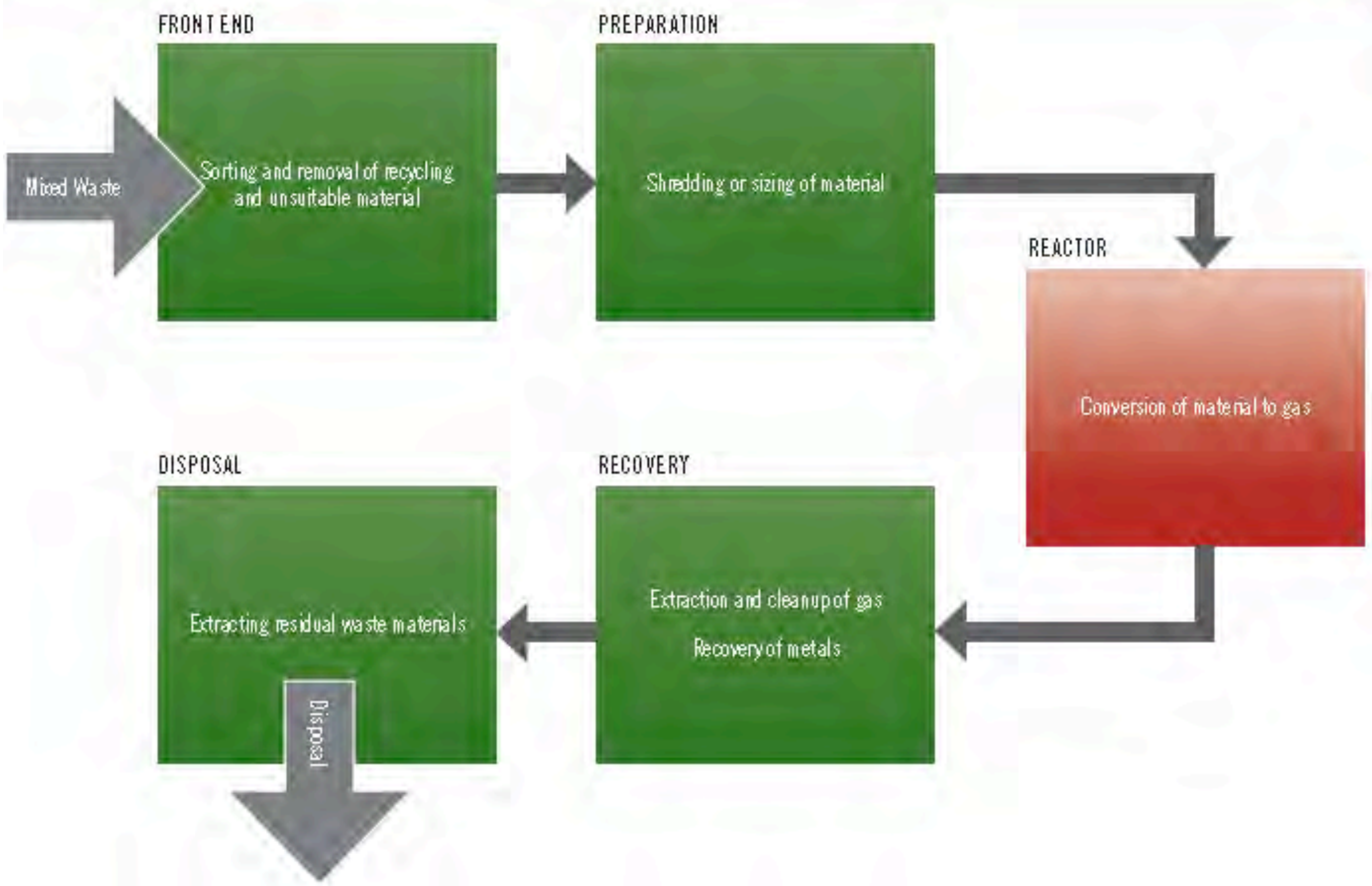
FIGURE 17: INDICATIVE SCHEMATIC OF A WASTE CONVERSION FACILITY (SOURCE: CITY OF SYDNEY)



THERMAL CONVERSION TECHNOLOGIES

These technologies are also referred to as 'gasification' technologies, because their principal by-product is syngas.

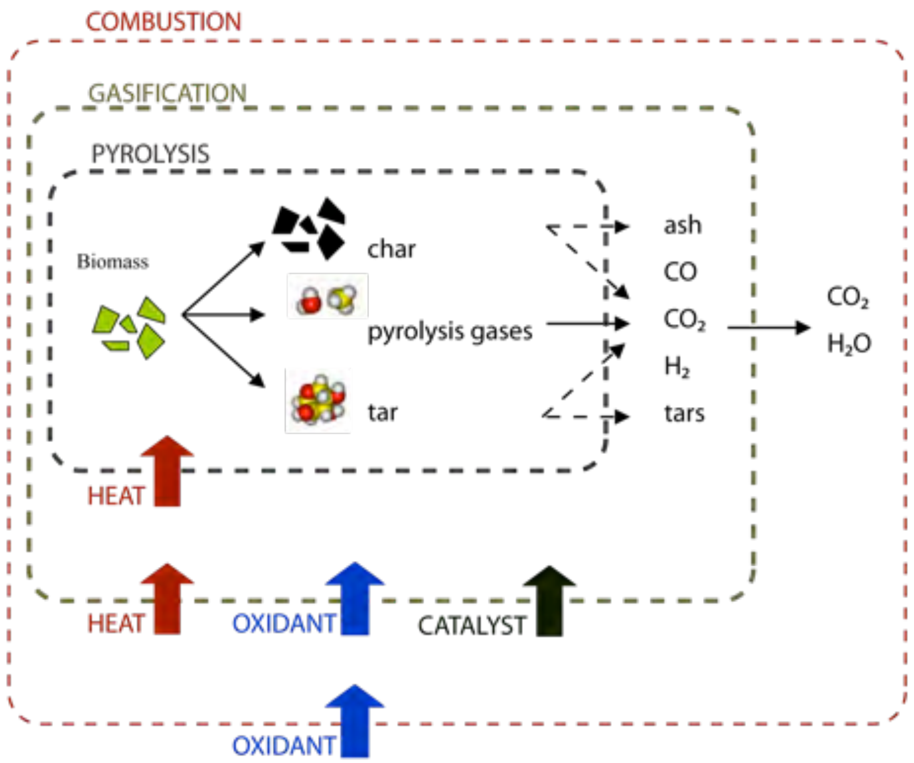
The principles of the thermo-chemical conversion of waste and biomass is based on the staged degradation of organic materials, where the intermediate steps of pyrolysis and gasification and the final step combustion are carried out and contained in separate reactors.

Newer gasification technologies are rapidly emerging as the platform of choice for energy-from-waste (EfW) schemes, as they present the following key advantages when compared with incineration-based approaches:

1. Produces a raw fuel gas (syngas) that stores energy for a variety of end uses;
2. Compact and flexible gas clean-up and pollution emission control systems;
3. High degree of integration with advanced resource recovery operations;
4. Greater flexibility to process lower levels of waste;
5. Significant reduction in residual material needing landfilling; and
6. Reduced negative visual impacts through more compact facilities.

The three main thermal technologies considered in this Master Plan are pyrolysis, gasification, and plasma arc gasification. They can be used in isolation or in combination with each other or even as an additional step following mechanical-biological treatment.

FIGURE 18: THERMAL CONVERSION PROCESSES: PYROLYSIS, GASIFICATION AND COMBUSTION (SOURCE: TALENT WITH ENERGY)



Pyrolysis

In pyrolysis processes, the feedstock is heated inside a conversion reactor in the absence of air or oxygen (the oxidant). Following the release of moisture (above 100°C) and other volatile fractions, the pyrolysis process begins at temperatures between 300°C and 400°C.

Overall, the process of thermal decomposition of the waste feedstock in the absence of oxidant (oxygen or air) yields three main product streams:

- A raw syngas, a gaseous mixture containing carbon monoxide (CO), carbon dioxide (CO_2), hydrogen (H_2), methane (CH_4) and other light hydrocarbons;
- A synthetic oil, obtained from the cooling of condensable vapours, including water, methanol, acetic acid, acetone and heavy hydrocarbon chains; and
- A char residue, containing the residual solid carbonaceous and inert materials from conversion of the incoming feedstock stream.

The relative distribution of these products depends on the chemical composition of the fuel and process conditions such as the heating rate and the temperature achieved in the reactor.

Pyrolysis is more commonly used on separated organic waste streams, which permit the char to be recovered for soil improvement. It can be used as an initial step in treatment of mixed waste.

Low pyrolysis temperatures and long residence times (slow pyrolysis) increase the yield of char product, while moderate temperatures and short residence times (low temperature fast pyrolysis) maximise yields of liquid products and high temperature and short to long residence times increase gas yields.

Gasification

In gasification processes, the conversion of solid carbonaceous fuels is carried out at high temperatures – in excess of 750°C to 850°C – and in a controlled atmosphere with levels of oxidant (air, oxygen or steam) kept below that needed for incineration to occur. The overall process, often referred to as partial oxidation, is endothermic and requires either simultaneous burning of part of the fuel (directly-heated gasification) or the delivery of an external source of heat such as heat derived from the gasification process itself (indirectly-heated gasification). There are four steps to gasification.

The first step is the heating and drying stage where the moisture content is removed as the thermal front advances into the interior of the fuel particles.

The second step is the pyrolysis stage which involves a complex series of chemical reactions resulting in the thermal decomposition of the organic compound in the fuel yielding a large variety of volatile organic and inorganic compounds, the types and the rates depending on the fuel composition and processing conditions.

The third step of gasification is solid-gas reactions, converting solid carbon into gaseous carbon monoxide, CO, hydrogen H_2 and methane CH_4 via a number of high energy chemical reactions.

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The fourth step of gasification is the gas-phase reactions which determine the final mix of gaseous products.

The final gas composition is strongly dependent on the amount of oxygen, air or steam admitted to the reactor as well as the time and temperature of reaction. For sufficiently long reaction times, chemical equilibrium is attained and the products are essentially limited to the light gases carbon monoxide CO, carbon dioxide CO_2, hydrogen H_2 and methane CH_4 (and nitrogen if air was used as a source of oxygen). Methane CH_4 formation is generally favoured at low temperatures and high pressures, whereas high temperatures and low pressures favour the formation of hydrogen H_2 and carbon monoxide CO or syngas.

Some gasification plants operate at far higher temperatures, or include a superheated treatment stage for gas. These gasification technologies melt and fuse together any ash particles and destroy unwanted compounds. This high temperature plus ash melting technology offers the opportunity to leave very little waste residue with low pollutant levels.

Plasma Arc Gasification

Plasma Arc Gasification is one such very high temperature gasification process. Within a reactor, an electric arc heats air or a process-specific gas high enough to generate plasma gas, from 3,000°C to 6,000°C. Waste is directed into the superheated plasma zone mechanically. Under this intense heat materials disintegrate into molecules. Metals are liquefied for recovery. Other materials are fused and melted into a glass-like material with engineering properties suitable for recovery and use.

This technology can also be applied in second stage treatments following conventional gasification and pyrolysis to melt residual bottom ash, flue gas and tar into the glassy material.

Enhanced versions of existing technology

Modern advanced waste treatment technology was introduced to Australia in the late 1990s. There are a number of mechanical –biological and anaerobic digestion treatment facilities operating in NSW.

The process of producing energy using the gasification method has been in use for more than 180 years. During that time both coal and peat were used to power these plants. Initially developed to produce town gas for lighting and cooking in the 1800s, it was also used in blast furnaces and more importantly, the production of synthetic chemicals where it has been in use since the 1920s.

During both world wars especially the Second World War the need of gasification produced fuel re-emerged due to the shortage of petroleum. Wood gasifiers were used to power motor vehicles in Europe. By 1945 there were trucks, buses and agriculture machines that were powered by gasification. It is estimated that there were close to nine million vehicles running on producer gas or syngas all over the world.

Current technologies are often highly redesigned and enhanced versions of earlier technology such as:

- The age-old method for creating charcoal is a pyrolysis reaction.
- Plasma arc gasification has been relied on in metals mining and refining since the 1950s.

EVALUATING THE TREATMENT OPTIONS

The treatment technologies considered in this Master Plan were subject to successive levels of analysis to evaluate their suitability to meet the City's key requirements. The evaluations included:

- High level risk evaluation;
- Multi-criteria analysis;
- Life Cycle analysis; and
- Gasification technology review.

The first three analyses were undertaken to establish the basis for a future business case for an energy from waste facility. This process could not sufficiently isolate a technology for a full analysis. The City chose to then comprehensively review the identified preferred gasification technologies, and this determined a preference within those technologies for processes which could recover additional resources such as melted ash (waste diversion) and deliver a refined syngas capable of and suitable for being converted to a substitute natural gas (suitability for end use energy supply).

The diversion of waste from landfill and the possibility for energy supply are both important factors in choosing a preferred technology group. The City was seeking the best option under both criteria. The inclusion of Energy Recovery as a tier in the waste hierarchy does not preclude the requirement to ensure from an environmental perspective that the energy recovery is optimised for the waste type treated. The City was seeking a sustainability solution for waste that integrated with its full complement of Green Infrastructure Master Plans, and delivered the highest efficiencies for recovering energy in terms of return of net energy delivered with lowest pollution impacts.

HIGH LEVEL RISK ANALYSIS

This evaluation of a broad range of possible technologies was intended to filter out at a high level those technologies at risk of not meeting key requirements. Those not eliminated would be moved forward to greater analysis. At this level a pass-fail approach was adopted against the following key requirements:

- Divert waste from landfill;
- Reduce greenhouse gas emissions; and
- Deliver a renewable/non-fossil fuel gas suitable for renewable gas grid injection for end use in the city, particularly for supplying the planned trigeneration network.

To evaluate against future best practice landfill options, the City included a "bioreactor" landfill in the analysis as a default for the "business as usual" model.

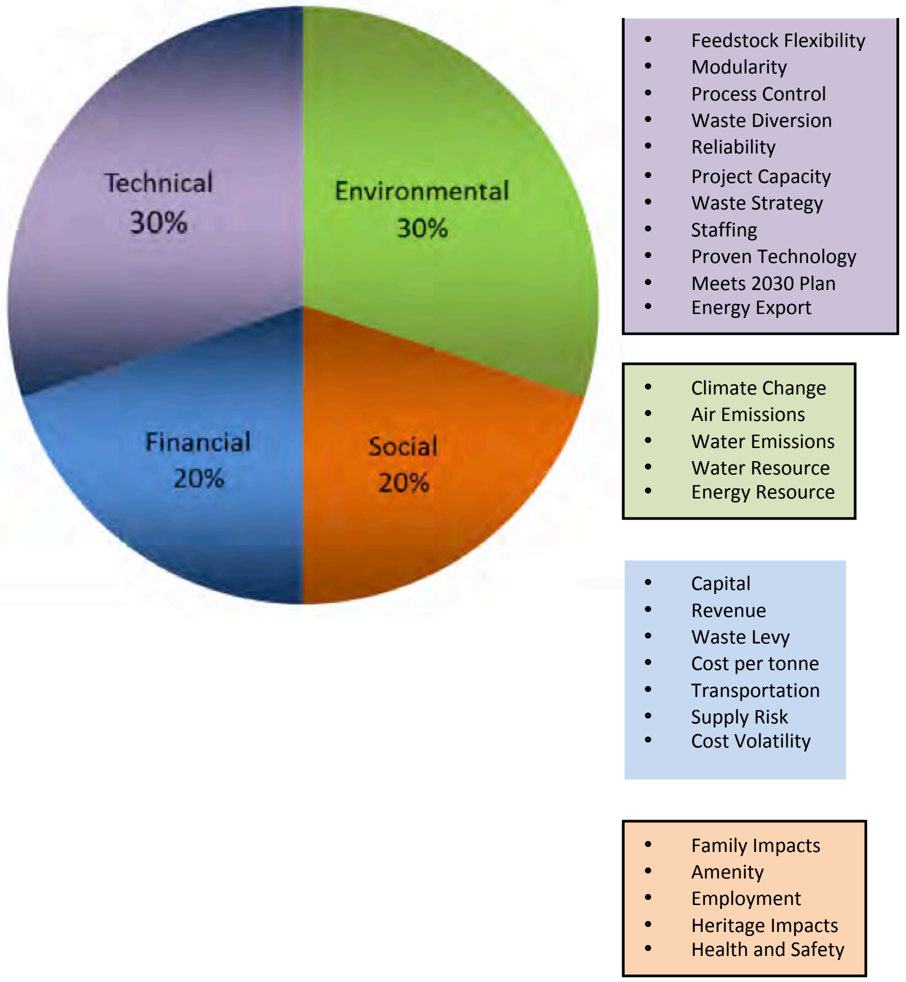
The Woodlawn landfill that will become the main landfill for Sydney region waste in the near future is a bioreactor A bioreactor is a landfill management technology that speeds up the generation of methane gas from waste and has efficient gas capture. This methane may in turn be used for electricity generation.

The City no longer directly disposes of waste to landfill, but this benchmark helps to measure any gains from the advanced waste treatment options, including the City's current Advanced Waste Treatment system.

FIGURE 19: HIGH LEVEL RISK EVALUATION OF WASTE TREATMENT PROCESSES (SOURCE: ARUP)

Initial Assessment	Mechanical Biological Treatment	Bioreactor Landfill	Anaerobic Digestion	Grate Incineration	Fluidised Bed Incineration	Gasification (two stage)	Pyrolysis	Plasma Arc Gasification
Significantly reduces GHG emissions	✔	✘	✔	?	?	✔	✔	✔
Generates renewable/ non-fossil fuel gas for end use energy supply	✔	✔	✔	✘	✘	✔	✔	✔
Waste diversion target	✔	✘	✔	✘	✔	✔	✔	✔

FIGURE 20: MULTI-CRITERIA ANALYSIS (SOURCE: ARUP)



MULTI-CRITERIA ANALYSIS

After eliminating bioreactor landfill and thermal combustion or incineration approaches, the City then carried out two detailed ranking evaluations on the remaining technology types.

The multi-criteria analysis assessed the technologies against key elements of four key objective areas:

- Technical performance;
- Financial impacts;
- Environmental impacts; and
- Social impacts.

The evaluation of each technology type within the four objective areas was weighted. A technology might be a mid-range performer in one area but a good performer in another and its ranking shift according to the weighting of the objective overall.

The multi-criteria analysis concluded that all of the technologies assessed could provide the performance in the key objective areas sought by the City, subject to performing in accordance with expectations of available research. However, pyrolysis was more suited for separated organic material than for mixed waste.

Gasification technologies ranked first in evaluation for highest weighted technical and environmental performance categories. The technologies ranked higher than biological treatments because of superior energy, carbon reduction and waste diversion outcomes.

Anaerobic digestion technologies ranked higher in financial impacts because they were technically simpler.

The technologies were equivalent in social criteria assessed.

LIFE CYCLE ASSESSMENT
The second ranking evaluation used was a Life Cycle Assessment, using an industry standard assessment tool to predict values. The tool used best estimates from operational facilities to represent each treatment process, rather than a particular proprietary technology. Any waste treatment (including landfill) has an impact on the environment. This assessment reviewed the totality of environmental impacts and analyses and any offsets each process could accumulate across its lifetime. If an operational impact is a cost, the potential resource recovery offsets are like a credit.

The aim of the Life Cycle Assessment was to produce a theoretical model of the ability of a given process to:

- convert waste to a renewable/non-fossil fuel gas;
- convert the gas to a substitute natural gas;
- transport the substitute natural gas via the gas grid; and
- generate electricity and heat, including via trigeneration in the city.

The processes reviewed (with abbreviations):

BAU – Bioreactor Landfill

AD – Mechanical-Biological Treatment (Anaerobic Digestion)

GAS – Gasification

GAS + PLASMA – Very high temperature gasification and secondary indirect processing with Plasma Gasification

PLASMA – Direct Plasma Gasification

AD + GAS – Waste is sorted and separately biologically treated and gasified.

PYR – Pyrolysis

To effectively rank the processes the life cycle methodology set a boundary common to all. The impacts for energy and waste disposal were assessed across five stages of process:

- Waste pre-treatment;
- Waste treatment (including treatment facility and conventional recycling);
- Residual waste disposal;
- Treatment and transportation of gas generated; and
- Electricity and heat generation.

The results presented in this Master Plan are based on the City's existing waste management system which offers kerbside recycling and waste collected separately. The total tonnages assessed using the tool are made up of the residential and commercial waste loads combined.

FIGURE 21: GREENHOUSE GAS REDUCTION BY PROCESS (SOURCE: ARUP)

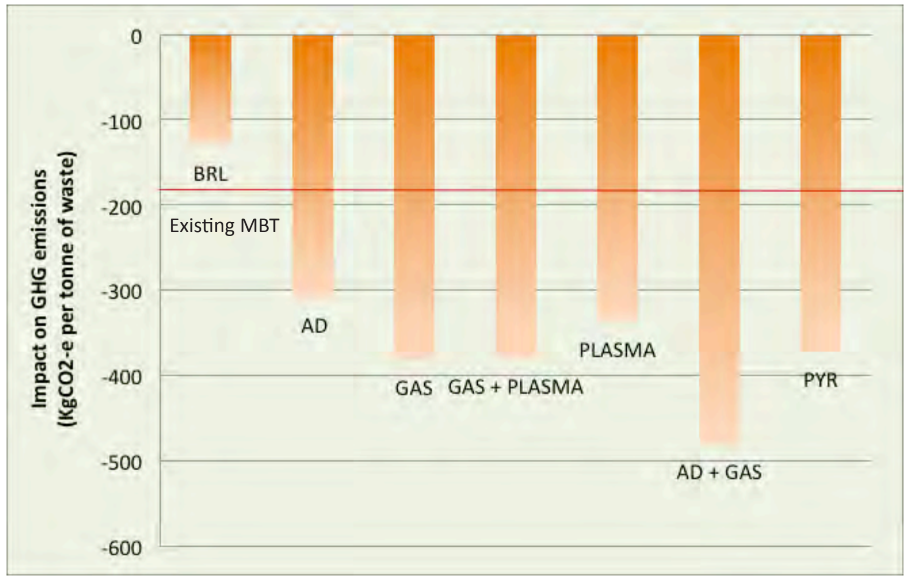
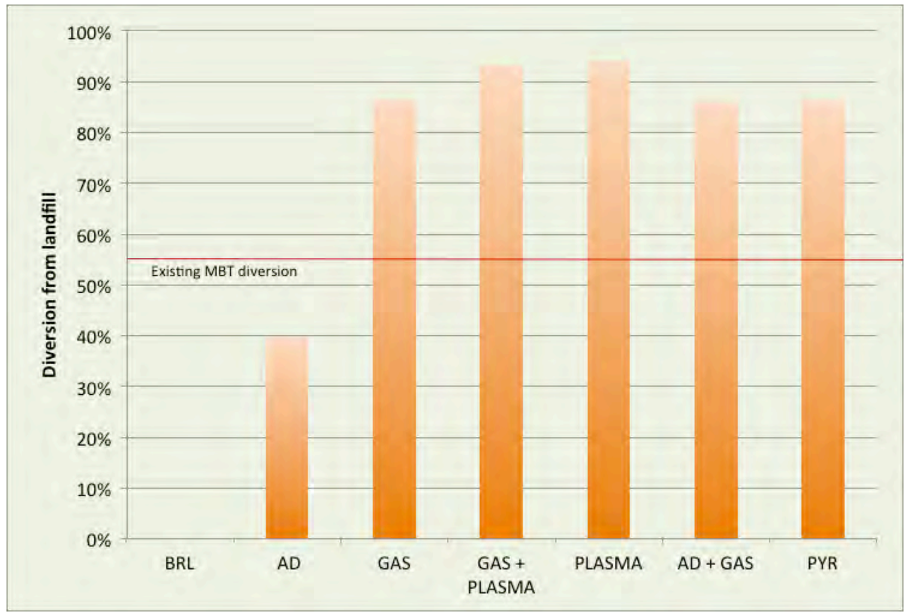


FIGURE 22: WASTE DIVERSION RATE BY PROCESS (SOURCE: ARUP)



Key offsets used to determine the life cycle assessment include:

- Avoided use of grid electricity or fossil fuel mains gas consumption as a result of renewable gas generation and use;
- Avoided paper, plastics, glass and metals production as a result of recycling;
- Avoided fertiliser production as a result of compost/soil conditioner use; and
- Avoided gravel extraction as a result of use of slag by-products from the process.

The City has used the Life Cycle Assessment to review the greenhouse gas and waste diversion impacts of each approach modelled on projected 2030 waste levels.

The reduction in greenhouse gas emissions for each major technology show that the thermal gasification technologies perform significantly above the other available advanced waste treatment options. The higher the negative number the greater the impact reduction. (Note that the BAU bioreactor recovers some energy from waste.)

In terms of reducing the City's dependence on landfill, only the thermal conversion (gasification) processes offer the required diversion rates, eliminating over 90% of non-recycled waste input to the technology. This assessment is measured only on the level of waste input and the resulting output of residual waste to landfill for the process treatment facility, not pre-treatment options.

Because of the low level of waste diverted from landfill for the AD process, it remains significantly exposed to the risk from rising landfill prices and landfill scarcity.

In terms of economics and cost of carbon abatement the AD + GAS process would require two conversion technologies to convert the renewable gases into substitute natural gas, upgrading for the biogas output from anaerobic digestion and the methanation process for the syngas output from gasification. In addition, the AD process is significantly exposed to the quality of source separated organics as AD requires homogeneous organic materials which lead to further cost imposts for source separated organics which is impractical for a city like the City of Sydney.

All scenarios offer a significant improvement over BAU. Thermal conversion (gasification) approaches also offer the highest diversion of waste from landfill with corresponding reductions in greenhouse gas emissions.

REVIEW OF GASIFICATION TECHNOLOGIES

The outcome of the Life Cycle Assessment identified the gasification technologies as providing the highest rates for diversion of waste from landfill and reductions in greenhouse gas emissions. However, both the Multi-criteria Analysis and Life Cycle Assessment relied on theoretical modelling of the processes evaluated. To determine the ideal type or class of gasification technology to treat the City's non-recycled waste, the City commissioned a Gasification Technologies Review which forms the Technical Appendix to this Advanced Waste Treatment Master Plan.

Five key selection criteria needed to be met for inclusion of suitable reference technologies to assess the likely performance, costs and benefits of gasification:

1) Commercial Maturity

To ensure consistent performance data, each technology had to be either

- **Demonstrated** – at least one reference facility operating successfully at a commercial-scale.
- **Proven** – at least one reference facility in continued, full-commercial operation.
- **Commercial** – several reference facilities in continued, full commercial operation.

2) Plant Throughput

Based on the City's waste levels (see Chapter 2) technologies needed to process between 40,000 to 150,000 tonnes per year with high diversion level. This avoids assumptions involving scaling up of emerging technologies not proven at this level of processing.

3) Feedstock

Each technology was capable of treating to an advanced degree the level and composition of feedstock residual wastes available to the City. Potential resources for gasification include the City's residential or municipal solid waste (MSW), commercial and industrial waste (C&I) in the city, and potentially one or more Councils waste within the vicinity of the advanced waste treatment plant.

4) Syngas generation

Each technology had to be capable of generating a syngas that could be converted into substitute natural gas via the methanation process for injection into the gas grid. ("Methanation" refers to the chemical engineering process for increasing the methane content, and thus energy value, of the raw syngas (see Chapter 2 for details).) This means that some commercial gasification approaches that combust the syngas within the same chamber as the gas is generated are not included.

5) Best available standard emissions performance

Each technology had to meet or be better than international emissions standards, including the European Union Waste Incineration Directive. The emissions from referenced advanced gasification technologies against the emission standards in the European Union Waste Incineration Directive are detailed in Chapter 4.

SHORTLISTED REFERENCE TECHNOLOGIES

Gasification technologies operating internationally run into the thousands. These operate on feedstocks from coal to biomass to mixed wastes. The uptake rate for these technologies as a means for managing waste is accelerating.

The gasification facilities treating MSW number around 80 facilities, at various levels of maturity.

A shortlist of 16 gasification technologies met the selection criteria, and can be organised into three broad categories depending on their thermal conversion temperatures. The example technologies assessed were already operating internationally.

These examples of technologies that can address the City's objectives form a set of reference facilities that were subject to detailed scrutiny to further refine the preferred options for the City, and this refinement is detailed in Chapter 2.

FIGURE 23: WORLWIDE GASIFICATION CAPACITY (CUMULATIVE) (SOURCE: GASIFICATION TECHNOLOGIES COUNCIL)

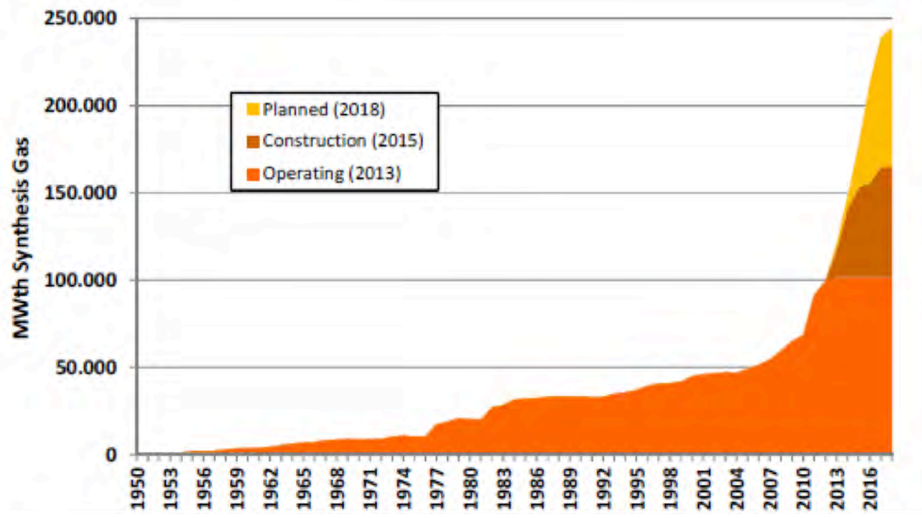


FIGURE 24: GASIFICATION TECHNOLOGIES THAT MET THE CITY'S CRITERIA
(SOURCE: TALENT WITH ENERGY)

Supplier	Technology Name	Type	Scale	Maturity	Application
Low-Temperature Conversion (LTC)					
Thide Environmental	EddiTh	Slow pyrolysis	small-medium	proven	MSW, industrial
IES	APS	Pyro-combustion	medium	demonstrated	MSW, industrial
Entech-RES	WtGas	Fixed-bed gasification	small-medium	commercial	MSW, sludge
High-Temperature Conversion (HTC)					
EnerKem	ByoSyn	Fluid-bed gasification	small-medium	proven	MSW, RDF
OE Gasification	SK 1000	Pyro-gasification	small-medium	proven	MSW
WasteGen	Pyropleq	Pyro-gasification	small-medium	proven	MSW, sludge
TPS	Termiska AB	Fluid-bed gasification	small-medium	proven	MSW, RDF
High-Temperature Conversion + Melting (HTCM)					
Advanced Plasma Power	GasPlasma	Plasma-assisted Gasification	small-medium	demonstrated	MSW, SR
AlterNRG	PGVR	Plasma gasification	medium-large	commercial	MSW, SR, RDF
Ebara TwinRec	TFiG	Fluid-bed gasification + melting	medium-large	commercial	MSW, SR
InEnTech	PEM	Plasma gasification	small-medium	proven	MSW, indl., haz.
Mitsui	R21	Pyro-combustion + melting	medium	proven	MSW, sludge
Nippon Steel	DMS	Fluid-bed gasification + melting	medium-large	commercial	MSW, sludge
Plasco	PGP	Plasma gasification	small-medium	proven	MSW
Toshiba	PKA	Pyro-gasification + melting	small-medium	proven	MSW
Thermoselect	HTR	Pyro-gasification + melting	medium-large	commercial	MSW

RE-THINKING WASTE AS A RESOURCE

RE-THINKING WASTE AS A RESOURCE

Treating waste to produce energy will require innovation within the traditional Sydney waste management sector.

It involves a reinterpretation of waste management systems as we know it, turning waste into a valuable resource with a high demand.

The environmental cost of continuing to treat waste as a liability rather than a resource is no longer morally or technically acceptable.

CHARACTERISING THE CITY'S WASTE

In the City local government area, waste is classified into three principal streams.

FIGURE 25: CITY OF SYDNEY WASTE CHARACTERISATION (SOURCE: CITY OF SYDNEY)

Waste Stream	Abbreviated	Includes
Municipal Solid Waste	MSW	Mixed waste and separated recycling from households. By extension can include waste collected by the City such as litter and street sweepings.
Commercial and Industrial Waste	C&I	Mixed waste and separated recycling generated by businesses, shops, offices, workshops and factories.
Construction and Demolition Waste	C&D	Waste materials such as demolished concrete, bricks, timber, offcuts and wastage from construction.

The City has a direct legislated responsibility to manage Municipal Solid Waste, which is largely made up of household waste and recycling. Commercial and Industrial waste contributes significantly to the overall greenhouse gas emissions and waste disposal performance for the city as a whole. Therefore, an inclusive role for managing this resource is necessary.

This Master Plan will at a minimum address the treatment options for the waste from its residents. However, an understanding of the potential contribution from non-residential waste to energy recovery, greenhouse gas emissions reduction, and facility viability is necessary for completeness of this Master Plan.

Construction and Demolition waste has not been included in the analysis. This waste stream has a set of economic drivers that mean resource recovery is already very high (>75%). Much of the waste from this sector also has a low energy value. This waste is not generated on a regular ongoing basis across the City, but rather is generated intermittently on a project by project basis.

The City is updating its Waste in New Developments management policy that addresses the Construction and Demolition waste stream at the time and place of its generation.

Other sources of waste outside the City such as agricultural, forestry, or similar are detailed in the Renewable Energy Master Plan.

The analysis will examine the availability of material and energy resources within the waste streams and how they can be utilised. The analysis will also measure the energy potentially available for recovery from the waste in those streams.

An operational gasification facility could potentially include Municipal Solid Waste from other local government areas within close proximity to the City. An assessment of these resources was made in the Renewable Energy Master Plan. A mapping of these resources will identify the potential energy resources from nearby waste.

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OVERVIEW OF THE CITY'S TOTAL WASTE

The City's Interim Waste Strategy separately set out how the City will optimise the minimisation and source-separated recycling of materials prior to collecting mixed waste. The Interim Waste Strategy specifically acknowledged that what the City terms as "waste" is best managed as a set of resources with a value.

Separate to waste avoidance, reuse and recycling approaches, there are opportunities available to manage the remaining mixed waste as a resource in itself. This focus on more effective mixed waste treatments applies to both Municipal Solid Waste and Commercial & Industrial waste sectors.

At its simplest analysis, the waste generated by the City's Local Government Area (LGA) provides opportunities for three resource recovery streams:

- Materials;
- Nutrients; and
- Energy.

There are also toxic materials that are disposed of, such as cleaning chemicals, batteries, computer parts, compact fluorescent lamps and medical wastes. Small percentages of these items can chemically contaminate the other materials in waste, rendering some of them unsuitable for recovery. The City has separately identified actions within the Interim Waste Strategy for reducing these items and introduced a number of innovative collection systems to separately handle these materials.

All figures used are derived from the 2012/13 financial year reported data unless otherwise stated.

The proportion of total waste generated from residents (MSW) is less than a quarter of the total City's LGA waste. The chart shows the total of materials generated in the City's LGA for these waste streams, before recycling is separated.

The combined total is 325,488 tonnes for the year.

The City currently has all of its mixed waste treated in a mechanical-biological treatment facility. Whatever cannot be recovered must still be disposed of to what is called a general solid waste putrescible landfill. Slightly less than half the C&I waste from businesses is also ultimately disposed of to these landfills.

These are the types of landfills under capacity pressure within the Sydney region. The C&I waste contributes heavily to the consumption of space in those landfills. The remainder of the C&I mixed waste goes to non-putrescible landfills and a small fraction to specialised incineration.

Commercial and Industrial waste levels and composition are estimated from visual audits carried out by the NSW government. Indications from actual data provided to the City by members of the Better Buildings Partnership are that levels are higher than this.

FIGURE 26: CITY OF SYDNEY WASTE GENERATED 2012/13 (SOURCE: CITY OF SYDNEY)

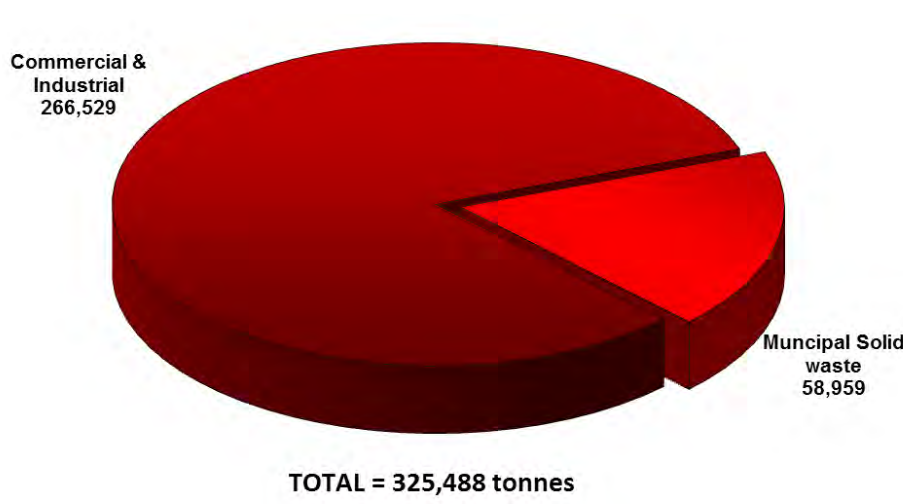
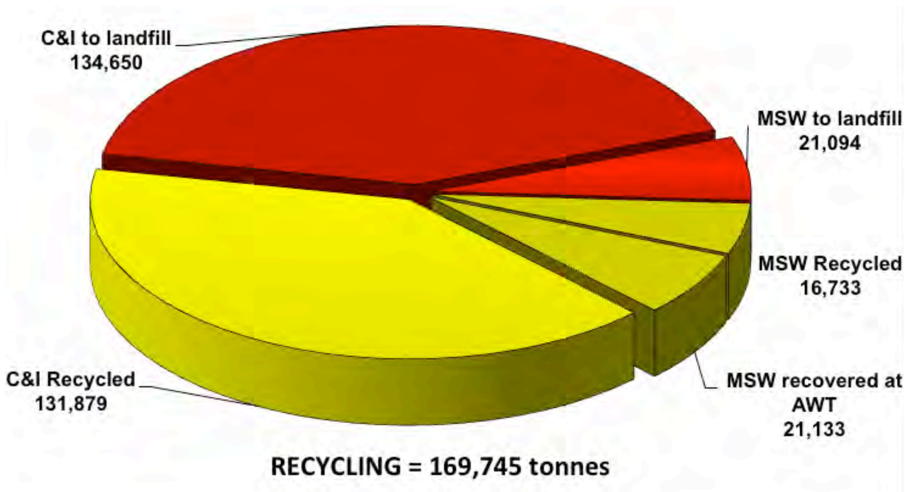


FIGURE 27: CITY OF SYDNEY RESOURCE RECOVERY 2012/13 (SOURCE: CITY OF SYDNEY)



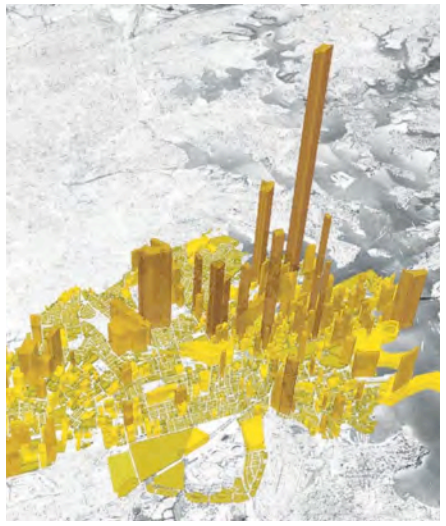
For the MSW waste stream, two-thirds of all materials are recycled. This includes recovery using the City's existing advanced waste treatment, which processes waste remaining after separate recycling activities divert almost 30% of total waste.

The City C&I waste stream sees around half of all materials recycled or recovered by processing.

The total City recycling and recovery level for the year across both streams was 169,745 tonnes or 52.15%.

The most common resources recovered are of materials such as paper, metals, glass and plastics, or nutrients recycled from garden or food organics.

FIGURE 28: CITY ANNUAL NON-RECYCLED (RED BIN) WASTE GENERATION BY WEIGHT FROM MSW AND C&I SOURCES (SOURCE: CITY OF SYDNEY)



Like every global city, Sydney generates different levels of waste across multiple business sectors and residential dwelling types. This projection is of non-recycled 'red bin' waste generated annually and excludes 'yellow bin' recycling. It is based on multiple data sources in order to realise the waste loads requiring management every day of the year. Since the map relies on average levels across business sectors and dwellings, it cannot be used to identify individual premises, but offers an insight into the complexity and scale of the City's waste generation. All non-recycled (red bin) waste represented here must be disposed of or processed, as set out in this Master Plan.

1 ADVANCED WASTE TREATMENT

2 RE-THINKING WASTE AS A RESOURCE

3 ADVANCED WASTE TREATMENT FOR THE CITY OF SYDNEY

4 PERFORMANCE MEASURES

5 ENABLING THE MASTER PLAN

6 CASE STUDIES

MATERIALS RECOVERY FROM MUNICIPAL SOLID WASTE

The City of Sydney existing waste treatment approach is to reduce or recycle materials in its waste as far as practicable.

The City relies on residents to separate waste and recyclable waste for separate storage and collection. Recycling is provided for paper and containers, and the City also provides an opt-in Garden Organics recycling where practicable.

Recycling these resources means less energy is needed to produce the next generation of products from these materials, and fewer resources are discarded into landfill.

Any remaining waste is then processed to recover the organic component as a compost-like output. The output of this treatment is restricted by government regulation, and the recovered portion of the City's waste is not used for agriculture or food production but primarily for mine site rehabilitation.

In addition to the residential waste separated into bins, other wastes are separately collected, such as bulky clean-up waste, whitegoods, E-waste and hazardous and chemical waste.

Clean-up waste is sorted for useful materials before landfilling.

Household hazardous waste collected via drop-off days is destroyed using a high temperature plasma arc furnace. However, this separate collection reduces chemical contamination of other recovery streams and thereby helps to improve resource recovery overall.

The other collected wastes are largely recycled in various ways.

Using these systems, the City is one of a limited number of councils in NSW to meet its existing target of diverting 66% of residential waste from landfill.

A third of all City household waste generated must still be landfilled after this recycling and treatment.

The figure is even higher at around 50% for the waste generated by the businesses of the city as C&I waste.

All of these residual wastes still going to landfill contain energy content resources that are unrecovered under the present treatment processes. This energy recovery would also significantly reduce the material requiring final disposal.

EXISTING MUNICIPAL SOLID WASTE RECOVERY AND DISPOSAL PATHWAYS

FIGURE 29: CITY MUNICIPAL SOLID WASTE COLLECTIONS PRIOR TO ADVANCED WASTE TREATMENT RECOVERY (SOURCE: CITY OF SYDNEY)

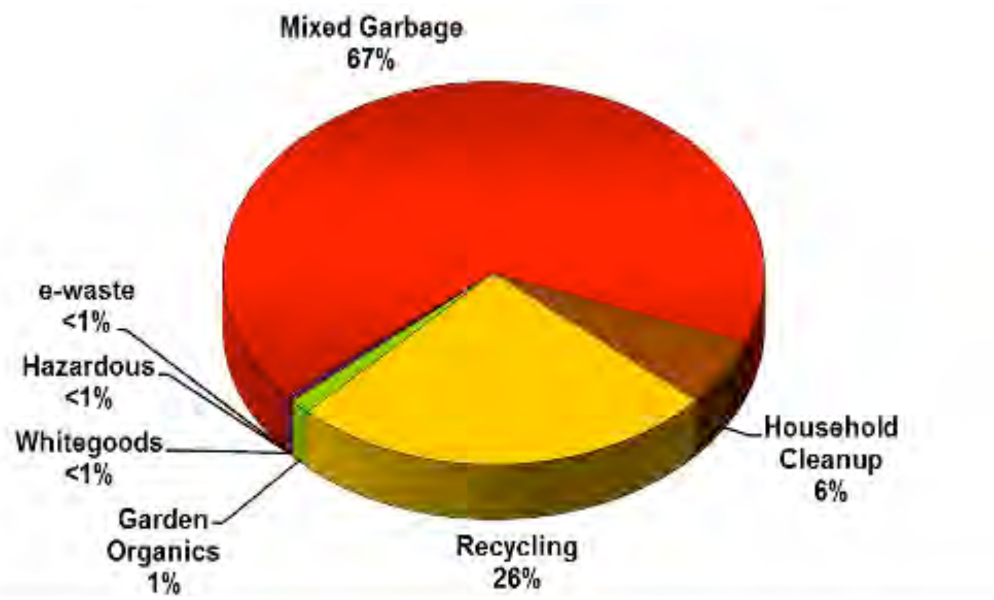


FIGURE 30: EXISTING MUNICIPAL SOLID WASTE RECOVERY AND DISPOSAL PATHWAYS
(SOURCE: TALENT WITH ENERGY)

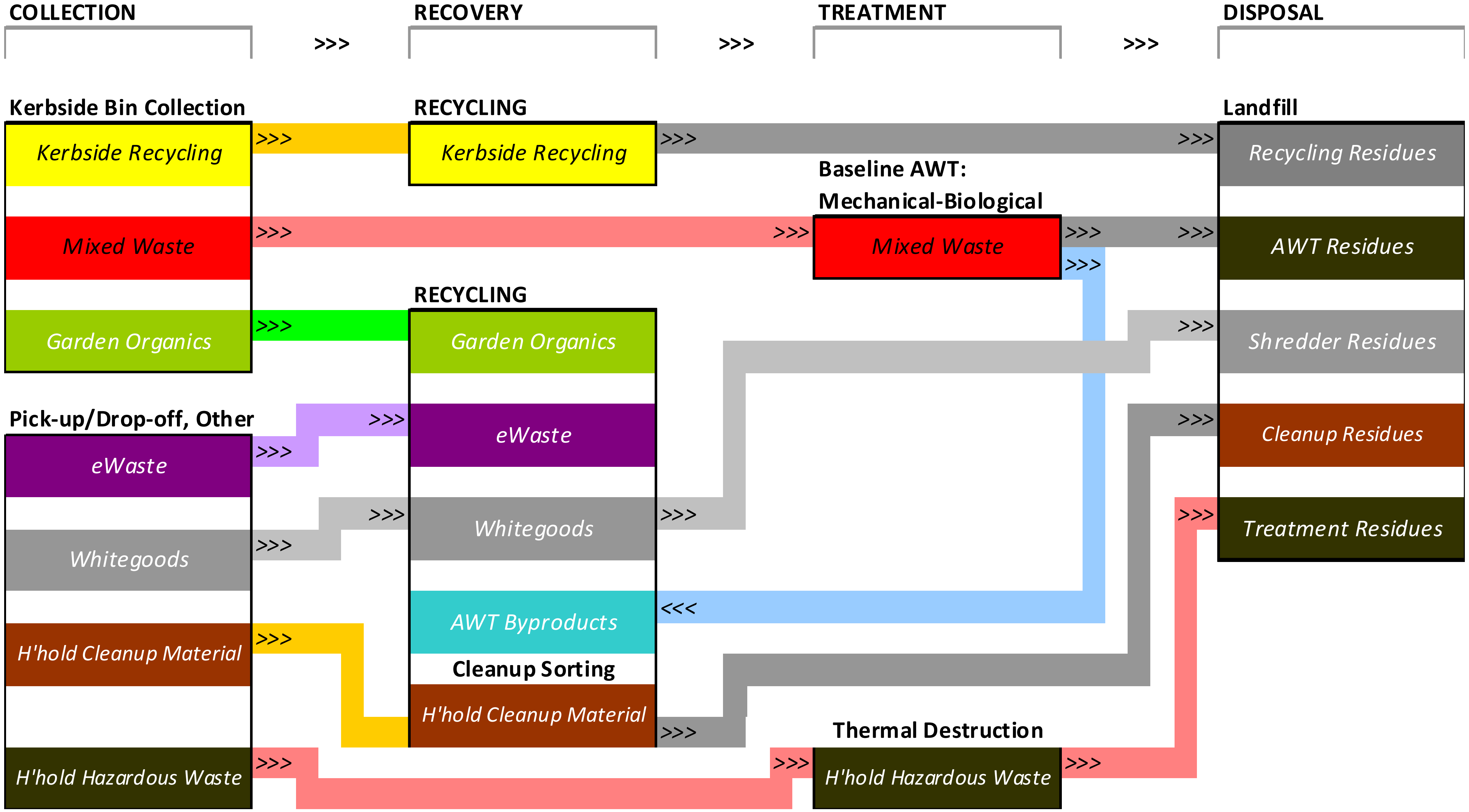


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FIGURE 31: CITY OF SYDNEY RESIDENTIAL WASTE DATA – HISTORIC AND PROJECTED BAU (SOURCE: CITY OF SYDNEY AND TALENT WITH ENERGY)

	2005–06	2006–07	2007–08	2008–09	2009–10	2010–11	2011–12	2012–13	2013–14	2014–15	2015–16	2016–17	2017–18	2018–19	2019–20	2020–21	2021–22	2022–23	2023–24	2024–25	2025–26	2026–27	2027–28	2028–29	2029–30
Residential population	148,367	165,596	170,173	173,444	177,920	180,679	183,567	187,426	191,091	195,170	199,509	203,785	207,733	211,527	215,393	218,988	222,885	226,744	230,589	234,406	237,499	240,321	242,445	244,393	246,310
RESOURCE COLLECTION									**PROJECTED DATA →**																
Mixed waste	39,999	36,865	37,816	39,378	39,453	40,209	39,653	39,550	41,403	42,134	43,090	44,038	44,914	45,755	46,612	47,410	48,274	49,129	49,982	50,828	51,514	52,140	52,611	53,043	53,468
Kerbside recycling	11,905	14,261	14,815	15,081	15,295	15,962	15,701	15,014	17,017	17,380	17,766	18,147	18,499	18,837	19,181	19,501	19,848	20,192	20,534	20,874	21,149	21,401	21,590	21,763	21,934
Garden organics	524	232	339	453	549	744	865	757	1,213	1,430	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438
Other wastes (a)	5,421	2,633	2,701	2,764	2,839	2,673	2,933	3,639	2,916	2,925	2,934	2,943	2,953	2,962	2,971	2,986	3,000	3,015	3,029	3,044	3,059	3,074	3,089	3,104	3,119
TOTAL Collected	**57,849**	**53,990**	**55,671**	**57,675**	**58,136**	**59,589**	**62,086**	**62,598**	**62,549**	**63,869**	**65,229**	**66,567**	**67,803**	**68,991**	**70,202**	**71,334**	**72,560**	**73,774**	**74,983**	**76,185**	**77,161**	**78,053**	**78,728**	**79,348**	**79,959**
RESOURCE RECOVERY, TREATMENT AND DISPOSAL																									
Source-separated materials (b)	11,477	13,352	13,969	14,327	14,620	15,429	15,310	14,569	16,869	17,419	17,783	18,133	18,457	18,768	19,084	19,379	19,698	20,014	20,329	20,642	20,895	21,127	21,301	21,460	21,617
Waste Diversion by AWT	0	0	0	0	3,693	11,834	18,576	18,417	24,345	24,775	25,337	25,895	26,409	26,904	27,408	27,877	28,385	28,888	29,389	29,887	30,290	30,658	30,935	31,189	31,439
Total MSW recovered (c)	**11,477**	**13,352**	**13,969**	**14,327**	**18,314**	**27,263**	**33,886**	**32,986**	**41,214**	**42,194**	**43,120**	**44,028**	**44,866**	**45,672**	**46,492**	**47,256**	**48,083**	**48,902**	**49,719**	**50,529**	**51,186**	**51,785**	**52,236**	**52,649**	**53,056**
Total residuals to landfill b	**40,951**	**38,006**	**39,001**	**40,585**	**36,984**	**29,652**	**28,199**	**29,612**	**18,419**	**18,750**	**19,174**	**19,596**	**19,984**	**20,358**	**20,739**	**21,093**	**21,477**	**21,857**	**22,235**	**22,611**	**22,916**	**23,194**	**23,403**	**23,595**	**23,784**

(a) includes whitegoods, e-waste, hazardous wastes and household cleanup collections
(b) assuming 8% contamination of recycling into landfill
(c) does not include recovery through waste avoidance and reuse options

DISTINCTIVE FEATURES OF THE CITY'S MSW

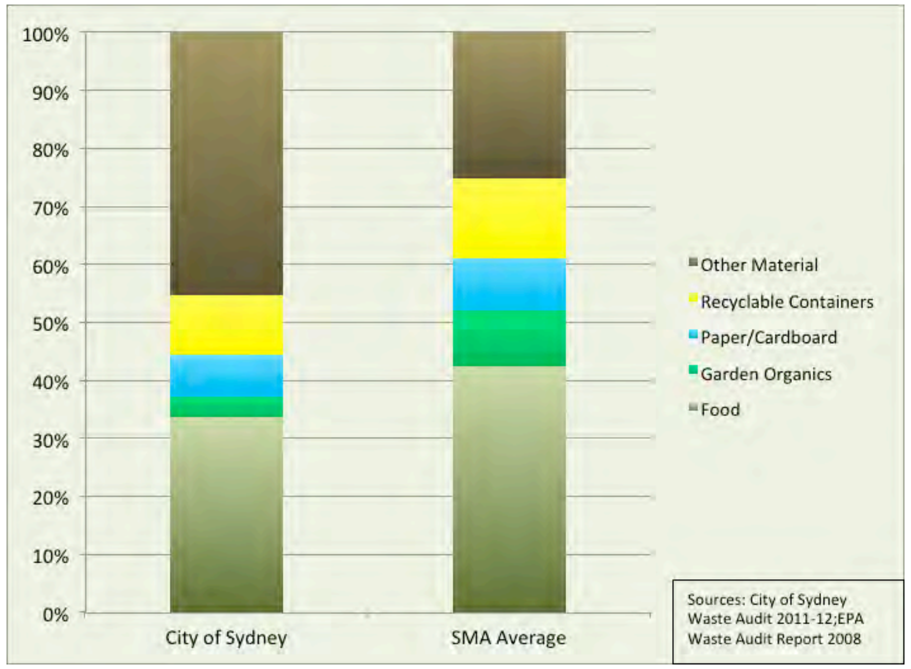
Residential waste in the City is different in composition to much of the rest of the Sydney metropolitan area. The combined food and garden organics within the City residential waste bins averages 37%, compared to over 50% in the Sydney Metropolitan Area (SMA). This means the City's organic fraction is only borderline for a viable organics recovery.

The greatest portion of the City's waste is other non-recyclable material, at a rate almost twice that of the rest of the Sydney Metropolitan Area. This material is composed of a range of wastes such as plastic films, items made from composite materials (plastic-wood-metal combinations), inert materials, and non-compostable organics.

The level of recyclable containers in the City residential bins is also lower at around 10%, compared to SMA average at 14%. The City already strongly markets its recycling program to residents. The City supports the introduction of a national Container Deposit Scheme which would provide an incentive for residents to reduce this level further.

The recyclable paper/cardboard stream at 7% is usually contaminated with bacteria from the organic material, and cannot be successfully separated for recycling once within the waste stream.

FIGURE 32: COMPARISONS OF WASTE AND RECYCLING BETWEEN THE CITY OF SYDNEY AND THE SYDNEY METROPOLITAN AREA (SOURCE: APC CONSULTING AND CITY OF SYDNEY BASED ON NSW EPA DATA)



RE-THINKING MIXED WASTE FOR ENERGY RECOVERY

The markets for existing separated resources are mature and the recovery of material resources by recycling will continue.

The highest opportunity for improving waste outcomes is to plan for the recovery of energy within the mixed waste fraction as an additional resource.

There are two ways of assessing energy values in waste. The energy values of the materials are:

1) the embodied energy value

Embodied energy is the energy content nominally accumulated by materials and products from their extraction as virgin resources through their manufacture or processing, their transport to the point of consumption and the energy used for their collection and disposal. It is an assigned value of the energy expended to turn a material or product into something consumed and disposed during its life cycle.

2) the gross heating energy or "calorific value"

The calorific value is the energy stored within the material itself, and can be released by thermal processing. Since this value is attached to the material and remains constant during processing, it allows a comparison of what energy can be extracted from a mixed waste stream by analysing the materials within that stream.

Embodied energy escalates rapidly as more complex items are manufactured, such that electronic appliances have higher embodied energy than sawn wood.

Embodied energy is why re-use and recycling offer higher use of resource value than re-processing of mixed waste. Re-use retains the complete resource value. Recycling reduces the energy needed to manufacture new goods.

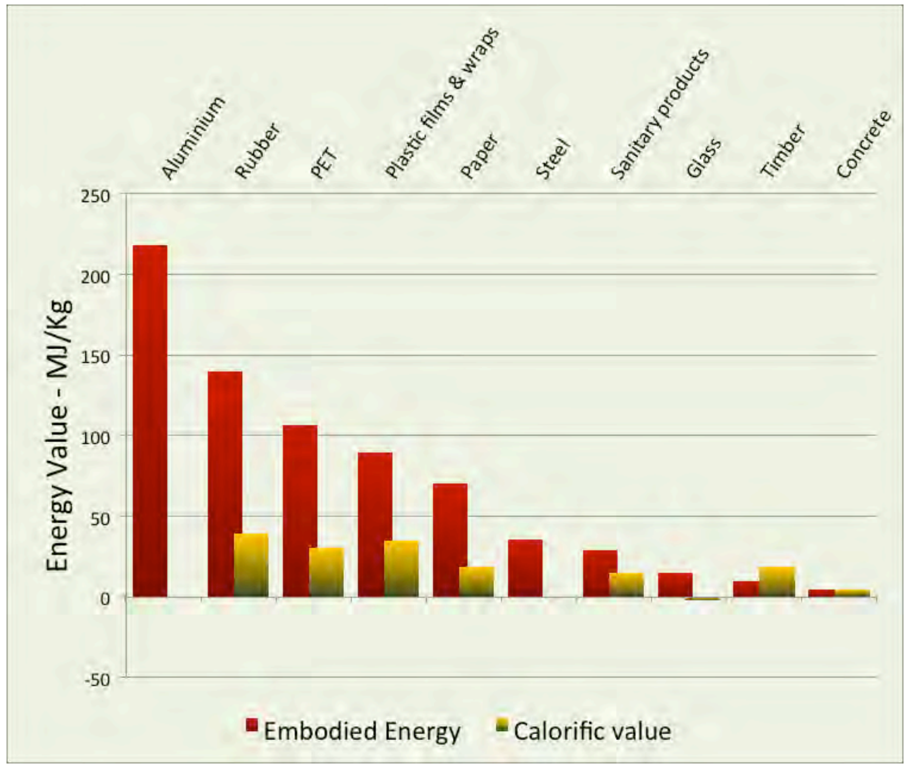
It is the heating value of the material that is available as an energy resource. The embodied energy value cannot be directly recycled. But the recovery of the calorific value as energy does return energy to the economy that would otherwise be lost to landfill.

Landfilling loses both the embodied and direct energy content of waste. Thermal conversion can recover the calorific value of waste to a high degree for other uses.

The level of embodied energy compared to calorific value shows why recycling and energy recovery are fully compatible. Materials such as aluminium, steel and glass have low or negative calorific values, and there is a clear driver to recover and recycle these materials rather than lose energy processing them in thermal conversion treatment. Other drivers for recycling will depend more on the market value of recyclable material and ease of recovery.

To understand what potential there is in MSW for energy recovery, the recovery of resources needs to be analysed not on the basis of material content but on the basis of calorific energy values.

FIGURE 33: EMBODIED ENERGY OF COMMON MANUFACTURED MATERIALS IN WASTE AND POTENTIAL ENERGY RECOVERY VALUE (SOURCE: UNIVERSITY OF BATH, TALENT WITH ENERGY)



ENERGY COMPOSITION OF THE CITY'S MUNICIPAL SOLID WASTE

The City has conducted seasonal audits of its resident's waste to ensure a high level of understanding of the materials making up the total. There are over seventy categories of waste materials in an audit, reflecting the diversity of materials consumed in a modern city.

This higher level grouping (Figure 34) shows the proportions of materials within the residential waste bin, with recycling already separated. Amongst many other materials, the food, paper and plastics fractions dominate. Metal is proportionately low. It should be noted that the "paper" within this waste is not readily available for recycling, as it is contaminated by other waste.

Existing materials recovery aims at sorting out these individual material categories for appropriate recovery or treatment. Because of the complexity of waste, some materials can cross-contaminate others so even after significant mechanical effort only a portion can be cleanly separated.

Figure 35 represents the same available material resources in residential waste based on their energy values. These form "process" categories with differing potentials for energy recovery. Each category has a different moisture level, energy yield or handling requirement when processed for energy recovery.

FIGURE 34: MATERIAL CATEGORIES WITHIN MSW (SOURCE: CITY OF SYDNEY BASED ON APC CONSULTING DATA)

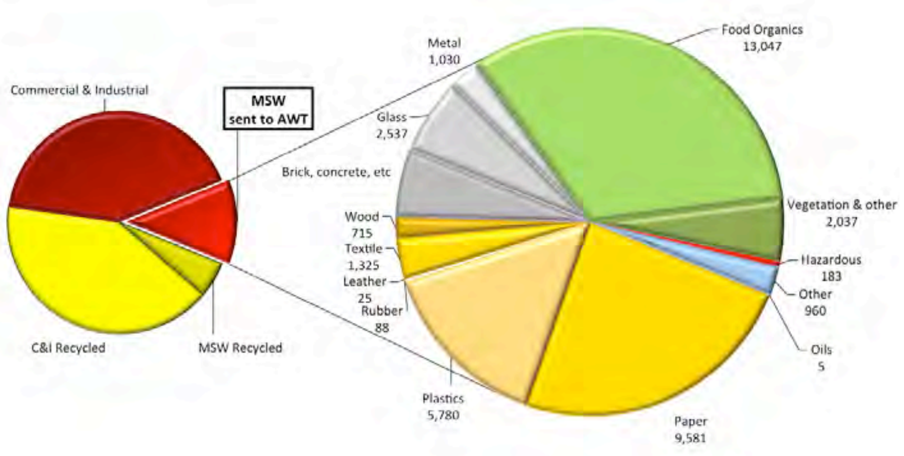
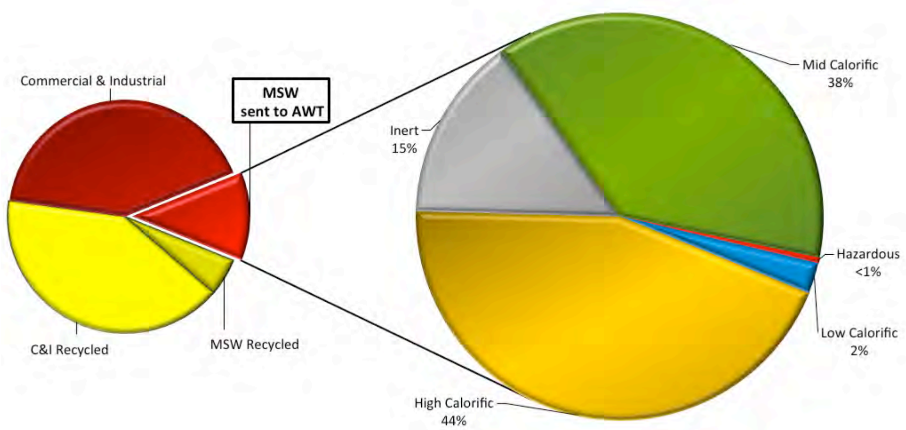


FIGURE 35: MSW PROCESS CATEGORIES FOR ENERGY RECOVERY (SOURCE: CITY OF SYDNEY BASED ON TALENT WITH ENERGY DATA)



Analysing the available resources in MSW mixed waste streams shows that there are five categories comprised of different materials with different energy values:

Category	Material Examples
High Calorific	Plastics, Paper, Rubber, Leather, Textiles, Wood, Oils.
Mid Calorific	Food Scraps, Vegetation, Kitty Litter, Pet Faeces.
Low Calorific	Sludge, Electrical Items, Cartridges
Inert	Building Materials, Ceramics, Dust, Dirt, Rock, Inert, Ash, Glass, Metal.
Hazardous	Paint, Batteries, Household Chemicals

For the purposes of recovering energy as a resource from waste, most technologies require the inert and hazardous components to be minimised or removed.

The inert fraction is not a material that rots, and could be sent to a local, cheaper non-putrescible landfill. Some of this material may be available for re-processing for construction or road base use. Metals remaining in the waste would be separated and recycled.

The remaining categories are all suitable for energy recovery.

ENERGY RECOVERY FROM WASTE

Each of the fractions identified within mixed waste contains materials that have different potential energy yields. The energy values are also affected by the moisture levels in the material, which reduces the net energy released.

Values listed in Figures 36 and 37 are for the process categories of the waste as received at the treatment facility. The overall value of the waste as an energy resource will increase as the material is prepared for use as a feedstock.

The Inert category contains material of low energy value, which is why it is usually removed prior to treatment as set out in Chapter 3. When waste received has been prepared by removing inerts and reducing materials to similar size, it becomes a feedstock for the energy recovery process. This feedstock will have a higher energy value per kilogram than raw waste as collected.

The materials that compose the Hazardous category of waste do contain some energy. However, the City already has avoidance, diversion and recovery programs set out in its Interim Waste Strategy to remove the hazardous material as a preferred approach.

The actual energy that may be recovered from the waste will depend almost entirely on the treatment technology selected. The impact of different technologies on energy recovery from waste is assessed in Chapter 3.

The High Calorific value category in MSW will contribute most to energy recovery, as it has the highest fraction by weight and a high energy yield of up to 17.52 Megajoules of energy per kilogram with low moisture content.

The Mid-Calorific value category in MSW has a relatively high moisture level. However, the energy content is still of sufficient value to recover at least 7.36 Megajoules per kilogram.

Based on weighted average, the overall energy value of MSW is 11.44 MJ/Kg. When processed into a feedstock this will reach 16.97 MJ/Kg.

The High Calorific category in C&I waste is also the dominant fraction for C&I waste, with a value of 18.19 Megajoules of energy per kilogram.

The Mid Calorific category is a far lower proportion of C&I waste, indicating a lower organic level. This category of waste shows a marginal increase on MSW values at 8.43 Megajoules per kilogram.

The average energy value for C&I waste is 13.59 MJ/Kg. When processed into a feedstock by reducing inert material this will reach 17.77 MJ/Kg.

FIGURE 36: MSW PROCESS CATEGORIES
(SOURCE: CITY OF SYDNEY BASED ON TALENT WITH ENERGY DATA)

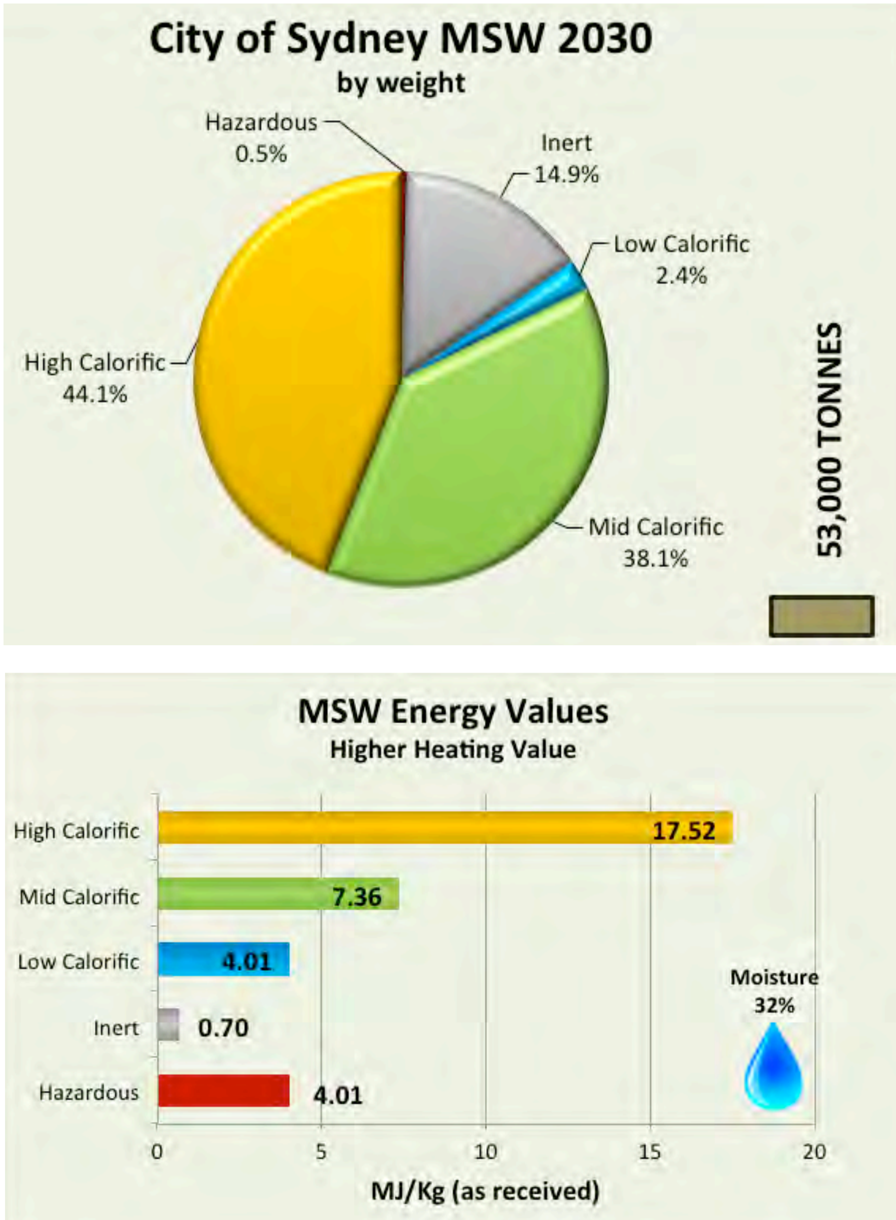
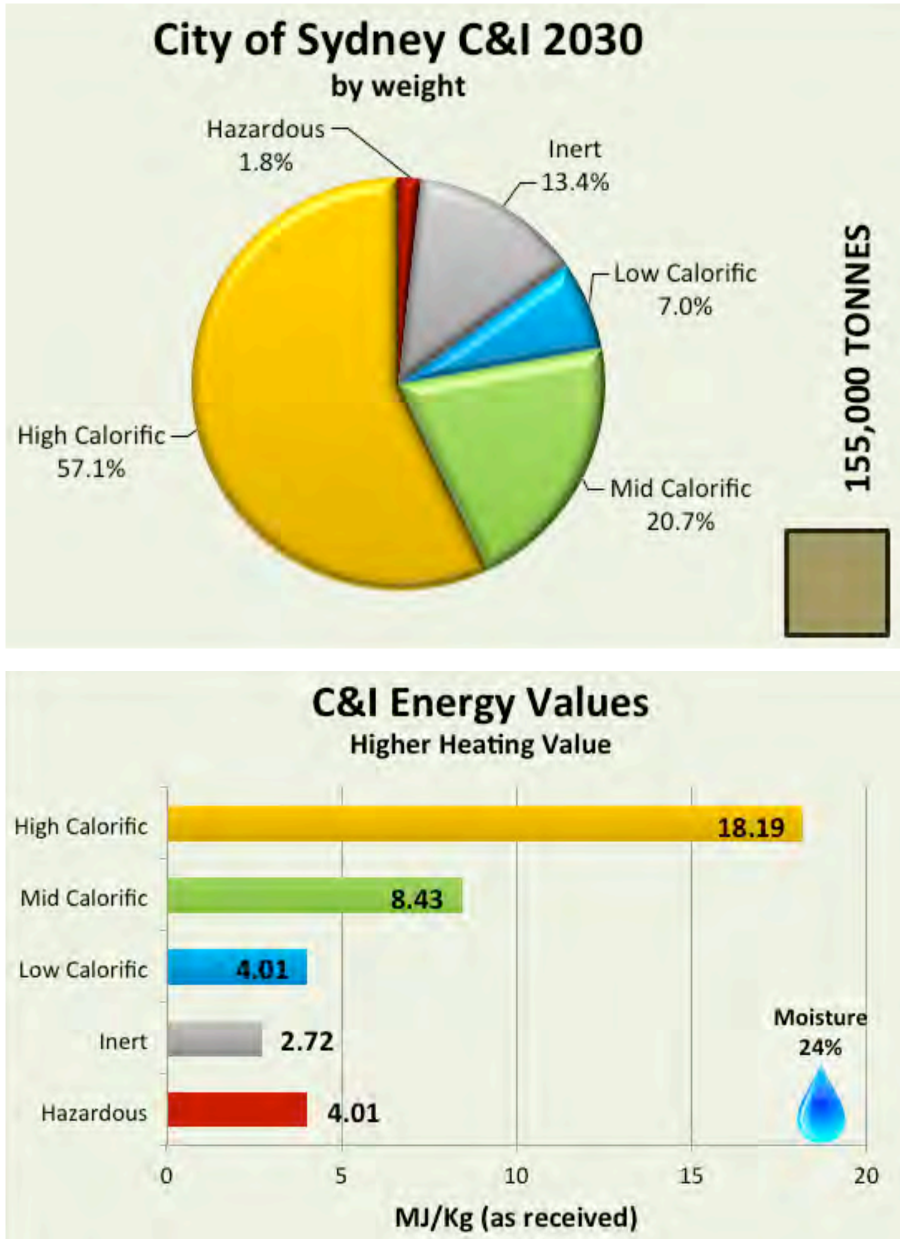


FIGURE 37: C&I PROCESS CATEGORIES
(SOURCE: CITY OF SYDNEY BASED ON TALENT WITH ENERGY DATA)



ADDITIONAL CITY GENERATED WASTE STREAMS

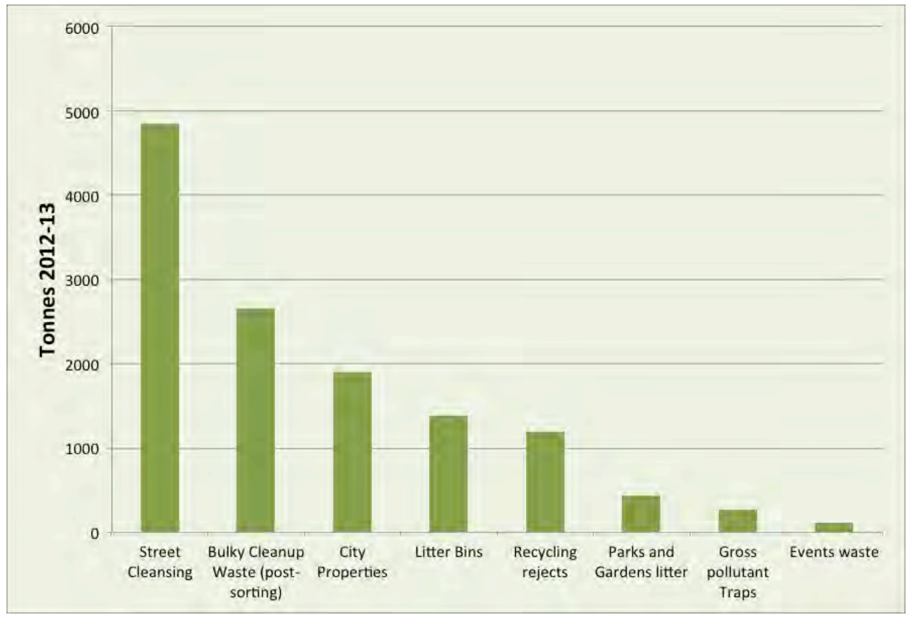
Other wastes are generated as part of the City's operations such as post-sorting bulky waste, recycling rejects (contamination), street litter and sweepings. These wastes may be included within the feedstock of municipal solid waste that will increase the levels of feedstocks available and may alter the energy characteristics. Their inclusion will be assessed depending on the technology available to the City.

Additional City LGA wastes that could be treated for energy recovery include sewage sludge from sewer mining and stormwater harvesting waste capture.

These additional streams will depend on the implementation of the Decentralised Water Master Plan in the City's LGA.

The precise characteristics of these waste streams will need to be evaluated prior to their inclusion for thermal conversion treatment. Because of their high biogenic carbon content, these additional wastes have the potential to increase the renewable energy content of syngas generated by thermal conversion.

FIGURE 38: CITY-GENERATED WASTE STREAMS FOR INCLUSION IN ADVANCED WASTE TREATMENT (SOURCE: CITY OF SYDNEY)



An additional commercial waste stream suitable for gasification is the waste materials left after the recycling of metals from whitegoods, cars and similar items. This is termed "shredder residue" or "floc" and is currently landfilled. In NSW, this floc exceeds 100,000 tonnes disposed a year. About half this material is unrecyclable mixed plastics.

At the scale of the waste levy in NSW, the landfill cost can negate the value of metals recovered, leading to movement of recycling facilities interstate or offshore. Many of the reference technologies reviewed for this Master Plan processed shredder residue, which could lead to improved economics of the local recycling sector as their waste becomes an energy resource.

1 ADVANCED WASTE TREATMENT

2 RE-THINKING WASTE AS A RESOURCE

3 ADVANCED WASTE TREATMENT FOR THE CITY OF SYDNEY

4 PERFORMANCE MEASURES

5 ENABLING THE MASTER PLAN

6 CASE STUDIES

OTHER POTENTIAL WASTE RESOURCES FOR ENERGY RECOVERY

SOUTHERN SYDNEY REGIONAL ORGANISATION OF COUNCILS
Councils in the Southern Sydney Regional Organisation of Councils (SSROC) adjacent to the City face the same waste issues of restricted landfill and environmental concerns as the City. As part of its broader potential resource evaluation, the City reviewed the characteristics of these regionally adjacent Councils waste to determine if suitable for integrating into a thermal conversion facility.

SSROC councils have a higher proportion of organics waste in the Mid-Calorific category on average. This adds to the overall moisture level, so some energy must be expended to dry this waste during processing. While lower in net potential energy values, the waste is still sufficiently similar to the City to be considered a potential resource for energy recovery.

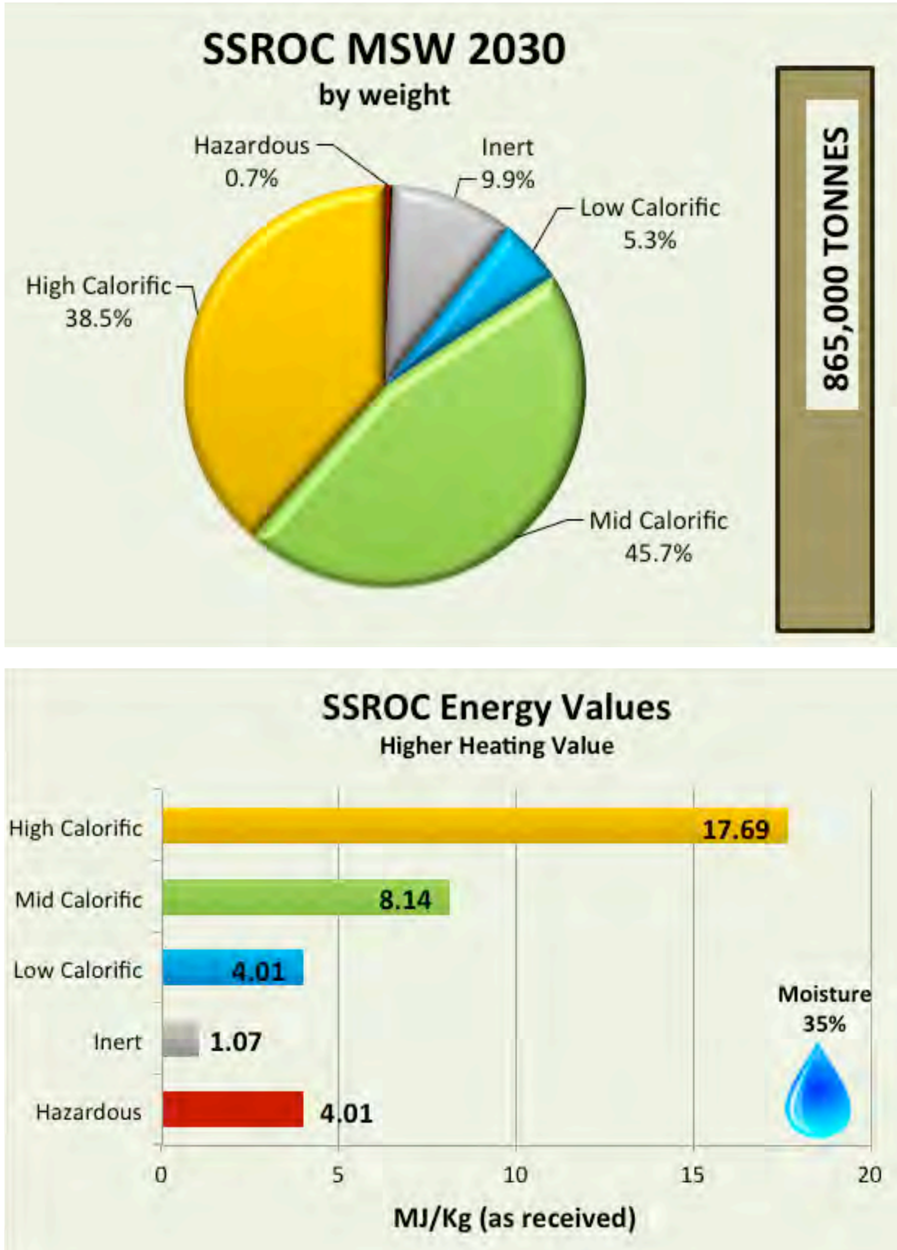
Several of these SSROC Councils have contracted for mechanical biological treatment of waste. The evaluation of potential resources still includes their waste as part of a long term assessment of available waste resources.

FIGURE 39: POST-RECYCLING WASTE SSROC COUNCILS (SOURCE: NSW EPA)

SSROC	Tonnes (2011–12)
Ashfield*	10,161
Bankstown	41,759
Botany Bay*	8,124
Burwood*	6,747
Canada Bay	16,504
Canterbury	34,075
Hurstville	21,402
Kogarah*	11,845
Leichhardt*	10,836
Marrickville	16,159
Randwick	27,294
Rockdale*	30,187
Sutherland	42,119
Sydney	39,653
Waverley*	13,957
Woollahra*	11,542
TOTAL	**342,364**

*These Councils have entered a waste processing contract, subject to planning approvals and construction of new facilities.

FIGURE 40: SSROC PROCESS CATEGORIES (SOURCE: CITY OF SYDNEY BASED ON TALENT WITH ENERGY DATA)



RESOURCE RECOVERY USING THERMAL CONVERSION

Thermal conversion treatment uses heat and chemical reactions to convert waste material as a feedstock into a number of valuable by-products. This makes it different to approaches such as thermal combustion which effectively only recovers the heating value of the waste as a fuel. Essentially, gasification relies on waste as a feedstock to recover a number of resources, not as a fuel. It is only the resulting gas which may be used as a fuel, or in turn used as feedstock for additional chemical processes.

The forms in which the material and energy resources are recovered are:

- synthesis gas (syngas);
- recyclable metals;
- vitrified slag (for aggregate, road base or rock wool);
- ash (used for concrete or construction materials);
- water; and
- chemicals.

SYNGAS

The principal output of thermal conversion (gasification) technologies is a high calorific (energy) value gas known as 'synthesis gas' or its abbreviation 'syngas'. Syngas is a mixture of hydrogen, methane, nitrogen, carbon dioxide, carbon monoxide and smaller quantities of other hydrocarbons. All these components can be recovered from the original materials within the waste.

Because it is re-utilising the original materials within the waste, gasification is like a very advanced form of recycling: waste materials are reduced back to their molecular building blocks and re-constituted for use again in a different form.

Syngas is a very flexible output as it can be used directly as a fuel for electricity generation, to provide a chemical basis for processing into fuels and chemicals, to provide hydrogen or converted into a substitute natural gas via a methanation process and injected into the gas grid for end use applications such as cogeneration, trigeneration and district heating/cooling in the city or as a transport fuel.

Syngas derived from organic materials such as agricultural waste, forestry, plant or food waste, is defined as renewable gas. The feedstock resources for these materials are set out in the Renewable Energy Master Plan.

Syngas derived from a mixed waste feedstock such as municipal solid waste or commercial and industrial waste will have only the organic (such as rubber, leather, textiles, contaminated paper, nappy waste, oils and food scraps waste) fraction of their waste defined as renewable gas.

Syngas derived from inorganic materials is defined as non-fossil fuel gas, although some countries consider syngas from the inorganic fraction of waste as renewable gas as well.

In general, the mid-calorific category of mixed waste will be composed of fully renewable materials. The High Calorific category will contain some materials that contribute to the renewable energy content, such as paper, textiles, rubber, leather and oils, but will also contain non-renewable materials such as plastics. In this Master Plan plastics are not counted towards the renewable energy content as they are manufactured from non-renewable resources. However, these include materials such as plastic films, composite plastics and similar, which cannot be viably recycled from mixed waste. Generating a gas that includes these high energy value materials avoids losing that energy resource to landfill.

POTENTIAL ENERGY AND INDUSTRIAL PRODUCTS FROM SYNGAS

After generation using thermal conversion treatment, syngas can be cleaned of any particulate matter and utilised directly or cooled and stored. At this stage, the syngas can be used as the basis for a number of products or energy recovery processes.

Direct Use for Electricity Generation

Steam Turbine Generation: Syngas can be used on site for generation of electricity by raising steam in a boiler to drive a steam turbine. Requires gas clean-up, catalytic reduction of nitrogen oxide, and air pollution controls. Efficiency would be in the range of 15–25% (ie, similar to the efficiency of incineration).

Gas Engines: Syngas is cleaned of particulate matter and any acidic gases. Large plants can achieve energy efficiencies when generating electricity of 35–40%. If the heat generated from the engine can be captured and utilised locally as a thermal energy source higher values could be achieved. Smaller plants processing to the level of the City's MSW feedstock for syngas could only anticipate 25–30% efficiency.

Gas Turbines: As per gas engines, but with efficiencies of 25–30% for gas turbines and up to 45% for combined cycle gas turbines. However, the City's waste is unlikely to ever be large enough to support such large scale plants.

Cogeneration/Trigeneration

If waste heat is able to be recovered from the electricity generation and used to supply heating and/or cooling to local end uses then the efficiency can be 75–85%.

Methanol/Ethanol

Syngas is cleaned of particulate matter, sulphur and any acidic gases. Recombining the hydrogen and carbon monoxide within syngas and using a copper-zinc catalyst process, syngas can be converted to methanol. This is another energy dense and easily transportable fuel. Energy efficiency is expected to be around 47%. With the addition of a further catalytic reaction and distillation step, ethanol can be produced as a fuel.

Synthetic Fuels and Hydrocarbons

By use of catalytic conversion, (a process known as Fischer-Tropsch synthesis), syngas can be processed into liquid fuels for transportation uses. Variations on the process can provide lubrication oils or waxes. The process relies on metals such as cobalt, nickel or iron for the catalyst. Aviation companies are investigating the feasibility for converting syngas from waste into aircraft fuel

Ammonia

The synthesis of the chemicals nitrogen and hydrogen in the syngas can generate ammonia for use as industrial applications.

Hydrogen

Syngas produced by gasification already comprises 40% (by volume) of hydrogen. Much of the remainder of syngas can be converted into hydrogen by conventional water gas shift to enable the production of pure hydrogen at a community scale on a highly competitive basis. Hydrogen will have an increasing role to play as a fuel, particularly as transport fuel for fuel cell vehicles and to supplement natural gas in the gas grid.

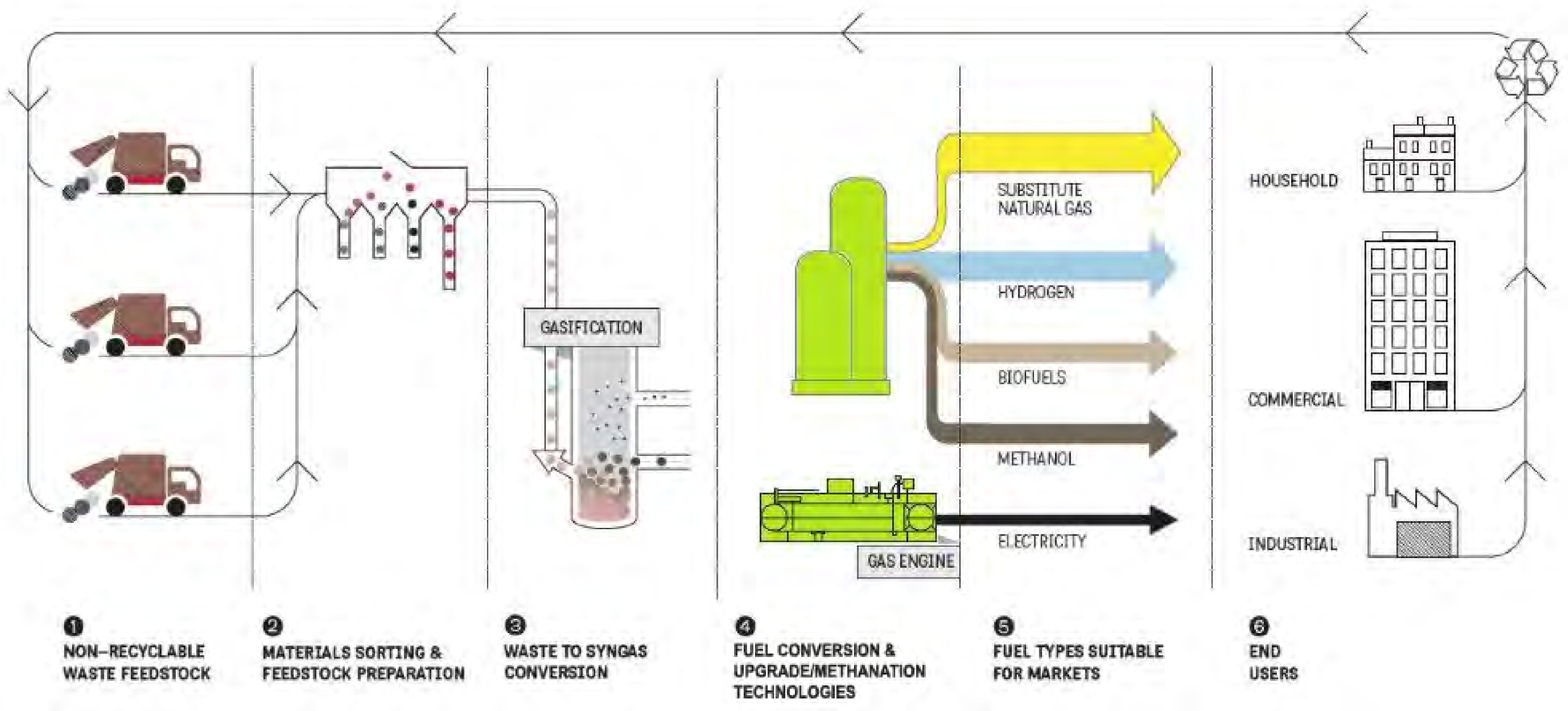
Fuel Cells for Electricity Generation

Syngas contains high levels of hydrogen that can be utilised to power hydrogen fuel cells. Hydrogen fuel cells are designed to generate electricity from reactions between the hydrogen fuel and an oxidant. Depending on the type of fuel cell used, efficiencies are between 45–70% as an electricity generator and 85% or more as cogeneration or trigeneration, generating electricity with less fuel and almost zero emissions.

However, hydrogen fuel cells can also obtain hydrogen from integrated reformers designed to reform hydrogen from natural gas or substitute natural gas derived from the gas grid.

Fuel cell cogeneration was identified as a desired longer term future energy outcome for the residential sector in the Trigeneration Master Plan.

FIGURE 41: END USE PRODUCTS FROM SYNGAS PRODUCED BY ADVANCED GASIFICATION (SOURCE: CITY OF SYDNEY)



Substitute Natural Gas

Substitute Natural Gas is produced through the methanation process, where carbon oxides (CO, CO_2) and hydrogen (H_2) react to form methane. This chemical engineering process to achieve higher levels of methane, and improved energy values, yields a gas product equivalent to natural gas that is compatible with pipeline natural gas specifications. The methanation process has an additional advantage of generating superheated steam as a result of the complex chemical reactions used. This additional thermal energy can be used for turbines , drying waste, or as an oxygen source within the gasification process (water = hydrogen plus oxygen).

After this reaction, the gas is de-humidified, compressed and injected into the gas grid. Various terms are given to this gas to differentiate it from fossil fuel natural gas, such as biomethane, bio-synthetic natural gas or synthetic natural gas, but the term Substitute Natural Gas is used in this Master Plan and the Renewable Energy Master Plan. Using advanced methanation processes efficiency can be as high as 85%.

Substitute Natural Gas can also be liquefied for tanker transport and transported to the nearest gas grid pipeline, re-gasified and injected into the gas grid.

USING RENEWABLE GAS STORAGE TO MAXIMISE RESOURCE RECOVERY

The drawback of direct use of syngas for electricity generation (or indeed, any renewable electricity generation) is that electricity once generated has to be immediately consumed. The value of electricity also varies during the day and over the week into peak, shoulder and off peak electricity tariffs. Off peak and shoulder tariff periods represent 82% of the total electricity pricing periods of which the off peak tariff period alone represent 37.5% of the total electricity pricing periods. Surplus electricity cannot be economically stored and exporting the surplus electricity receives low volatile wholesale electricity prices generally making export electricity at relatively low volumes uneconomic. These are some of the reasons why Europe and other advanced economies are converting renewable gases derived from waste into Substitute Natural Gas for injection into the gas grid instead of exporting renewable electricity into the electricity grid.

By converting syngas to Substitute Natural Gas, the surplus energy from waste can be stored in the existing gas network which has inherent energy storage. For example, the Eastern Australian Gas Market alone has an inherent energy storage capacity of 150 petajoules (PJ) or 150 billion megajoules (MJ), which is equivalent to storing 41,700 gigawatt hours (GWh) of renewable electricity, more than 90% of the entire Australian Renewable Electricity Target of 45,000GWh by 2020.

Renewable gas once generated does not have to be immediately consumed since it can be stored in the existing gas network and consumed at a later time or day of the week. The value of gas also does not vary during the day or throughout the week providing certainty for the economics of renewable gas grid injection projects. Renewable gas in the gas grid can be used for any end use of energy that fossil fuel natural gas previously supplied, such as cogeneration, trigeneration and transport or hydrogen and chemical fuel processing. The Substitute Natural Gas is simply a carrier of the energy to an end user.

Because much of the energy in Substitute Natural Gas is derived from organic or renewable sources, mixed waste provides a very much lower carbon gas supply than fossil fuel natural gas and if avoided methane emissions from landfill is taken into account a negative carbon form of gas supply.

Within the trigeneration network, its efficiency value is increased in line with the trigeneration efficiency gains for locally generated and distributed electricity and thermal energy, typically two to three times the efficiency of electricity generation only.

MATERIALS BY-PRODUCTS FROM THERMAL CONVERSION

In addition to syngas, thermal conversion processes can recover or generate by-products. This additional material recovery shows that recycling and diversion of materials can actually be extended when advanced waste treatments such as gasification are deployed, rather than simply destroyed as with incineration or lost as with landfilling.

METALS: At high temperatures, metals are turned into liquids which can be extracted. These include iron and steel, aluminium, and various lesser amounts of copper, brass, and stainless steels. Market value will be sensitive to the purity to which these materials can be refined.

SLAG: For some high temperature conversion processes any remaining materials such as ceramics, minerals, dust or inert materials are melted, fused and locked into a glassy rock substance, known as vitrified slag. Vitrified slag far exceeds minimum standards for resistance to leaching of any environmental pollutants. With minimal grinding and grading, these slag residues can be used as clean fill or as aggregate for construction material, or road base.

ASH: Even non-vitrified ash is useful as asphalt aggregate, or road base. However, it has a low financial value and often high impurities so that much of this lower grade material may still need to be sent to landfill.

WATER: Some of the reviewed technologies can generate water as a by-product for re-use in the facility. While the production of water from high temperature processes may seem unusual, it must be stressed that the processes operate by chemical conversion, so water can be recovered from the waste itself or created from reactions of hydrogen and oxygen.

CHEMICALS: Higher temperature technologies can produce recoverable levels of chemicals such as sulphur and salt.

Each by-product recovered means less waste handling, transport and less residual disposal to landfill. Markets are already well-developed in New South Wales for each potential by-product. However, the additional processing can add to the capital cost (but increase the revenue from the sale of by-products) and risk and needs assessment as part of any business case.

FIGURE 42: THERMAL CONVERSION SCENARIOS
(SOURCE: CITY OF SYDNEY BASED ON TALENT WITH ENERGY DATA)

	Feedstock											
	Process Categories											
	Inert	Hi Calorific	Mid Calorific	Low Calorific	Hazardous (separate recovery in City)	**Sizing Limit** (maximum dimension)	**Moisture Limit**	**Waste diversion***	**Material Reduction in Reactor**	**Syngas yield** (Petajoules per year, HHV)	**Energy Recovery** (cold gas efficiency, HHV)	**By products*** (from process)
Low Temperature Conversion						25-300 mm	5-40%	80-91%	80-96%	0.36-0.40	57%	Ash
High Temperature Conversion						50-150 mm	tbc	80-83%	75-90%	0.40-0.45	60%	Ash, Slag, Metals, Water
High Temperature plus ash melting						80-1000 mm	12-40%	95-96%	99%	0.42-0.50	67%	Slag, Metals, Water, Chemicals

* Reference to primary reactor only.

Additional diversion and slag could be achieved by use of secondary ash melting reactor.

THERMAL CONVERSION SCENARIOS

In order to compare the syngas generating technologies best suited for the City's objective to balance waste management and energy recovery needs, the shortlist of 16 technologies reviewed were categorised in one of three scenarios:

- The specific temperatures at which waste is treated.
- The ability of the technology to handle the waste streams.
- Syngas and by-products yield.

The conversion scenarios were:

Low Temperature Conversion (LTC)

The first scenario is modelled on conversion technologies operating at temperatures below 750°C.

High Temperature Conversion (HTC)

The second scenario is modelled on high temperature conversion technologies operating at temperatures at or above 750°C.

High Temperature Conversion + Ash Melting (HTCM)

The third scenario is modelled on the outcomes of a syngas from waste facility operating at an ultra-high temperature melting zone (above 1500°C) where minerals (ashes) and metals present in the waste stream are brought above their fusion temperature.

COMPARING THE SCENARIOS

Each scenario indicates that trade-offs exist between the diversion potential for waste, ability to handle different wastes and recovery of energy. Indicative costs of the technologies also increase as preferred outcomes are optimised.

Each technology has strengths and weaknesses to handle mixed waste. The differences are mapped against the stages of thermal conversion.

Feedstock: Waste type accepted based on the process categories.

Waste Diversion: Diversion from disposal per tonne, accounting for waste fractions such as inert or hazardous materials that may be separated, plus post-processing residual waste. The syngas generation stage is where most waste diversion occurs.

Material Reduction in Reactor: The ability of the scenario technologies to gasify materials into gas, leaving low levels of residue.

Syngas Yield: Syngas generated per tonne of waste.

Energy Recovery: Efficiency of the conversion technologies to extract the potential energy value of the waste materials. Measured as Cold Gas Efficiency (higher heating value).

By Products: Other resources recovered using the technologies that are diverted from landfill. (Indicative only -based on reference technologies).

The preferred technologies are those within the high temperature plus ash melting scenario. The level of diversion is almost total, and higher levels of syngas with a greater purity can be achieved.

The preferred technologies are those that can achieve both high diversion rates and a high yield of syngas with properties suitable for conversion to substitute natural gas and other secondary energy uses and products. For descriptive purposes, this is best exemplified within the High Temperature plus ash melting scenario.

While the use of secondary ash melting components is available for other gasification technologies, for comparative purposes only, the scenarios were principally derived from the ability of some conversion technologies to reach ash melting temperatures within the primary reactor, and in the differences in syngas quality available for conversion to substitute natural gas.

The use of secondary ash melting components to achieve high diversion results means that the market could deliver a facility to achieve a set of preferred specified outcomes, rather than limit options to a specific gasification scenario. Noting this, the Master Plan describes the preferred gasification plus ash melting scenario as comparative results against criteria being achieved in the primary reactor. This should not be considered as negating the potential for other gasification scenarios to achieve similar outcomes using alternative processes.

Eight technologies were reviewed within the high temperature plus ash melting scenario. These utilised three conversion approaches to the generation of syngas:

Pyro-Gasification plus Ash Melting

In this conversion approach, sufficient air or oxygen is used in the process to allow pyrolysis to continue, keeping the reactor temperatures high. A separate stage high temperature furnace is used to clean syngas and melt particulate matter to form a reusable slag.

Fluidised Bed Gasification plus Ash Melting

Waste is heated and broken down using a circulating ("fluidised") superheated bed of sand to ensure thorough processing of materials in the reactor. A separate stage high temperature thermal furnace is used to clean syngas and melt particulate matter to form a reusable slag.

Plasma Gasification

Waste is injected into a chamber where an electrically generated superheated plasma rapidly disintegrates the waste into syngas and is at high enough temperature to melt and fuse solids into a reusable slag.

Any of these high temperature plus ash melting conversion approaches would meet the City's objectives for waste diversion and syngas generation for energy recovery. Plasma gasification is a rapidly emerging approach for treatment of solid waste, and existing demonstration facilities have produced the best results in terms of addressing the City's objectives.

The process described in this chapter is descriptive of a high temperature plus ash melting scenario for processing solid waste from either municipal and/or commercial sources.

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RENEWABLE ENERGY RESOURCES IN MIXED WASTE

The nature of the content of the City's LGA non-recyclable waste will generate a gas from waste with high renewable energy content.

The City of Sydney LGA domestic, commercial and industrial non-recyclable waste will contribute 1.62PJ/year of Substitute Natural Gas based on plasma gasification, of which 1.04PJ/year is renewable gas and 0.58PJ/year is non-fossil fuel gas, representing 64% as renewable gas and 36% as non-fossil fuel gas of the total Substitute Natural Gas injected into the gas grid. It should be noted that non-fossil fuel gas is as much a form of repeatable energy as renewable gas.

This calculation is based on the energy values for the materials in the process categories detailed earlier in this chapter. The generation of total Substitute Natural Gas level and the proportions of renewable and non-fossil gases will depend on the waste type and gasification technology selected. Plasma gasification generates the greatest amount of syngas and therefore, Substitute Natural Gas so the calculation of the renewable and non-fossil fuel gases has been based on this technology for Master Planning purposes. The composition of materials and relative energy values in non-recyclable waste may change from time to time and Commercial and Industrial waste will tend to provide a lower renewable gas component than municipal solid waste.

FIGURE 43: RENEWABLE SYNGAS YIELD BY PROCESS FOR MSW ONLY (SOURCE: TALENT WITH ENERGY

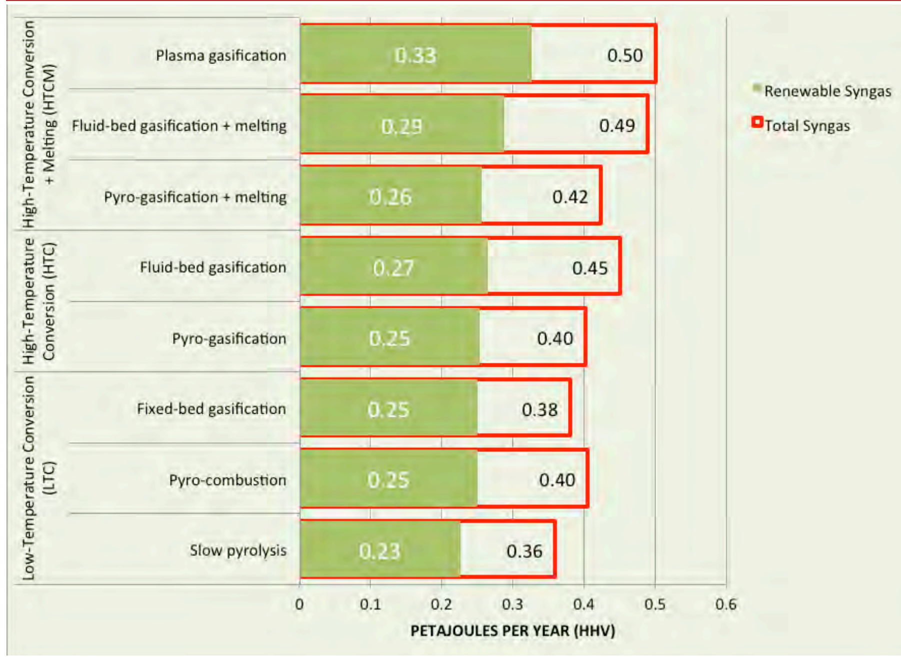
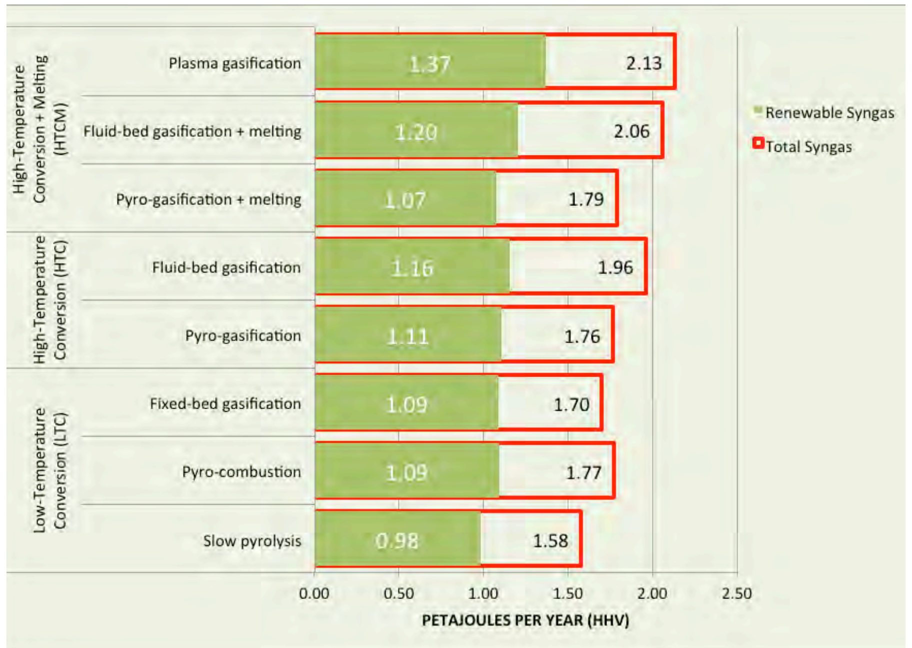


FIGURE 44: RENEWABLE SYNGAS YIELD BY PROCESS FOR MSW PLUS C&I WASTE (SOURCE: TALENT WITH ENERGY)



The renewable energy content of the feedstock, is the ratio of the combined energy content of the biomass fractions, to the total energy content of the incoming waste feedstock, both calculated on an as received, higher heating value (HHV) basis.

The renewable energy content of the feedstock, adjusted for the introduction of any non-renewable auxiliary thermal input (eg, from fuel combustion) in the conversion reactor, is used to determine the renewable energy content of the syngas generated, a key performance parameter in the analysis of renewable energy content.

COST OF CARBON ABATEMENT

The marginal social cost of carbon abatement represents the additional cost per tonne of carbon abated by installing and producing renewable energy compared to business as usual energy over the lifetime of the technology. Energy from coal fired power stations receive many hidden government subsidies such as discounted coal, coal terminal lease fees, providing infrastructure so that coal can be transported to electricity generators or to port loading facilities, rail upgrades, avoidance of the NSW waste levy for the landfill of coal ash, tax credit on diesel fuel for coal trucks and machinery.

The carbon abatement costs are calculated using a base unit of carbon reduction over the life of the technology. Those technologies that deliver the greatest outcomes at the lowest cost of carbon abatement can then be prioritised.

The cost of carbon abatement improves the business case for those technologies that generate both electrical and thermal energy, particularly where the thermal energy at end use is able to offset emissions from intensive electricity use (such as electric air conditioning, hot water systems and induction heating).

The greatest abatement over the period to 2030 will occur for technologies, particularly non intermittent technologies, which can be installed in the near to medium future. These technologies will offset grid gas and/or electricity at current emission intensities currently dominated by fossil fuel technologies which are likely to be phased out by market forces.

Estimating the cost of abatement into the future is based on many assumptions. For example, trigeneration fuelled by renewable gas derived from waste may include full retail prices factors for their output electricity and thermal energy compared to the alternative low wholesale electricity rates that renewable electricity derived from waste could obtain if exported into the electricity grid rather than the gas grid.

However, it should be noted that advanced economies such as Germany, UK, Denmark, California and others have achieved far higher levels of renewable energy penetration than Australia on the back of energy policy not carbon pricing or emissions trading. Also, the cost of renewable energy technology is likely to decrease, whereas fossil fuel generated electricity is likely to increase.

FINANCIAL INCENTIVES

RENEWABLE ENERGY CERTIFICATES

Fossil fuel generation has a regulatory framework that supports large scale fossil fuel power stations on a centralised grid. This regulatory framework creates regulatory barriers to smaller scale decentralised renewable energy technologies which makes it difficult for renewable energy technology to compete on cost alone.

The Commonwealth Government has a Renewable Energy Target (RET) of 20% of electricity to be supplied by renewable energy by 2020 to improve the financial viability of renewable energy.

Revenue can be generated from producing renewable energy through large-scale generation and small-scale technology certificates. However, the certificates are forecast to decrease beyond 2020. 1 REC is equal to 1 MWh of electricity generated from renewable sources.

1 ADVANCED WASTE TREATMENT
2 RE-THINKING WASTE AS A RESOURCE
3 ADVANCED WASTE TREATMENT FOR THE CITY OF SYDNEY
4 PERFORMANCE MEASURES
5 ENABLING THE MASTER PLAN
6 CASE STUDIES

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FEED-IN TARIFFS
A well designed feed-in tariff has the ability to rapidly expand the uptake of renewable energy technologies at a marginal cost to society, as seen by the massive uptake of solar and renewable gases in Germany which has resulted in lower overall bills in part due to the merit order effect whereby network peak events (when energy prices are highest), are minimised.

Australia has installed more than 2 million small-scale renewable energy systems in the last five years with a capacity to displace approximately 6,882 GWh of electricity annually, equivalent to the electricity supply to over 1.25 million homes for a year, enough electricity to power Perth, Hobart, Darwin and Canberra combined. Of these installations, more than 1 million households in Australia now have solar energy systems installed, investing more than $6 billion of their own money in renewable energy, indicating strong public support for renewable energy.

Poorly designed feed-in tariffs are not a cost effective or sustainable way of implementing renewable energy which increases electricity bills for all electricity consumers and be prone to sudden changes in policy. The tariffs also fail to target the non-intermittent or mix of renewable energy technologies that are needed for renewable energy to replace fossil fuels. A better management approach may be to eliminate the "red-tape" preventing the appropriate accounting of renewable energy in gas to the same level as the renewable energy in electricity. This flexible approach can possibly eliminate the need for feed-in tariffs of any design.

REGULATORY REFORM FOR RENEWABLE GASES DERIVED FROM WASTE
Neither Australian nor NSW Governments have established a 20% renewable gas target yet similar to the 20% renewable electricity target in the Renewable Electricity target. Also, with the exception of Victoria, the current gas regulations do not provide for gas purchase agreements between renewable gas generators and customers. A national accreditation program for GreenGas similar to power purchase agreements and GreenPower for renewable electricity does not currently exist.

A regulatory regime for renewable gases should be developed to remove the regulatory barriers to renewable gases and to enhance the financial, security of supply and greenhouse gas performance of cogeneration, trigeneration, district heating/cooling and transport fuelled by renewable gases.

The City has made formal submissions to Australian and NSW Governments for regulatory reform of the Gas Act and meetings have been held with the regulators on the City's proposals.

The regulatory regime for renewable gases should be designed to ensure that renewable gases are preferentially used to supply decentralised energy (cogeneration, trigeneration and fuel cells), renewable heat and transport applications to maximise the efficiency and reductions in greenhouse gas emissions of the renewable gas market. The preference for renewable gases in highly efficient energy generation systems is borne out by analyses showing large gains in greenhouse gas reduction for uses other than immediate electricity generation (see Figure 68: Greenhouse gas emissions savings)

In order to support this, regulatory reform should also ensure that renewable gas is treated differently to and incentivised over fossil fuel natural gas. Renewable gas should be granted preferred network access to the gas grid, preferred network entry by gas grid operators and extended accounting balance for transport applications to stimulate the renewable gas market.

CLEAN ENERGY ACT 2011
The Australian Renewable Energy Agency (ARENA) was created by the Act to consolidate the existing government programmes for renewable energy into a single body. ARENA's $3.2 billion in funding is legislated and extends out until 2022 providing long term funding and policy certainty for industry. Around $2 billion of ARENA's funding is currently uncommitted and available for ARENA to invest in accordance with its functions and powers. However, with the election of the Coalition Government $150 million from ARENA's funding will be directed to the million solar roofs program.

The Clean Energy Finance Corporation (CEFC) is the other main renewables initiative in the climate change package. It will use publicly provided money to drive renewable energy and energy efficiency projects, investing where private sector investors are not willing to invest. The CEFC has a $10 billion budget over five years. Half of the CEFC's budget is set aside for investment in 'the commercialisation and deployment of renewable energy and enabling technologies'. The CEFC has so far invested $500 million in projects worth $2 billion. However, the Coalition Government plans to abolish the CEFC as part of its Direct Action policies.

At least one of these initiatives will support the increased take up of renewable energy, particularly for innovative technologies such as renewable gases from waste conversion.

BETTER BUILDINGS PARTNERSHIP

The Better Buildings Partnership was launched by the Lord Mayor, City of Sydney on 30 June 2011 along with founding members: AMP Capital Investors, Brookfield Office Properties Australia, Charter Hall, City of Sydney, Colonial First State Global Asset Management, DEXUS Property Group, Frasers Property, The GPT Group, Investa Property Group, Lend Lease, Mirvac, Stockland, the University of Sydney, and the University Technology Sydney.

These founding members have since been joined by the Sydney Harbour and Foreshore Authority, and TAFE Sydney Institute, by organisations engaged in building and property management Jones Lang LaSalle, CBRE, Knight Frank and Colliers International, and by key policy advocates and government departments the Green Building Council of Australia, the Property Council of Australia and the NSW Office of Environment and Heritage.

With the Better Buildings Partnership representing over 50% of the office floor space across the City of Sydney LGA, these commercial landlords have an important role to play in improving the energy, water and waste efficiency of Sydney's existing buildings.

The Better Buildings Partnership 2012/13 Annual Report, showed that the Partnership had exceeded its emission reduction targets of 24% from the Sustainable Sydney 2030 baseline of 2005/06 of 310,024 tonnes of CO_2 for its commercial office portfolio.

The Partnership commercial office portfolio consists of 94 reporting assets, a total of 2.5 million square metres of office space in the City of Sydney LGA worth over $30 billion. The average emissions intensity of the portfolio is 88kg CO_2/m^2 a year, 42% less than the market average for building intensity, demonstrating the importance of environmental sustainable development to the Partnership members.

Better Buildings Partnership members have identified two priorities relevant to waste generated in buildings: the operational (daily) waste that goes to landfill and the minimisation of waste that occurs during commercial tenancy fitout works.

The City's strategic objectives for the Advanced Waste Treatment Master Plan provide the additional step in the waste hierarchy of energy recovery before landfill. This offers the City and its partners a meaningful and relevant option after recycling to increase diversion of waste by a commercially practical means.

A well located facility would offer benefits that suit the waste strategies of many in the Partnership. The impacts of transport would not increase, yet competitively priced waste processing for early adopters offers increased diversion of waste together with a closed loop return of substitute natural gas to the City. The City's business sector will be encouraged to take advantage of reducing greenhouse gas emissions by avoided landfill and the uptake of a source of renewable energy delivered through existing infrastructure.

NSW ENERGY FROM WASTE POLICY STATEMENT

The NSW Energy from Waste Policy Statement is currently out of step with recovery performance from available advanced waste treatment technologies and processes in Europe, North America and Asia.

In terms of delivering for NSW the best available technologies for recovering energy from waste, the Policy does not sufficiently demarcate between the options for incineration of waste and the increasing international use of conversion by thermal treatment of waste into a wholly or partially renewable gas. The use of waste as an incineration fuel is not an efficient and effective recovery of the energy resource within waste. Conversion of waste to a gas with measurable renewable energy content is a far more commercially flexible and environmentally better and safer option.

The Policy restricts eligible levels of waste for energy recovery on the basis of a Council's bin configuration which is unnecessarily prescriptive and counter-productive in avoiding waste going to landfill. Similar restrictions apply for permitted eligibility levels of commercial waste. Defining the eligibility of waste as feedstock is therefore not yet consistent within the draft Policy itself. The eligible levels defined are arbitrarily low and may lead to unnecessary disposal of material fully suited to energy recovery. In attempting to reinforce the recycling tier of the waste hierarchy, there is not sufficient emphasis on supporting energy recovery as a tier of the waste hierarchy preferable to landfill disposal.

In contrast, the Western Australian and Victorian energy from waste policy principles and settings have instead been based around licencing of energy recovery facilities. This approach sets strict controls for the output emissions from energy recovery facilities, while still allowing facilities to utilise waste feedstocks available in accord with the provisions of the waste hierarchy.

Notwithstanding this, the City considers this Master Plan can accommodate the technical, thermal and resource recovery criteria of the Policy, and welcomes that the Policy settings have been provided prior to the full emergence of the energy from waste sector in NSW.

The City intends to meet the Policy settings by

- approaching the NSW EPA for guidance on the waste loads that can be permitted to a facility given the unique characteristics of the City compared to many other Councils in NSW.
- engage with nearby Councils as part of the SSROC Regional Waste Strategy to increase available waste levels for energy recovery.
- continue to inform and engage its business community through the Better Buildings Partnership on energy recovery opportunities.

Given the inconsistencies between jusrisdictions resulting from the NSW Policy approach, The City would prefer to see a National Energy from Waste policy that encourages the highest level of energy efficiency and recovery, rather than arbitrary feedstock control. This should permit the best available technologies to be introduced where need is highest, and not where policy settings are less restrictive.

Limitations by Council bin systems and restrictions on feedstock will not alter any of the expected environmental outcomes for energy from waste technologies, meaning the best environmental approach for energy recovery should still be addressed.

DRAFT NSW WASTE AVOIDANCE AND RESOURCE RECOVERY STRATEGY 2013–21

Although the City, in principle, welcomes the review and replacement of the draft *NSW Waste Avoidance and Resource Strategy 2013–21* it is disappointing that the targets within the draft Strategy still project 25–30% of waste generated in NSW to be lost to landfill after another eight years of action. The draft Strategy fails to adequately explain why such a high level to landfill is acceptable given the best available technologies and techniques available in modern waste management.

The Master Plan sets a preference for diversion of waste including recycling at the level of 95%. The objective of diversion of waste is consistent with the Regional Waste Strategy.

The draft *NSW Waste Avoidance and Resource Recovery Strategy 2013–2021* remains in draft-only at the date of this report to Council. The City provided a submission to the NSW EPA on the draft strategy in October 2013. The City acknowledges the draft targets set out in the proposed strategy, noting however that these may be altered within the final released version.

The City further notes that these are specifically state-wide targets calculated from NSW total waste generation. The targets are not intended to be binding on any individual council, although the City intends to significantly contribute to the state targets (as finalised).

In particular, the draft Strategy makes no direct provision for addressing greenhouse gas emissions arising from waste management. The draft Strategy abandons a meaningful use of "resource recovery" and separates this into two elements: recycling and diversion of waste from landfill. While a distinction is useful, an almost exclusive focus within the draft Strategy on recycling of materials as the means to resource recovery fails to capture the full environmental and economic value of recovering all resources, including renewable energy, from a waste stream.

The recovery of energy resources is measured within the draft Strategy only in terms of "diversion of waste" from landfill. By restricting energy recovery measures to this indicator, demonstrates a lack of understanding of the potential value of energy recovery in terms of environmental benefits and economic value.

In the absence of maximising the full value of the resource chain from waste and achieving the best environmental and economic outcomes, the City submitted a number of amendments or inclusions to the draft Strategy that will improve its effectiveness and allow NSW government to achieve far higher targets than it has so far nominated.

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SECURING A RENEWABLE GAS SUPPLY FOR THE CITY

Advanced waste treatment to generate an energy rich renewable gas can help solve three of the most urgent challenges facing cities today, those being:

- finding less polluting sources of non-intermittent renewable or repeatable energy;
- reducing greenhouse gas emissions;
- diminishing landfill space; and
- managing waste responsibly for the longer term environmental improvement.

The value to the City of securing localised renewable energy production is significant.

Energy from waste is ultimately recovered as a resource by using it to generate other useful forms of energy such as gas or electricity and/or heat. A means to bring that energy back into the City will create a closed loop for recycling waste into renewable energy for local residents and businesses.

There is sufficient renewable gas resource derived from waste within 250km of the City of Sydney LGA to replace not only the fossil fuel gas supplying the planned trigeneration network but also to supply the residential fuel cell cogeneration and existing domestic gas for heating and cooking.

Historically, most gasification facilities utilise the syngas onsite for electricity generation and export to the electricity grid. However, there is a growing trend in Europe for syngas sourced from biomass and waste to be converted to Substitute Natural Gas and injected into the existing gas pipeline network.

This renewable gas effectively decarbonises the existing gas grid in the same way that renewable electricity decarbonises the electricity grid. If this is achieved locally it will reduce the greenhouse gas emissions across a broad energy storage and supply network for the City of Sydney.

The City has already identified the planned trigeneration network in the Trigeneration Master Plan as one of the main carbon reducers for the city reducing greenhouse gas emissions across the entire City of Sydney by up to 32%. That Master Plan identified a series of low carbon infrastructure zones and 'hot spots' across the City that had intensive energy demand and would benefit most if provided with low carbon thermal energy derived from decentralised energy generation. However, this is on the basis of supplying the trigeneration network with fossil fuel natural gas which, although low carbon, is still a fossil fuel. Together with renewable electricity generation, replacing fossil fuel natural gas with renewable gas derived from waste would reduce greenhouse gas emissions from trigeneration and renewable energy by 70.4% by 2030 as detailed in the Renewable Energy Master Plan.

In terms of renewable gas resource and supply this Master Plan is a sub-set of the Renewable Energy Master Plan but there is an additional 5.2% reduction in greenhouse gas emissions from avoided landfill methane emissions with this Master Plan increasing the reduction in greenhouse gas emissions to potentially 75.6% below 2006 levels by 2030, exceeding the 70% reduction in emissions target in Sustainable Sydney 2030 with all three Decentralised Energy Master Plans working together.

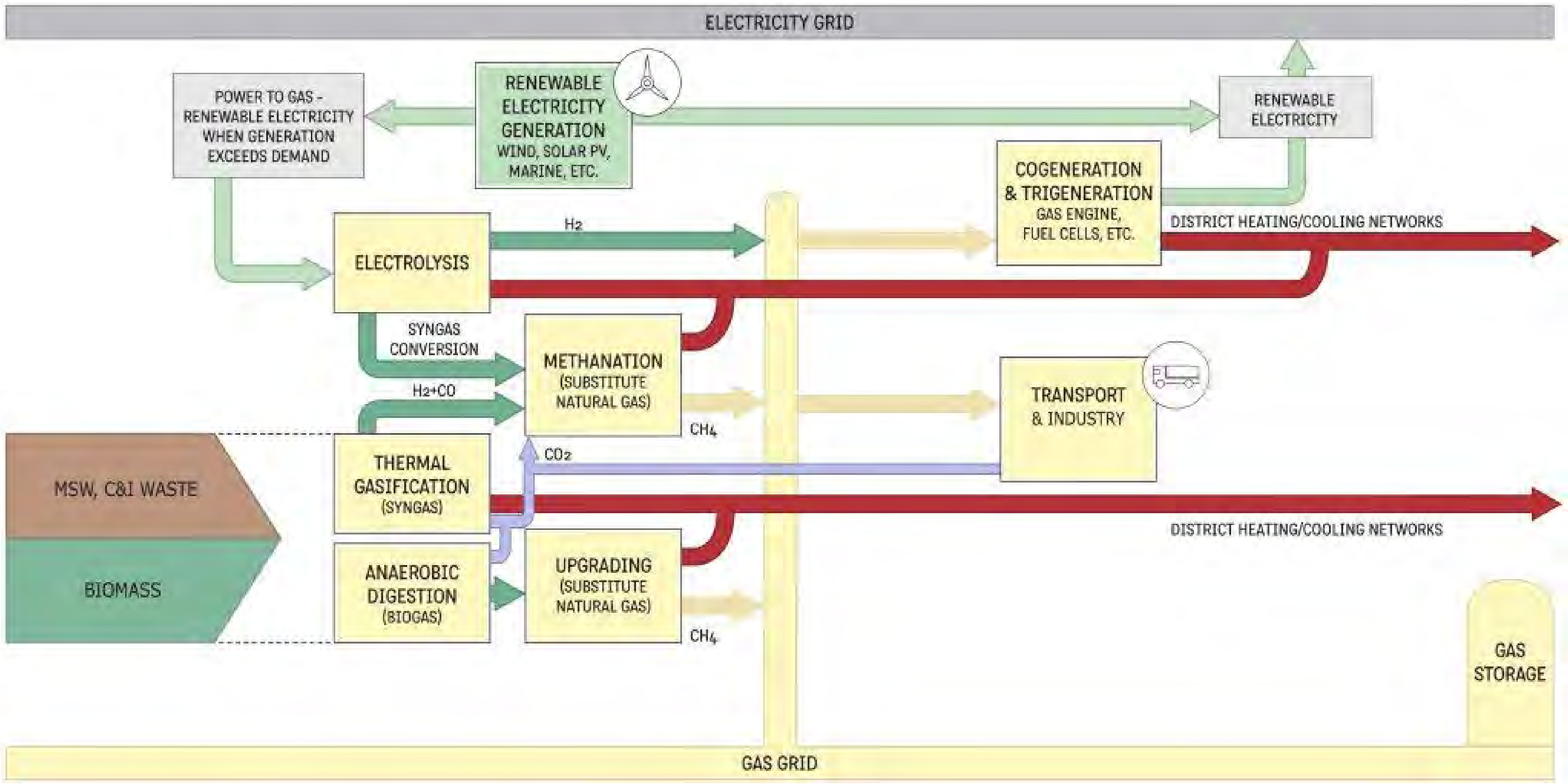
INTEGRATED 100% RENEWABLE ENERGY SYSTEM

Both this Advanced Waste Treatment Master Plan and the Renewable Energy Master Plan researched advanced waste treatment and renewable energy best practice, the mix of renewable energy resources, and the technologies deployed for extracting renewable energy from waste. This is important to understand how other countries are overcoming the intermittency of renewable energy generation in delivering a 100% renewable energy future.

The integrated smart grid system being developed by advanced economies in Europe shows how electricity, heat and gas can be integrated to provide a 100% non-intermittent renewable energy system. Renewable gas developed from waste converted into substitute natural gas and injected into the gas grid, the use of 'power to gas' technologies for surplus renewable electricity from intermittent renewable electricity generation technologies such as solar and wind converted into renewable hydrogen or renewable gas and injected into the gas grid and heat recovered from decentralised electricity generation for supplying heating and cooling are key features of such a system.

A key reason why renewable electricity is converted into renewable hydrogen or renewable gas for injection into the gas grid is that transporting electricity is 20 times more expensive than transporting the same amount of energy via a gas pipeline. Existing gas grids also automatically provide low cost energy storage.

FIGURE 45: HOW RENEWABLE ELECTRICITY, HEAT AND GAS CAN BE INTEGRATED TO PROVIDE A 100% NON-INTERMITTENT RENEWABLE ENERGY SYSTEM (SOURCE: CITY OF SYDNEY)



ADVANCED WASTE TREATMENT FOR THE CITY OF SYDNEY

ADVANCED WASTE TREATMENT FOR THE CITY OF SYDNEY

This Master Plan identifies the conversion of the city's non-recyclable waste into a renewable content gas as the optimal long-term waste solution for the City of Sydney.

This is a flexible energy recovery solution that aligns with the City's Renewable Energy and Trigeneration Master Plans. It forms part of the City's ongoing commitment to divert waste from landfill and reduce greenhouse gas emissions.

This Master Plan sets out how the City can create renewable gas from waste using an advanced gasification process. This recovers energy resources in addition to material resources from waste, resulting in almost zero waste to landfill.

Energy recovery using gasification is highly flexible in its usage and allows for multiple options along a staged process. The Master Plan integrates resource recovery from waste with a sustainable energy solution.

This integrated waste and energy planning system will help to deliver a 70% reduction in greenhouse gas emissions based on 2006 levels, by 2030.

The City's high density urban form requires innovative and advanced forms of waste treatment that can successfully deliver significant waste diversion outcomes without additional pressure on available land, transport, and living space, and yet still provide the ability to close the loop for returning resources from that waste to the City.

The City has already sought out the best available waste treatment for its current needs. This Master Plan reviews the options for increasing the environmental benefit to the City from waste treatment, by not settling for just material recovery alone but to additionally harness the resources in waste that can deliver against one of the City's most valuable environmental measures: renewable energy.

For Sydney, the shift to renewable energy will not be a simple case of installing technology in the city. A self-sufficient 'renewable energy city' becomes part of the ecosystem of how a sustainable city functions. Part of the challenge is successfully adding acceptable renewable energy technologies to urban environments.

Sydney has less suitable physical climatic conditions, less land available, urban form restrictions, and fewer resources to tap into for conventional renewable energy technologies such as solar and wind than in regional areas of NSW. This impacts the technical performance and the suitability of some renewable energy technologies such that conventional renewable energy means cannot achieve 100% of the city's energy demand.

Instead, there is a need to lead a shift in mindset to becoming an innovative and more sustainable Australian city by generating renewable energy by less conventional renewable energy technologies and resources. Recovering renewable gas from waste feedstocks can help overcome these urban environment constraints while still only drawing on unrealised energy resources available in the city.

The advanced waste treatment technologies in this Master Plan will provide a transformative, clean and reliable waste treatment and renewable energy solution to the City of Sydney's Local Government Area, with significantly higher diversion of waste from landfill and lower greenhouse gas emissions than current waste treatment.

The solution can be implemented at a cost that is practical and affordable when compared with current and future (by 2030) waste treatment costs and the social costs of existing and other renewable energy generation and supply systems. It also provides a solution that is capable of generating renewable gas for of quality and quantity for meeting proposed trigeneration and other on-demand renewable electricity generation.

RENEWABLE GASES FROM WASTE AND BIOMASS WITHIN AND BEYOND THE CITY OF SYDNEY LGA

The City of Sydney resolved on 18 June 2012 that by 2030 renewable gases from waste and other renewable energy sources will replace fossil fuel natural gas in the proposed trigeneration systems enabling them to provide carbon free electricity as well as carbon free thermal energy for heating and cooling in addition to the City's 30% renewable electricity target.

Renewable gases can be converted into substitute natural gas that can displace natural gas in the proposed 372 MWe trigeneration decentralised energy network or even the full trigeneration/cogeneration network as well as domestic gas used for domestic heating and cooking across the City of Sydney's LGA.

Existing options for waste treatment and disposal are becoming increasingly expensive owing to their high dependence on landfill disposal of unrecovered material post-processing. The use of recovered organic material from mixed waste as a low-grade soil replacement with single use only applications may also prove to be far less than sustainable over time.

It is anticipated that the increasing cost of waste disposal will drive the renewable gas market to a point where advanced waste treatment technologies will become more economic and sustainable.

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In places where the City of Sydney has operational control, such as the City's own waste, the fuel conversion process will be able to be controlled by the City or its project partner(s) to maximise the renewable gas produced.

With many advanced gasification processes now mature, the trend worldwide is to use energy from waste for gas production for offsite use via the gas grid rather than exporting electricity into the electricity grid. Displacing natural gas with renewable gas for the City's proposed trigeneration network would make a significant contribution to reducing greenhouse gas emissions. It would also assist to make the City of Sydney energy independent with an alternative source of renewable electricity, heating and cooling.

WHAT IS THE MASTER PLAN PROPOSING?

This Advanced Waste Treatment Master Plan sets out the technical options for the City of Sydney to improve the long term sustainability of its waste management needs, while providing a renewable energy recovery solution integrated with the targets of the Trigeneration and Renewable Energy Master Plans.

This Master Plan proposes a different approach to existing practice in Sydney waste management, in three main ways:

- Recovering both material and energy resources from waste with virtually no waste going to landfill;
- The conversion of non-recyclable waste to renewable and non-fossil fuel gases; and
- The conversion of the renewable and non-fossil fuel gases into substitute natural gas for injection into the gas grid for lower carbon energy delivery, including to supply the City's planned trigeneration network.

The Renewable Energy Master Plan set out the size and availability of renewable energy resources needed to meet the City of Sydney LGA energy and climate change targets and the potential investment required.

A first objective was to determine how much of the City's 30% renewable electricity target could come from within the local government area. The Renewable Energy Master Plan showed that up to 18% of renewable electricity generation could be met from within the City's LGA and at least 12% of renewable electricity generation could be met within 250km of the City's LGA.

A second objective was to determine whether there was enough renewable gas resource to replace fossil fuel natural gas to supply the proposed trigeneration network. The Renewable Energy Master Plan showed that there was more than enough renewable gas resource within 250km of the City's LGA to not only replace 100% of the fossil fuel natural gas needed for the proposed trigeneration network as well as domestic gas supplying heating and cooking.

This Advanced Waste Treatment Master Plan informs these objectives of the Renewable Energy Master Plan setting out the renewable gas resources and technologies for the City of Sydney LGA's own domestic, commercial and industrial waste available within the City's LGA.

A key element of the proposed advanced waste treatment is thermal or advanced gasification which can convert both the organic and the inorganic fractions of waste into a sustainable synthesis gas or syngas.

Any of the high temperature plus ash melting gasification technologies would meet the City's objectives for waste diversion and syngas generation for energy recovery, with plasma gasification offering the highest outcomes in this category within the Gasification Technology Review.

The expanded recovery of resources from waste to include renewable gas is in addition to existing recycling and recovery approaches. The City's Interim Waste Strategy adopted the view that waste is a resource, and not a liability.

The key is to extract the full economic and environmental resources from waste and return these to the economy at the most viable level, while delivering environmental benefit. Recycling of materials that does not return materials to the economic cycle they were produced from, either because of lack of market demand or through re-direction to lower cycle uses ("down-cycling") may not meet these resource recovery criteria.

Injecting, storing and utilising the renewable/non-fossil gas recovered from non-recyclable waste in the gas grid will replace fossil fuel natural gas with a non-intermittent form of renewable energy recovering up to three times the primary renewable energy resource than electricity generation alone. Similarly, renewable gas grid injection will reduce greenhouse gas emissions by up to three times as much than renewable electricity generation alone. Advanced waste treatment will therefore, use waste as a valuable resource and not as a pathway for waste disposal or destruction.

Converting renewable and non-fossil fuel gases into a substitute natural gas and injecting the gas into the existing gas grid provides low and zero carbon fuels for end use in the City, such as the City's planned trigeneration network and domestic gas uses. Advanced waste treatment ultimately provides an "energy from waste" solution for the City that

- Virtually eliminates waste going to landfill;
- Generates renewable and sustainable sources of energy;
- Reduces greenhouse gas emissions by displacing fossil fuels and avoiding landfill gas emissions; and
- Reduces environmental impacts from the City's waste.

The City's planned trigeneration network will encourage growth in the a market for renewable and non-fossil fuel gases to replace fossil fuel natural gas in the gas grid. Renewable gas feedstocks from waste both inside and beyond the City's LGA were identified in the Renewable Energy Master Plan.

This Advanced Waste Treatment Master Plan identifies the waste feedstock resource that can be converted into renewable and non-fossil fuel gases for conversion into a substitute natural gas via a methanation process for injection into the gas grid for use in supplying the City's planned trigeneration network and for domestic gas purposes in the City's LGA.

The concept of developing a market for renewable gases injected into the gas grid for supplying cogeneration/ trigeneration networks, district heating and cooling or for transport applications is not new to Europe but is new to Australia and offers a highly efficient closed loop recovery of resources in the market for advanced energy from waste technologies.

The proposed high temperature gasification with a substitute natural gas methanation process will provide a high level of export of the energy resource in non-recyclable waste.

DETERMINING THE IDEAL SOLUTION FOR THE CITY

The key to the City's integrated waste and energy infrastructure approach is to find a technology that best optimises a balance between a maximum waste diversion objective and an optimal delivered renewable energy solution, with low environmental impact in comparison to landfill. Gasification technologies offer that balance.

The City will be seeking a solution for an advanced waste treatment facility primarily for treating the City's own domestic, commercial and industrial waste. Advanced gasification technologies are small scale when compared to energy from waste incineration facilities and can be built up in modules over time to match the growth of the residual waste resource by 2030. The advanced waste treatment facility can be combined with recycling facilities or separately located but should be sited close to good transport links and the gas grid.

The City's proposed recovery of syngas from waste will utilise existing and demonstrated gasification technologies.

The City has reviewed thermal conversion technologies that produce clean syngas to benchmark performance. These facilities demonstrate that the technical ability to convert mixed wastes to syngas exists, producing sufficient levels of syngas that can be converted to Substitute Natural Gas for injection into the gas grid and exporting the renewable gas for end use energy consumption in the City's planned trigeneration network and other end-uses can be delivered within regulated emissions limits.

To provide net renewable energy and reduction in greenhouse gas benefits the advanced waste treatment facility must produce more renewable energy than it consumes in the treatment process. It must be a net exporter of energy, and not a net energy consumer. The analysis of gasification technologies based on the composition of the City's waste shows that a substitute natural gas with around 65% renewable content can be achieved.

Gasification also provides the highest level of diversion of waste from landfill of the advanced waste treatment technologies reviewed. These levels are sufficient to meet the requirement for 90% diversion of waste from landfill from advanced waste treatment set out in the Interim Waste Strategy.

To adopt this technology will require not only understanding and evaluation of technology, but community support for this approach. Internationally, communities have accepted these technologies, and in major cities such as Copenhagen, Gothenburg, London, Shanghai, Seoul and Tokyo, these facilities are sufficiently accepted to be integrated into urban areas. The City has sought, and will continue to seek, community views on which approaches to recovering energy from waste will meet with acceptance and provide understanding and trust of the process.

Assurances regarding what the technology can deliver in benefits both financially and environmentally will be necessary, but so will greater certainty over the criteria for locating a facility.

The City has also undertaken reviews of the essential factors that will contribute to the successful location of a facility. This will offer the community and the City security that a facility addresses and meets the technical constraints of the technology.

Overall, transport movements should be reduced providing a suitable site in proximity to the City is achieved, and since the gasification facility outputs such low levels of waste almost no secondary haulage to remote landfill sites will be required.

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A NEW APPROACH TO ENERGY FROM WASTE

Gasification technologies are more typically designed to utilise syngas on the same site by using fully integrated electricity generation. Historically, the thermal conversion of waste provides syngas simply as an intermediate pathway to the generation of electricity. Any electricity generated is distributed to energy markets via the electricity grid.

The City instead proposes to make use of available technologies for syngas conversion via the 'methanation process to a Substitute Natural Gas (SNG).

By converting syngas to Substitute Natural Gas (SNG) using the 'methanation' process, the City can utilise the existing gas grid infrastructure to transport and deliver renewable gas to the City of Sydney LGA, without the poor energy conversion to electricity generation only and the high transmission and distribution losses of the electricity grid infrastructure. By recovering the energy content in waste and converting to Substitute Natural Gas it can be utilised and/or stored in the gas grid for efficient, optimal and non-intermittent use of renewable energy in the form of a renewable gas supplying energy efficient end-use demands such as cogeneration, trigeneration, district heating/cooling and transport applications rather than generating electricity only which would lose most of the renewable energy content in the waste.

By injecting Substitute Natural Gas into the gas grid, gas can be delivered with the highest renewable energy content from waste to supply the planned trigeneration network as set out in the Trigeneration and Renewable Energy Master Plans. Notwithstanding its use as a renewable gas supplying the planned trigeneration network, renewable gas will also reduce the carbon intensity of the existing gas grid.

In standard thermal conversion treatment facilities, the gas generation and electricity production are closely coupled. Syngas can be combusted with minimal cleaning or cooling to provide heat to generate steam used in electricity generating steam turbines. In some instances, syngas combustion is performed within the same reactor chamber as the gasification step. Either approach means that any additional step of converting syngas to gas grid pipeline quality gas can be avoided.

The generation and distribution of energy from closely integrated electricity generating systems can be well below optimum for energy recovery.

The energy stored in the syngas is mostly used to heat water to raise steam to generate electricity through a steam turbine. This operates at 15–25% efficiency for energy conversion to electricity. The facilities combusting syngas are not typically optimised for location based on energy demand, meaning that the electricity must be transmitted and distributed to remote end-users across the electricity grid. In NSW, the electricity grid transmission and distribution grid losses are 10% so the quantum and value of exported electricity is reduced further, quite apart from the poor time of day wholesale electricity prices as detailed in Chapter 2 of this Master Plan.

Close coupling of the gas and electricity production also means that the facility must provide a full suite of air pollution control systems at the site to clean the exhaust from the energy generating system.

The City will essentially replace this final step with a gas clean-up and methanation process to convert the clean syngas to Substitute Natural Gas. This means that the generation of energy from waste and any associated emissions does not take place at the Advanced Waste Treatment site as the Substitute Natural Gas is injected into the gas grid and any on-site energy requirements or parasitic energy demands will be supplied by Substitute Natural Gas "behind the meter" and will be much smaller and of a value similar to natural gas generation.

Given that less external air has been added to the syngas, if it is not combusted on site, then the clean-up and methanation process will be made simpler and more efficient. This also means that there would be minimal requirements for air pollution control and exhaust stack at the gasification facility itself.

The City's approach to energy from waste will therefore be to utilise suitable technologies to:

- Maximise the diversion of waste requiring final disposal;
- Generate syngas;
- Refine and process the syngas using methanation into gas pipeline quality gas (ie, Substitute Natural Gas); and
- Inject the Substitute Natural Gas into the gas grid and use the gas grid as an energy carrier to supply renewable gas for end-use energy demands such as cogeneration, trigeneration, district heating/cooling and transport applications to maximise the energy efficiency and carbon reduction gains of the process.

CITY OF SYDNEY LGA TRIGENERATION NETWORK

The City is developing a potential trigeneration network for the Town Hall precinct which is currently at design stage. Other trigeneration precincts will be developed by others, although the City may be involved in enabling these networks in terms of facilitating thermal energy networks between buildings within the precincts.

The City's first priority for renewable gas supply from the Advanced Waste Treatment facility will be to replace fossil fuel natural gas for its own trigeneration projects in the course of development and its existing gas demand. The City's second priority for renewable gas supply will be to replace fossil fuel natural gas supplying other trigeneration networks or domestic systems in the City of Sydney LGA followed by cogeneration, district heating/cooling and transport applications. Trigeneration distributes electricity, heating and cooling to local precincts, at around 85% energy efficiency.

The City's total annual gas consumption plus the estimated annual gas consumption of the City's planned Town Hall precinct and Aquatic Centres trigeneration systems would amount to about 0.2PJ/year so would be more than met by the 1.62PJ/year of renewable and non-fossil fuel gas produced by advanced gasification from the City's non-recyclable or residual waste. In other words, the City's proposed advanced waste treatment would replace 100% of the City's existing and planned fossil fuel gas consumption with renewable gas via the existing gas grid with the majority of the renewable and non-fossil fuel gas produced left over to supply more than half of the City of Sydney LGA current gas consumption. This includes existing trigeneration in the City of Sydney LGA amounting to 12.9MWe of trigeneration capacity over 12 sites.

Renewable gas replacing fossil fuel natural gas supplying trigeneration will reduce greenhouse gas emissions by a further 19.3% and 5.2% for displaced fossil fuel natural gas and avoided methane emissions at landfill sites, respectively, increasing the reduction in greenhouse gas emissions across the entire City of Sydney LGA by up to 57.4% below 2006 levels.

THE CITY'S PROPOSED ADVANCED WASTE TREATMENT

Collection
Mixed waste will be collected in the same way as currently, including source separation of recycling, and programs to reduce hazardous materials in the waste stream.

Source Separated recycling
Source separated recycling will be delivered to dedicated recycling facilities. For gasification processes, improved source separated recycling will improve gas quality and quantity.

Materials Sorting and Feedstock Preparation
MSW and any C&I waste will be delivered direct to the AWT facility pre-processing area. A sorting stage will remove inert or hazardous material unsuitable for gasification. Any metals or other nominated materials can be separated for recovery. Acid-making materials such as PVC can be removed using optical sorting technology.

This step could be conducted off-site from the gas generating facility, with delivery of waste pre-processed to specification.

Materials are reduced in size by shredding. This reduction allows more surface area to be exposed in the conversion reactor. As conversion process temperatures increase, less pre-processing is required.

The material may also be partly dried to reduce or standardise moisture levels that might otherwise lower the heating value in the conversion reactor.

High Temperature Gasification with Ash Melting
Processed materials are fed into the conversion chamber. Depending on the technology, they will be exposed to temperatures between 850 and 6,000 degrees. The high temperature drives a thermal chemical conversion, but not enough oxygen is allowed in to let the waste burn.

The waste materials degrade into a carbon/hydrogen rich gas. A stage with very high temperature above 1,500 degrees C is used to melt any soot or ash in the gas, and this becomes a molten glass-like slag that can be recovered for use in construction or sand-blasting industries.

Syngas Cooling and Cleaning
Exiting the conversion chamber, the syngas is hot and carries some acidic gases and contaminants. Quenching and cooling the exit gas quickly prevents chemicals reforming. The particles are removed with separators or filters, the acidic gases are neutralised and scrubbed out in either a wet or dry process.

Methanation and Compression
Clean syngas is used in a specialised process reactor to generate a substitute natural gas to pipeline specification. This is done using reactions between the carbon oxides and hydrogen with water to increase the methane level of the gas.

These reactions during the upgrade chemically generate heat. This be fed into the conversion process to dry incoming waste or preserve heat in the conversion chamber. It may be sufficient to drive a steam turbine for electrical generation.

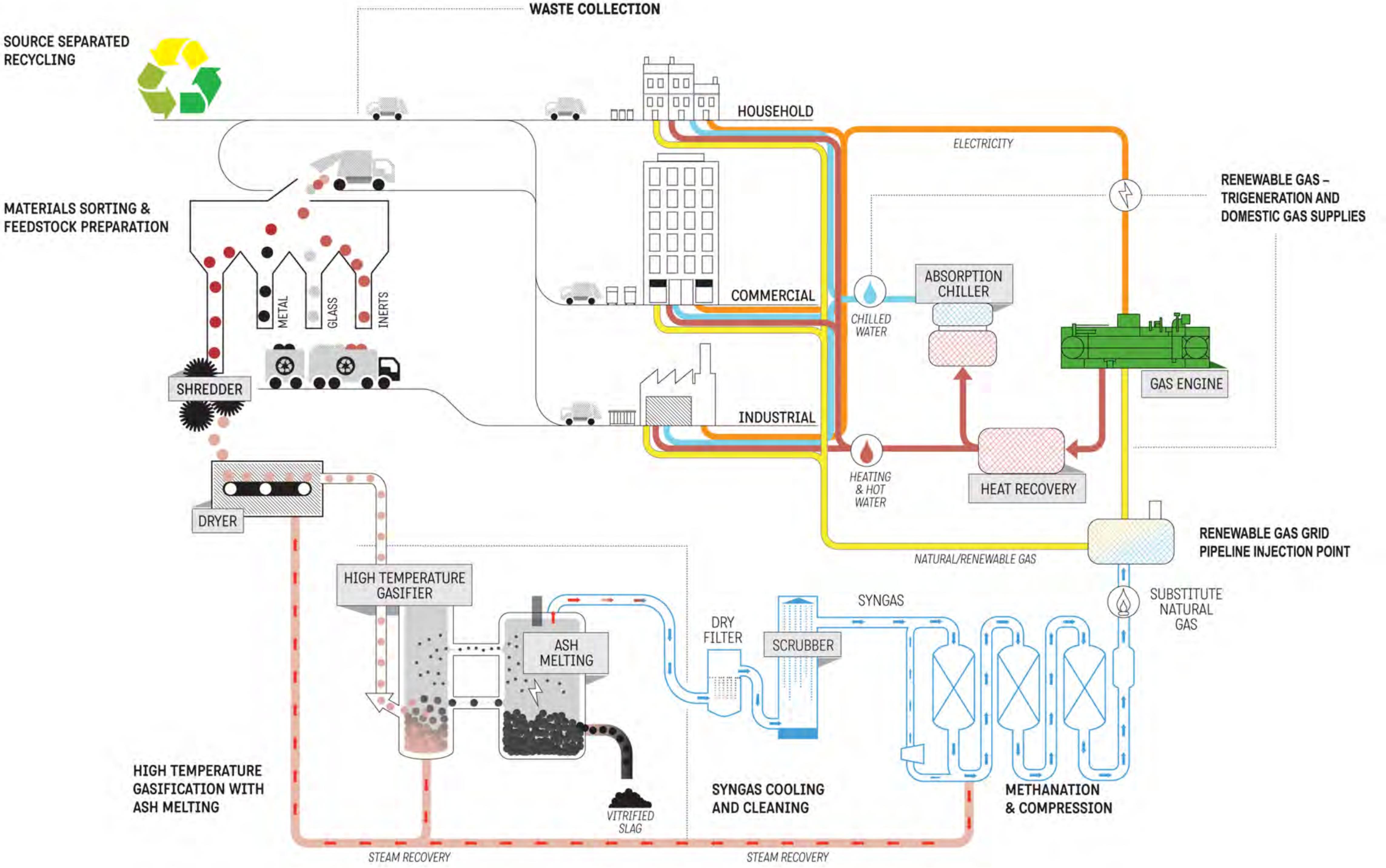
During this process stage, the upgraded gas is compressed, dehumidified and inoculated with an odour compound for safe application in domestic gas use.

Renewable Gas – Grid Pipeline Injection Point
The substitute natural gas can be either liquefied for tanker delivery to trigeneration engines, or when confirmed at natural gas standards be injected into existing gas pipelines of sufficient capacity for distribution.

Renewable Gas – Trigeneration and Domestic Gas Supplies
The substitute natural gas is now indistinguishable from natural gas. It is distributed via the gas grid for use in domestic gas supply, or to replace natural gas in the City trigeneration network for even higher efficiency energy recovery.

The energy resource in waste is now in a closed loop of recovery.

FIGURE 46: ADVANCED WASTE TREATMENT – RENEWABLE GAS GRID INJECTION
(SOURCE: CITY OF SYDNEY)



SYNTHESIS GAS, UPGRADING AND DELIVERY

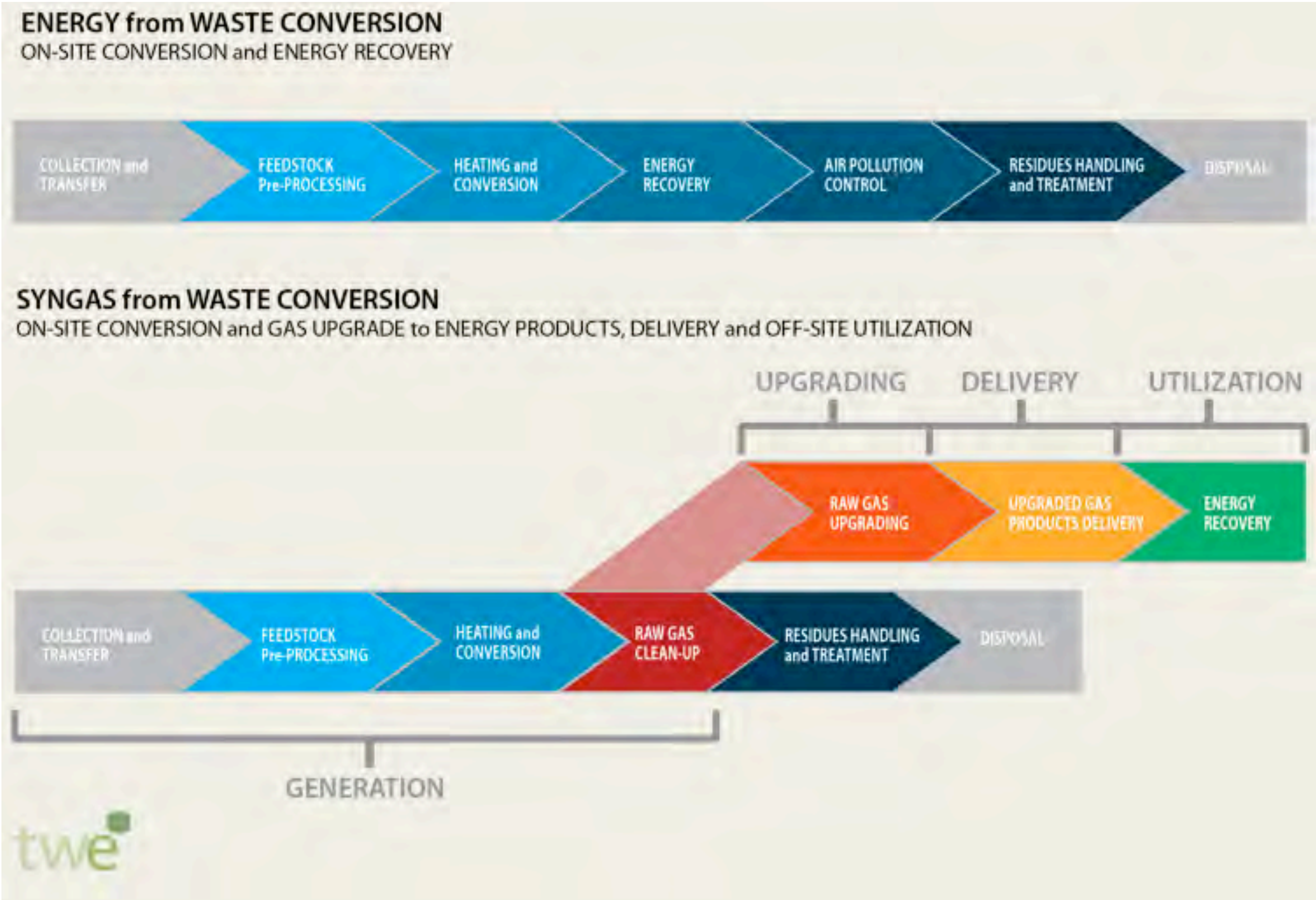
The generation of intermediate gaseous fuels from residual waste and biomass resources enables the adoption of advanced energy recovery schemes, where the gases can be cleaned and/or upgraded to meet quality requirements for several applications, including cogeneration, trigeneration, transport, feedstock for industrial processes and conversion to substitute natural gas for injection into the gas grid for end use in the City of Sydney LGA.

This enables a novel platform of waste to energy recovery schemes, or pathways, where the key operations of conversion and end use recovery are effectively decoupled. This is referred to as syngas from waste (SfW) pathways, to differentiate them from conventional energy from waste schemes with on-site conversion and energy recovery.

The syngas from waste supply chain comprises three major pathway steps:

- **generation** including (waste and biomass) resource harvesting, collection and transfer, and thermo-chemical or biological conversion;
- **upgrading and delivery** including raw syngas clean-up and upgrade, handling, transport and distribution of upgraded syngas products; and
- **utilisation** for end use energy recovery.

FIGURE 47: ENERGY FROM WASTE CONVERSION (SOURCE: TALENT WITH ENERGY)



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SYNTHESIS GAS UTILISATION

Raw synthesis gases generated from thermo-chemical conversion and renewable gases from waste and biomass resources can be utilised in various ways:

- **direct use of raw syngas** as a fuel in industrial kilns and steam generators (industrial or power plant boilers);
- **clean-up and use** as a fuel in advanced energy conversion equipment, such as gas engines, gas turbines and fuel cells; or
- **clean-up and upgrade** including substitute natural gas (SNG), hydrogen or methanol.

The clean-up and upgrade of syngas into a substitute natural gas for injection into the gas grid has the highest end use efficiency, greatest reduction in greenhouse gas emissions, greater economic value as a renewable gas than as renewable electricity and provides the pathway for the City's own contribution of renewable gas to supply the planned trigeneration network and other end use energy consumption.

SYNGAS CLEAN-UP AND METHANATION

Syngas Cleaning Technologies

Syngas cleaning refers to the processing steps adopted to bring the raw synthesis gas mixture from the gasification reactor to the desired composition and purity required by the different applications.

Water-gas shift reactors are commonly adopted to increase the hydrogen to carbon monoxide (H_2/CO) ratio in the syngas.

Usually, carbon dioxide and acid gases are removed using chemical or physical scrubbing processes. More typically in sulphur-containing synthesis gases, such as those from the gasification of waste, chemical scrubbing is employed integrated with a sulphur tolerant catalyst.

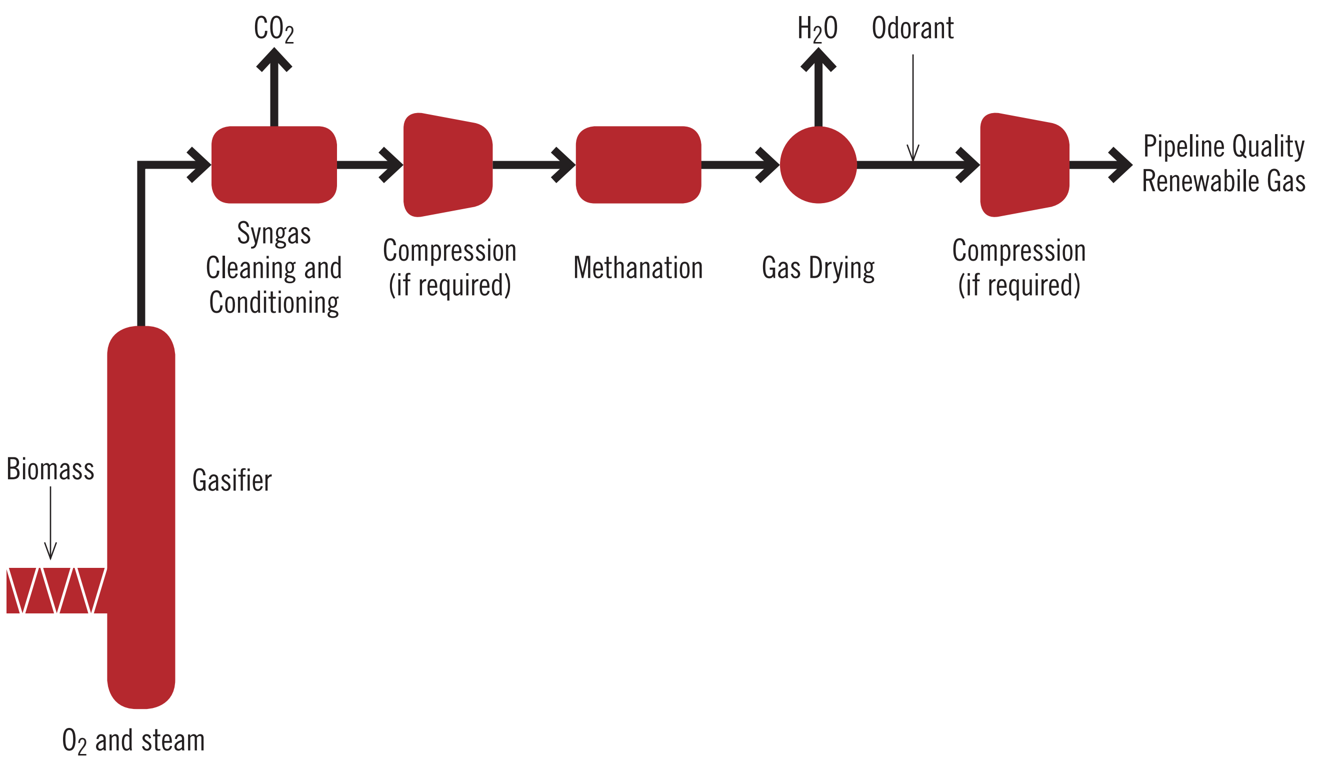
Substitute Natural Gas (SNG)

Substitute Natural Gas (SNG) is generated from synthesis gases which is compatible with gas grid pipeline and engine/turbine specifications.

SNG as a syngas upgrade pathway provides the following advantages:

1. Accepts a wide range of synthesis and other renewable gases (eg, biogas),
2. Generates an energy carrier compatible with existing natural gas infrastructure and technology.

FIGURE 48: THERMAL GASIFICATION (SOURCE: US NATIONAL GRID)



Substitute Natural Gas is produced through the methanation process where carbon oxides (CO, CO_2) and hydrogen (H_2) react to form methane according to the following reactions:

$$CO + 3H_2 \leftrightarrow CH_4 + H_2O$$

$$CO_2 + 4H_2 \leftrightarrow CH_4 + 2H_2O$$

Both reactions generate a significant level of heat (and water), and industrial methanation technology recovers about 20–22% of the heating value of the synthesis gas in the form of high pressure, high temperature steam. This high temperature steam can be used as a source of thermal energy within the gasification plant itself, for example, for drying waste or maintaining the temperature of the gasifier. It could evenbe used to drive a steam turbine for on-site emission free electricity generation.

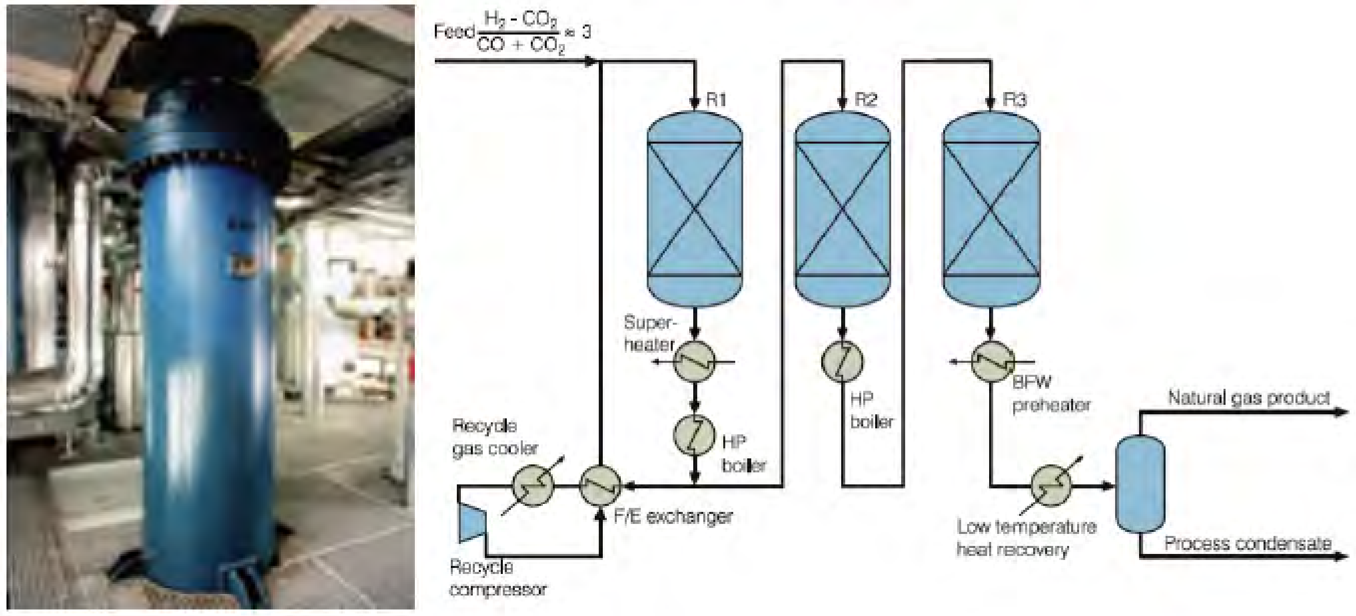
Similar to fossil fuel natural gas, hydrogen can be extracted from Substitute Natural Gas via steam reforming which is normally integrated with both commercial and residential fuel cells.

Thermal gasification is also used for municipal solid waste, commercial and industrial waste. The conditioning step is a key element for creating renewable gas. Carbon dioxide (CO_2) and other trace elements are removed using numerous commercially available adsorption or separation systems. These processes can recover up to 98% of the methane from syngas and are the same processes used in conventional natural gas production processing.

Injecting renewable gas in the form of Substitute Natural Gas into the existing natural gas grid pipeline for use in supplying the City's proposed trigeneration network is 250% to 400% more energy efficient than just generating electricity at remote locations where more than two thirds of the primary renewable energy would be rejected into the atmosphere in the form of waste heat similar to fossil fuel power stations.

One example of industrial methanation technology is the Haldor-Topsøe TREMPTM process. A 200 Nm_3/h unit and a schematic of the process are shown in Figure 49.

FIGURE 49: HALDOR-TOPSØE TREMPTM SUBSTITUTE NATURAL GAS PROCESS (SOURCE: HALDOR TOPSØE)



In the TREMPTM process, close to 85% of the heat released by the methanation reactions is recovered in the form of superheated steam. Typical Substitute Natural Gas and steam specifications are set out below:

FIGURE 50: TYPICAL PRODUCT SPECIFICATION FOR TREMPTM SUBSTITUTE NATURAL GAS PROCESS (SOURCE: HALDOR TOPSØE)

Substitute Natural Gas (SNG)		
CH_4	94-98	mol%
CO_2	0.2-2	mol%
H_2, mol%	0.05-2	mol%
CO	<100	ppm
N_2 + Ar	2-3	mol%
HHV	37.4-38.4	MJ/Nm^3
Superheated steam		
Rate	3-3.5	$kg/Nm^3{}_{SNG}$
Temperature	540	°C
Pressure	10	MPa

SOURCE: (Haldor Topsøe 2009)

RENEWABLE GAS DELIVERY
There are two principal technologies for producing renewable gas. One is based on thermal gasification and the other on anaerobic digestion. Each technology involves the production of raw gas that is subsequently upgraded to substitute natural gas or pipeline quality gas. These processes are similar to how conventional natural gas is delivered.

The two main transportation methods considered as part of the Renewable Energy Master Plan is directly by pipeline to the nearest gas grid pipeline or indirectly by liquefaction and road freight to the nearest gas grid pipeline. Whether a fuel is transported directly by pipeline or indirectly by road freight is primarily a function of proximity to the gas grid infrastructure.

RENEWABLE GAS FEED INTO THE GAS GRID
Internationally, particularly in Europe, the generation of renewable gases from waste feedstock and their injection into the gas grid has become a mature technical and regulatory operation.

The Renewable Energy Master Plan sets out the gas grid injection in greater detail.

The inclusion of locally generated substitute natural gas into the gas grid is of no greater difficulty than the inclusion of other methane sources such as coal seam gas, which also requires cleaning and preparation prior to injection into the network.

While possible agreements to accept gas into the grid are not the subject of this Master Plan, the City has reviewed the ability of its proposed SNG methanation process to meet the specifications for natural gas equivalence and considers this straightforward to achieve.

For the City, this will also mean close attention to locating a facility within a viable distance from a gas injection point. In addition, the City will need to determine that the injection point for substitute natural gas is capable of accepting the volume generated. This volume will be largely constrained by the type and scale of SNG methanation process selected. For a process which generates up to 20MW of substitute natural gas (a level commensurate with the modelled facility in the financial analysis in Chapter 4), the injection point to the gas grid must be of a scale able to accept that throughput.

FIGURE 51: SUBSTITUTE NATURAL GAS DELIVERY PATHWAYS (SOURCE: TALENT WITH ENERGY)

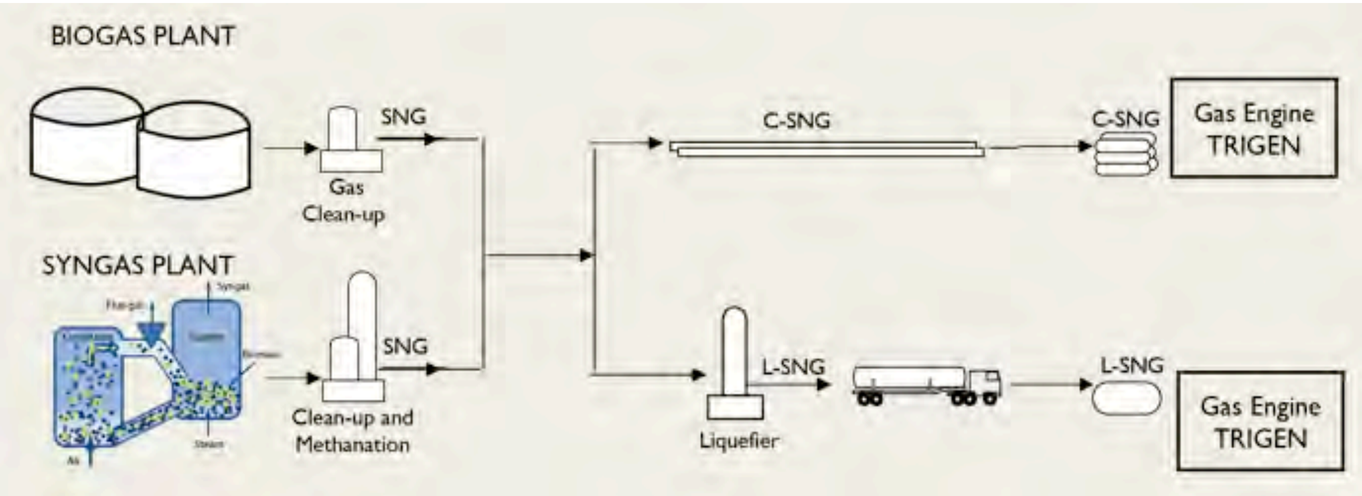
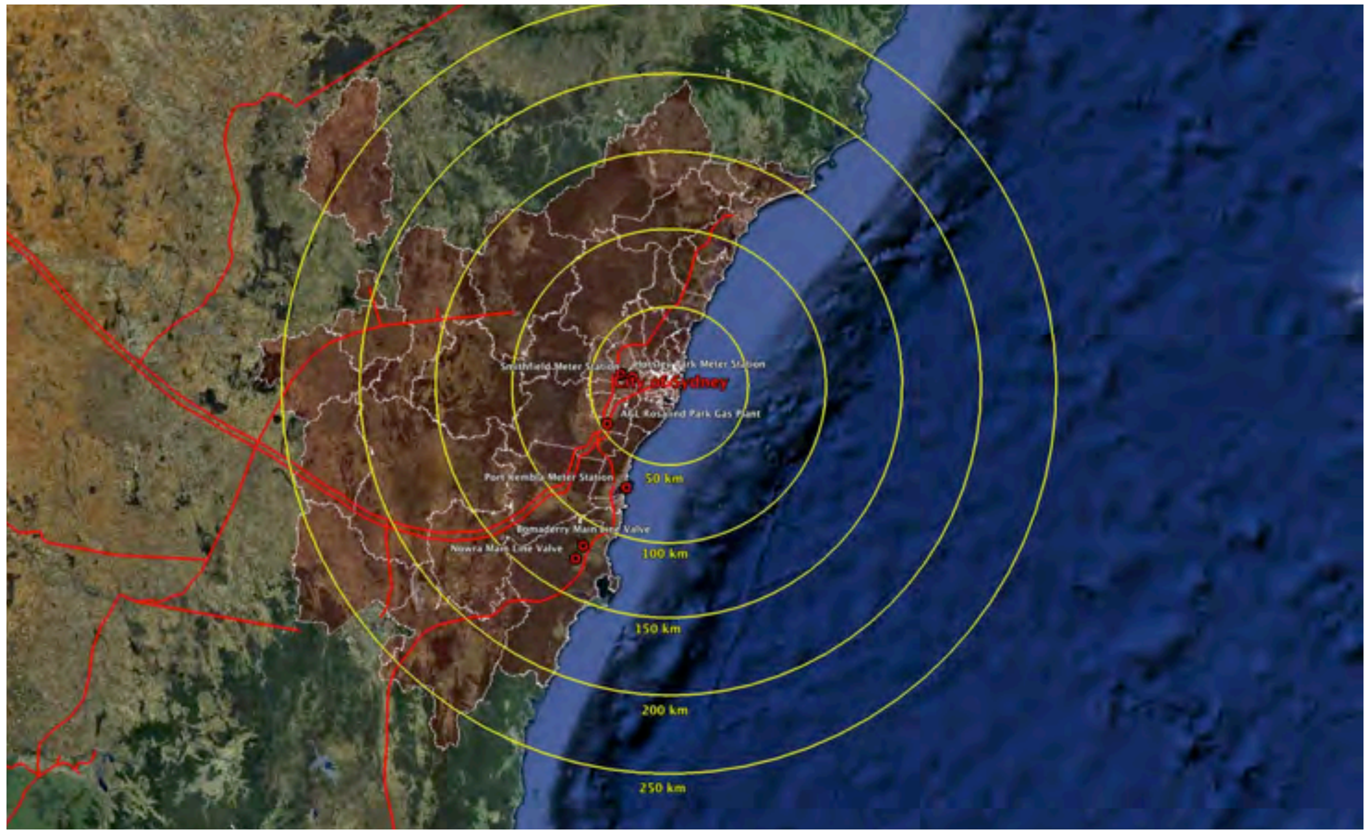


FIGURE 52: MAIN GAS GRID NETWORK BEYOND CITY OF SYDNEY LGA (SOURCE: TALENT WITH ENERGY)



FEEDSTOCK LEVELS AVAILABLE

Technical studies have determined that there is sufficient waste available locally to make a syngas from waste facility technically viable. The City's MSW is projected to reach around 50,000 tonnes per year for treatment in 2030. If a corresponding proportional amount is sourced from the City's commercial waste, a 100,000 to 150,000 tonnes facility can be adequately supplied. Sufficient additional waste is available within the City's LGA and locally to supply over twice that level even under the NSW energy from waste policy framework.

FIGURE 53: FEEDSTOCK SCENARIOS FOR ADVANCED WASTE TREATMENT FACILITY (SOURCE: TALENT WITH ENERGY)

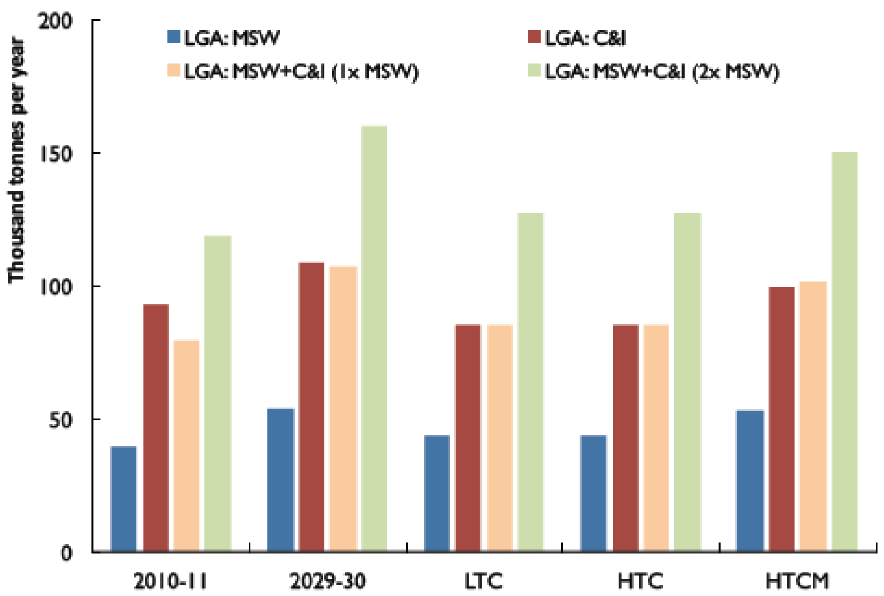
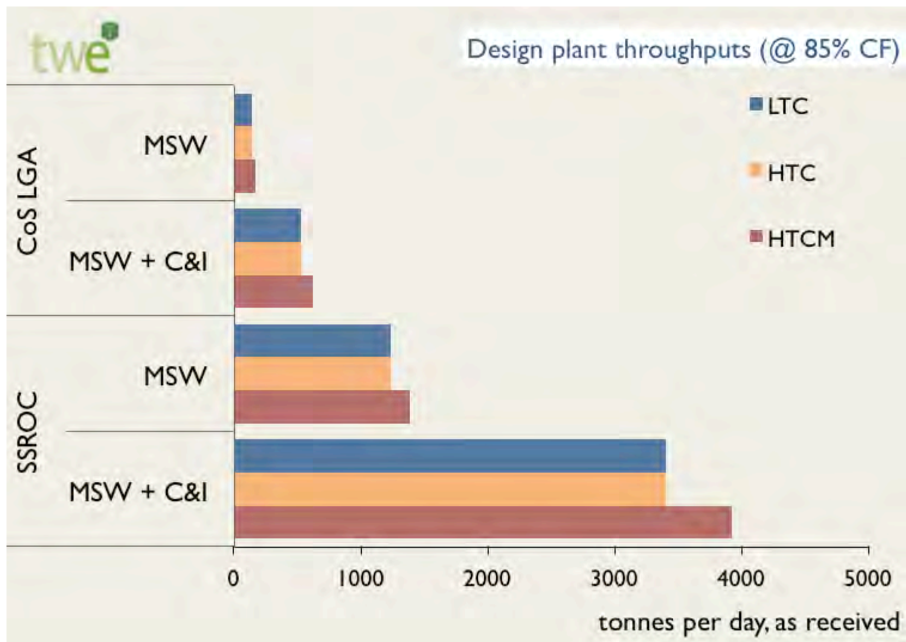


FIGURE 54: SCALING THE ADVANCED WASTE TREATMENT FACILITY – TONNES RECEIVED PER DAY BY FEEDSTOCK (SOURCE: TALENT WITH ENERGY)



PROCESSING CAPACITY THROUGHPUTS

A treatment facility must be appropriately scaled to match the waste processing capacity in tonnes per day. Thermal conversion facilities can operate with reduced or variable volumes of waste and still remain technically viable. Typically waste is pre-processed and then buffered in storage tanks at a ratio twice or more that of the processing chamber throughput capacity.

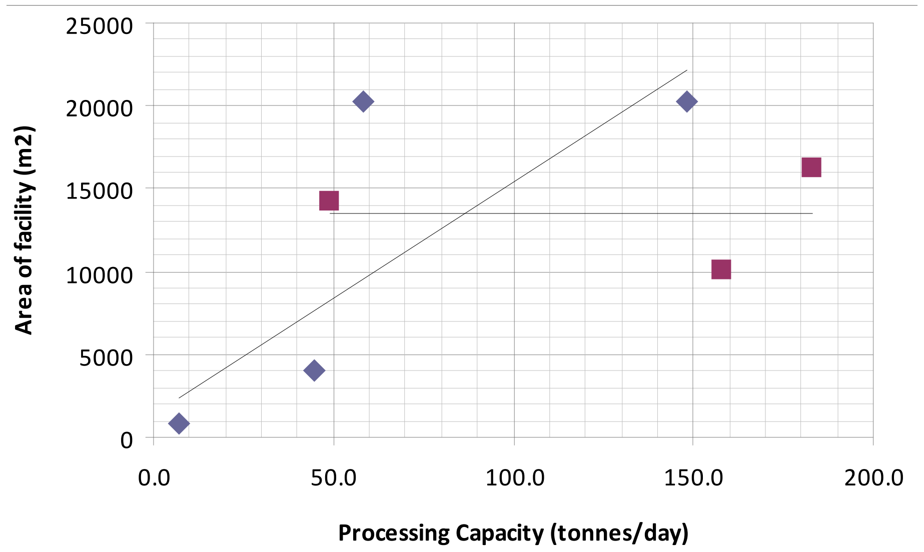
A waste treatment facility receiving residential waste at City of Sydney levels would need to be a medium scale plant at 150 to 180 tonnes of waste per day (45,000–50,000 tonnes a year).

A treatment facility accepting commercial and industrial waste would need to be a larger scale plant at above 300 tonnes of waste per day. This may require a minimum of five hectares of land to provide appropriate buffers from the plant to the site boundary.

Based on reference facilities, the area required for a facility will be around 15–25,000 square metres for a medium scale plant capable of processing the City's MSW with additional processing filled by commercial waste.

If a higher proportion of commercial waste is to be included for processing, around 25–35,000 square metres may be needed. This does not include any waste storage or a sorting add-on facility. Such additional processes could double the land requirement.

FIGURE 55: LAND AREA SCENARIOS FOR ADVANCED WASTE TREATMENT FACILITY (SOURCE: TALENT WITH ENERGY)



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LOCATING A FACILITY

The preceding discussions of technology types, conversion to SNG, gas delivery options, availability of feedstock, and appropriate scaling of the facility are key variables that will impact on any final location for a facility. Until those variables are resolved, nominating a preferred site or sites will be premature. However, there are a number of considerations that have been reviewed by the City to assist in guiding a suitable location for a renewable gas from waste facility.

These considerations are grouped as:

- Principal constraints – controlling factors determining the selection of a location
- Secondary constraints – factors influencing or of concern in the selection of a location.

There are three principal constraints on any location of a gasification type facility:

1. **Planning Zones** permitting a waste recovery facility. Heavy industrial zones are one of those permitted areas.

2. **Proximity to gas pipelines of suitable capacity** for reticulating the anticipated supply of renewable gas back into the City. The output of substitute natural gas from the facility must be matched to the ability of a gas injection point and pipeline that can accommodate that level of gas.

3. **Size of the facility** itself, housing all of the processes that need to be integrated on one site. This includes not only the gasification unit itself, but the inclusion of waste sorting and preparation areas, and the inclusion of SNG methanation technologies will determine the facility footprint. The site must be sufficiently scaled to allow for any staged introduction of additional processes.

Secondary constraints will help determine the optimal location of a facility.

4. **Proximity to source of waste:** The location of an advanced waste treatment facility will ideally be situated as close as possible to where the major sources of waste supply, to reduce transportation and encourage commercial partners to utilise the facility. Therefore, sites within or in close proximity to the City will be the priority for investigation. Travel distance is a primary consideration for the cost of commercial waste management. Travel distance impacts the economics because it can affect driver costs, vehicle maintenance, and importantly the ability to improve efficiency by collecting greater aggregated volumes of waste in a set period of time.

5. **Transport Impacts:** Limiting the transport distance and subsequent costs and carbon footprint for waste collection vehicles will greatly influence the suitability of where to locate an Advanced Waste Treatment facility. A location where the re-direction of vehicles from existing waste management facilities to the waste treatment facility does not adversely impact on congestion, transport times and the local community is required.

Finally, there are criteria that will address amenity and compatibility issues concerning a facility location over time, that will influence decisions. The City has identified the determination of all these criteria as an Enabling Action for the Master plan, and will engage the broader community on their final composition (see Chapter 5 Enabling Actions).

PERFORMANCE MEASURES

PERFORMANCE MEASURES

This Chapter describes the relevant performance measures of advanced waste treatment technologies assessed against a number of key criteria:

1. **DIVERSION OF WASTE FROM LANDFILL**
2. **GENERATION OF SYNGAS AND SUBSTITUTE NATURAL GAS**
3. **AIR QUALITY**
4. **FINANCIAL AND ECONOMIC VIABILITY**

The measures indicate performance across the scenarios into which reference technologies were classified:

- Low Temperature Conversion (LTC)
- High Temperature Conversion (HTC)
- High Temperature Conversion plus ash Melting (HTCM)

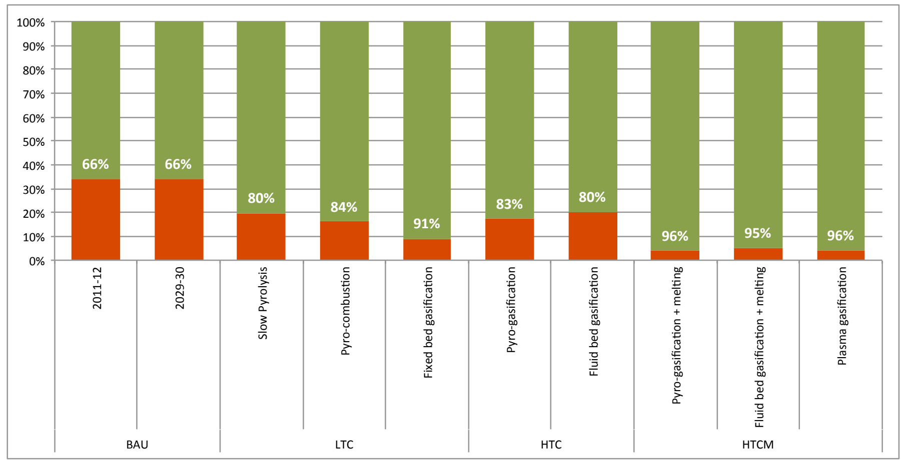
Indicative financial analysis was only developed for the City preferred HTCM technologies.

This Chapter also sets out additional environmental performance measures and contribution to the City's Sustainable Sydney 2030 targets. It also analyses the contribution of the advanced waste treatment of the City's waste to the performance outcomes of the Renewable Energy Master Plan.

SUMMARY OF KEY TECHNOLOGIES

These tables present the key results for each technology or feedstock that have been analysed in this Master Plan.

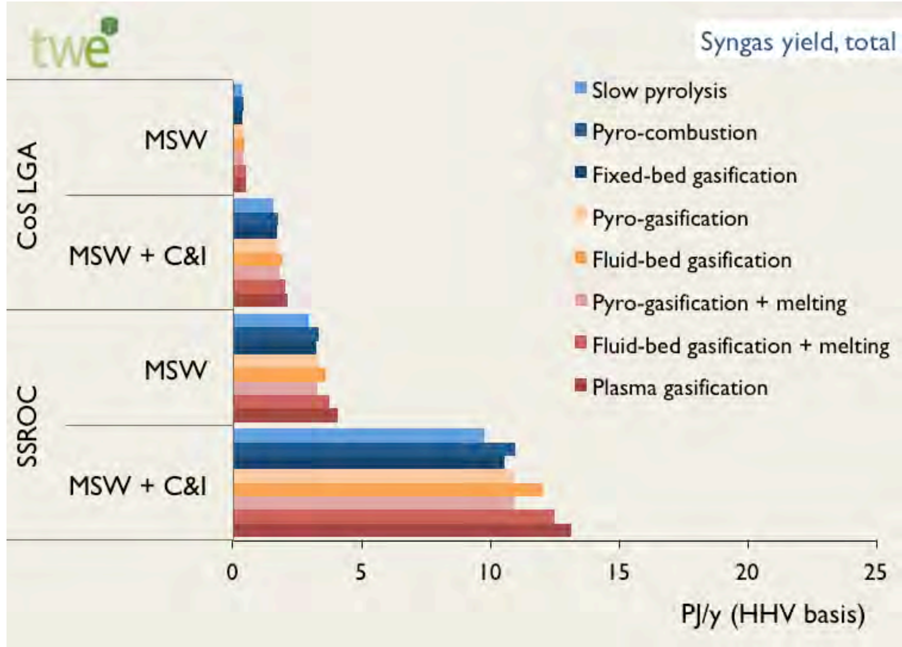
FIGURE 56: MSW RESOURCE RECOVERY ACHIEVED FROM SOURCE-SEPARATED RECYCLING AND CONVERSION SCENARIO 2030 (SOURCE: CITY OF SYDNEY BASED ON TALENT WITH ENERGY DATA)



Based on projected waste levels for the City's residential waste in 2030, the performance of the reference technologies to achieve diversion of waste objectives. This measures a combination of City residential recycling programs and the thermal conversion of non-recyclable waste performance.

- BAU –reliance on existing mechanical-biological treatment of waste – diversion of 66%
- LTC – Low temperature conversion – waste diversion ranging from 80% to 91%
- HTC – High temperature conversion – waste diversion ranging from 80% to 83%
- HTCM – High temperature plus ash melting – waste diversion ranging from 95% to 96%

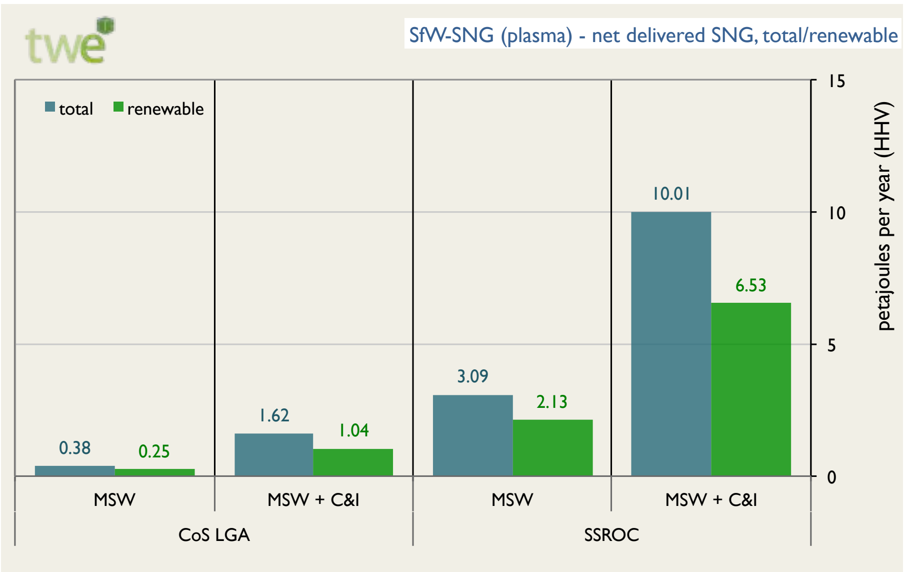
FIGURE 57: SYNGAS FROM WASTE BY 2030 (SOURCE: TALENT WITH ENERGY)



This graph indicates the potential delivery of syngas from waste for use as a fuel or for conversion to substitute natural gas. Composition of mixed waste from City MSW, local region MSW, City and local region C&I wastes were analysed and the delivery performance of each reference technology measured.

- **City of Sydney LGA – MSW**, ranging from 0.27 PJ/y for LTC – slow pyrolysis, to 0.38 PJ/y for HTCM – plasma gasification;
- **City of Sydney LGA – MSW + C&I**, ranging from 1.20 PJ/y for LTC – slow pyrolysis, to 1.62 PJ/y for HTCM – plasma gasification;
- **SSROC region – MSW**, ranging from 2.25 PJ/y for LTC – slow pyrolysis, to 3.09 PJ/y for HTCM – plasma gasification; and
- **SSROC region – MSW + C&I**, ranging from 7.42 PJ/y for LTC – slow pyrolysis, to 10.01 PJ/y for HTCM – plasma gasification.

FIGURE 58: SUBSTITUTE NATURAL GAS – NET, DELIVERED PETAJOULES BY HIGHEST PERFORMING HIGH TEMPERATURE PLUS ASH MELTING TECHNOLOGY (SOURCE: TALENT WITH ENERGY)



Cleaning, upgrade and methanation of the syngas into a subsistute natural gas, and the delivery via gas grid results in a reduction of energy delivered to end users. Gas pipeline losses are very small proportions in comparison to electricity distribution and transport losses.

The potential delivered SNG and its renewable energy content for the highest performance technology assessed (plasma) indicates

- City of Sydney LGA MSW – Net delivered 0.38 PJ/yr – Renewable energy content 0.25 PJ/yr
- City Of Sydney LGA MSW + C&I – Net delivered 1.62 PJ/yr – Renewable energy content 1.02 PJ/yr
- SSROC Region MSW – Net delivered 3.09 PJ/yr – Renewable energy content 2.13 PJ/yr
- SSROC Region MSW + C&I – Net delivered 10.01 PJ/yr – Renewable energy content 6.53 PJ/yr

ACHIEVING ENVIRONMENTAL BENEFITS

The diversion rates from landfill, renewable gas capacities and outputs and reduction in greenhouse gas emissions are based on the waste feedstocks available identified in the previous chapter.

The Renewable Energy Master Plan showed that the City can meet its carbon reduction and renewable electricity and renewable gas targets using technologies that are commercially available today or will become commercially viable by 2030.

This Master Plan shows the contribution that the City's waste can make towards the renewable gas target as well as further reductions in greenhouse gas emissions through avoided methane emissions from landfills due to greater diversion rates from landfill utilising advanced waste treatment gasification technologies.

By 2030, the contents of a City household's weekly garbage bin if converted into substitute natural gas and used to generate electricity locally could deliver energy equal to 9% of a household's average weekly electricity consumption. The ash waste from the coal power avoided would equal 80% of the average weekly garbage bin content by weight.

DIVERSION OF WASTE FROM LANDFILL TARGET

This Master Plan shows that the City can achieve its Interim Waste Strategy landfill diversion requirement of 90% or more for advanced waste treatment based on world waste management best practice by 2030 by continuing source separation of recyclables and introducing advanced waste treatment by thermal conversion of non-recyclable waste.

Thermal conversion technologies included under the High Temperature Conversion plus Ash Melting scenario, have the greatest diversion rates of waste from landfill for any advanced waste treatment of mixed waste available.

International reference facility data suggests diversion rates for the City of over 95% may be achievable, with even higher rates for some technologies such as plasma arc gasification.

It is important to note that this is based on the diversion rate of materials fed into the reactor for conversion to gas. Some materials sent for processing will include an inert or hazardous fraction so will be unsuitable for energy conversion and this material will therefore still require separate treatment or disposal. These materials may be unsuitable, for example because they would excessively contribute to gas cleanup costs, or could interfere with mechanical handling systems.

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For these reasons, should any material be pre-processed offsite for use as a feedstock in a thermal conversion facility, the City will need to account for the disposal of any waste created as a by-product of that feedstock's preparation.

The high conversion and recovery rates identified are not expected to be achieved in the earliest phases of operation, as technical commissioning and the adaptation of any selected treatment option to local waste conditions would precede optimum recovery rates. Factors such as community awareness, recycling behaviour and recycling markets influence waste diversion.

The estimated diversion of waste to landfill, greenhouse gas reductions, and avoided NSW Waste Levy, if a high temperature conversion with ash melting gasification technology was utilised to treat the City of Sydney LGA residual waste by 2030, is shown in Figure 59.

FIGURE 59: IMPACTS OF DIVERSION FROM LANDFILL OF CITY OF SYDNEY LGA WASTE BY 2030 (SOURCE: CITY OF SYDNEY)

				Reduced GHG emissions by diversion (tonnes CO_{2-e})			
Waste stream	2012 tonnes	2030 Tonnes	2030 additonal tonnes diverted from landfill	2012	2030	2030 avoided landfill GHG emissions (tonnes CO_{2-e})	2030 avoided NSW waste levy $million**
MSW							
MSW total collected	**62,086**	**79,959**					
MSW separated recycling	16,771	23,742		20,053	28,490	8,437	
MSW recovered by current MBT	21,077			25,292			
MBT output to landfill*	**18,576**						
MSW recovered by proposed AWT		50,188			60,226	34,934	
Proposed AWT output to landfill*		**3,280**					
TOTAL MSW DIVERTED	**37,788**	**73,930**	**36,142**	**45,345**	**88,716**	**43,371**	**$3.9**
C&I waste total collected	**264,139**	**307,154**					
C&I recycled or otherwise recovered	130,696	151,980		143,766	167,178	23,412	
Potential C&I recovered by proposed AWT		136,408			150,049	150,049	
C&I waste to landfill	133,443	28,852					
TOTAL C&I DIVERSION	**130,696**	**288,388**	**157,692**	**143,766**	**317,227**	**173,461**	**$18.7**

*Excludes cleanup waste
**Using 2013 value of $107.80 per tonne

AIR QUALITY EMISSIONS MANAGEMENT

Thermal treatment of waste materials can potentially create a wide array of air pollutants during the conversion reactions.

Any mixed waste waste stream may include an extensive range of manufactured products with low but variable degrees of the precursors to these pollutants. Removing known chemical precursors to pollutants before the reactor is the optimum course.

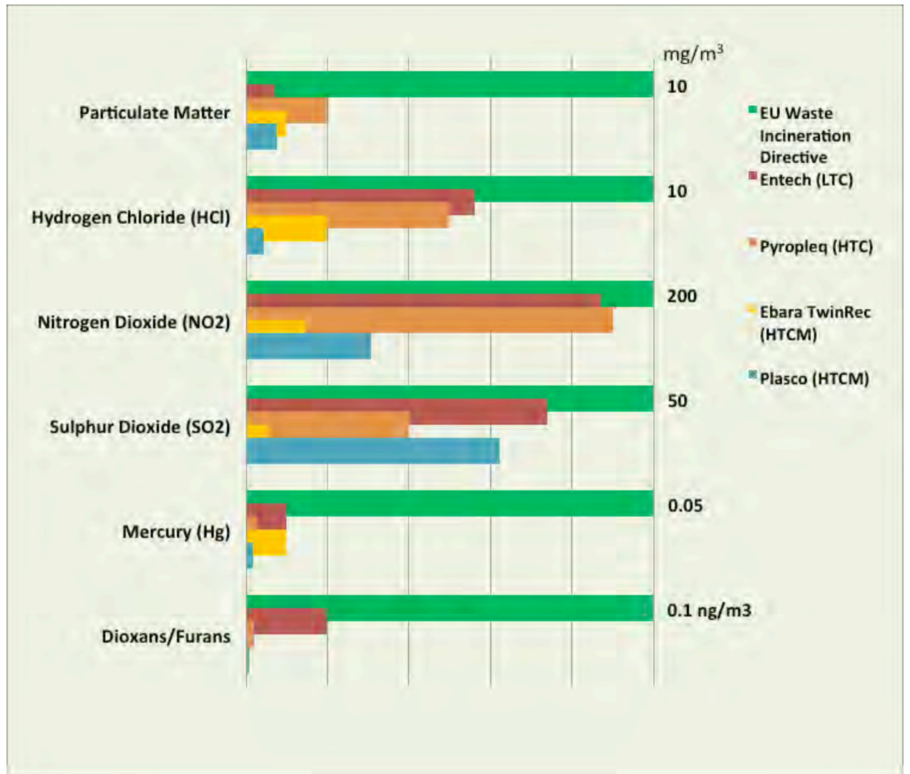
Reviews of the existing technologies performance published data shows that throughout the full process of generation of syngas and combustion of syngas for energy generation, each technology was already significantly below or in compliance with emissions standards internationally.

These facility emissions are released from the on-site combustion of syngas for electricity generation.

The City's advanced waste treatment proposal will instead rely on commercially available technologies to first clean up and then convert the syngas to a substitute natural gas of a quality high enough to be injected and transported in a natural gas pipeline (See Chapter 3). Air quality will be managed by cleaning at the scale of gas generated, not the high volume of exhaust resulting from gas combustion. Emissions from substitute natural gas will be the equivalent of combusting natural gas.

This approach not only returns a level of energy to the City up to four times higher than on-site electricity generation, but significantly reduces pollutant loads arising from energy generation when compared to other forms of base power generation. Harnessing the energy resource of the City's waste as substitute natural gas even reduces the pollutant levels compared to existing technologies on-site electricity generation from syngas.

FIGURE 60: EVALUATION OF EMISSIONS FROM THERMAL CONVERSION TECHNOLOGIES PROCESSING MUNICIPAL SOLID WASTE AND BIOMASS (SOURCE: TALENT WITH ENERGY AND ONTARIO MINISTRY OF ENVIRONMENT)



Note: All values at 11% oxygen and standard conditions.

REDUCING ASH WASTE FROM COAL POWER

Around 80% of the City of Sydney LGA electricity supplies come from coal fired power stations outside the city. In addition to greenhouse gas emissions into the atmosphere, coal fired power stations also generate large amounts of waste in the form of ash.

Based on the Hyder report that by 2030 the Trigeneration, Renewable Energy and Advanced Waste Treatment Master Plans would together, reduce coal ash waste attributable to the City's electricity consumption by 414,667 to 521,136 tonnes a year for 7am-10pm and 24 hours a day trigeneration operation, respectively.

This level of coal ash waste far exceeds the total waste landfilled by the City's residents and businesses combined, at only 157,600 tonnes in 2012.

REDUCING POWER STATIONS WATER DEMAND

A typical 1,000MW coal fired power station consumes water at the rate 17GL/year. To this must be added the 3.8GL/year of water used by the electric air conditioning cooling towers across the four low carbon zones of the city.

By 2030, the Trigeneration, Renewable Energy and Advanced Waste Treatment Master Plans would together, reduce electricity demand by 714MW (including grid losses). This would reduce water demand from coal fired power stations by a net 9.5GL/year, equivalent to a 22% reduction in the City of Sydney LGA 2030 potable and non-potable water demand.

TRACKING TOWARD OUR 2030 TARGETS

GREENHOUSE GAS EMISSIONS REDUCTION TARGET

The target in Sustainable Sydney 2030 to reduce greenhouse gas emissions by 70% by 2030 is based on 2006 levels. In 2006, emissions were 5.437 MtCO$_{2-e}$. Therefore, the City's emissions cannot exceed 1.631 MtCO$_{2-e}$ per year by 2030.

Without action, annual greenhouse gas emissions are forecast to rise to 6.359 MtCO$_{2-e}$ by 2030. Despite a small average decline in recent years, electricity and gas consumption within the City of Sydney will continue to grow into the future driven by new development, increased population and air conditioning loads. Therefore, the 2030 emission reduction target accounts for this additional growth.

The combination of the Trigeneration and Renewable Energy Master Plans will reduce emissions by 4.475 MtCO$_{2-e}$ per year by 2030 which equates to a 70.4% reduction against 2030 business as usual emissions. This included levels of renewable gas energy potential and associated reduction in greenhouse gas emissions for the City's LGA own domestic, commercial and industrial waste.

This Advanced Waste Treatment Master Plan additionally accounts for the avoided landfill methane emissions that result from a significant reduction of waste going to landfill.

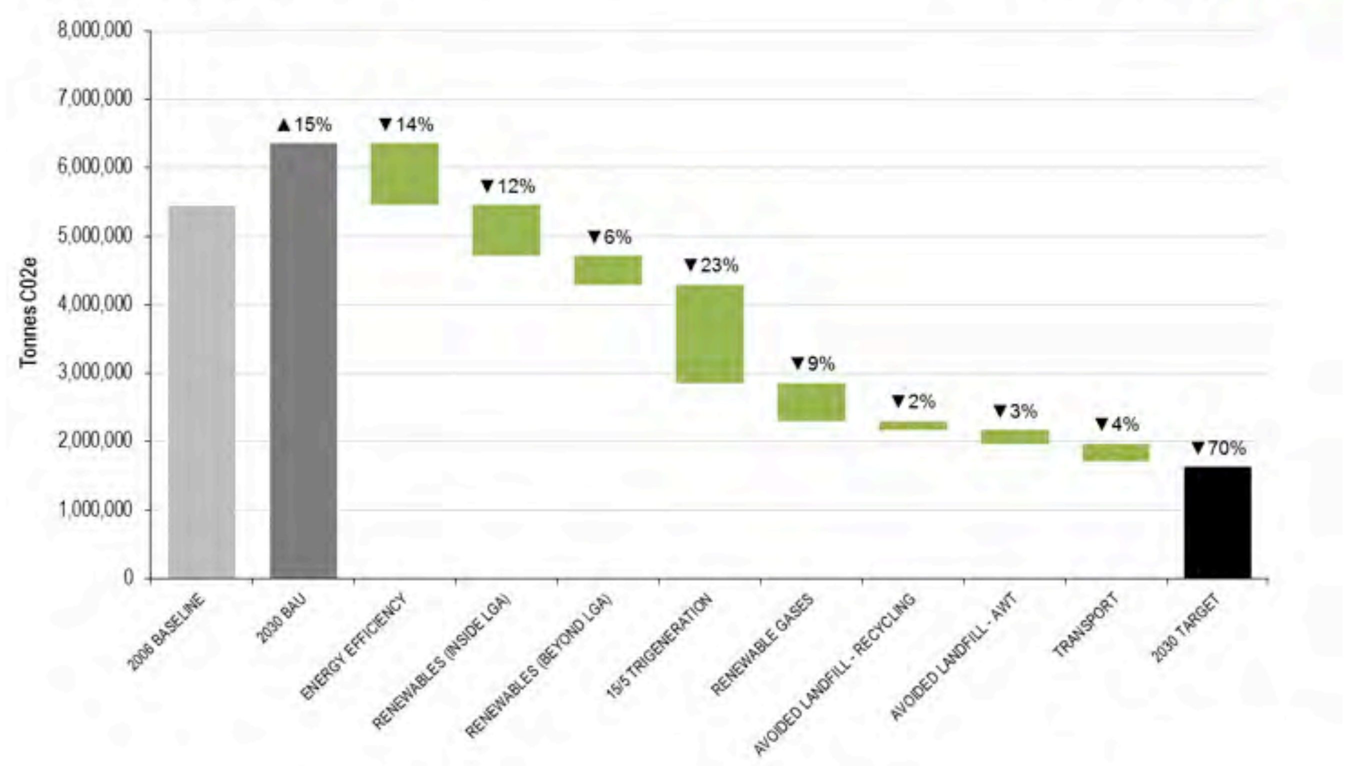
Renewable gases supplying the proposed trigeneration network is key to achieving the carbon reduction target and delivering a constant non-intermittent renewable energy supply.

Greenhouse gas emissions from landfilled waste arise from the decomposition of a number of materials over time, not just food. Waste disposed to landfill is assigned a greenhouse gas factor per tonne depending on the originating sector (MSW, C&I) of the waste, as that sector determines the average composition of materials in waste. As a result of the method used to assign a greenhouse gas factor to MSW and C&I, the same value applies to waste disposed to landfill even after current forms of waste treatment. This means that the level of waste disposed is as important to greenhouse gas reduction for waste in landfill as changing the composition of that waste. This is not an ideal determination for encouraging various waste treatments aimed at impacting the greenhouse gas potentials of waste, but allows for ready estimates of greenhouse gas emissions from multiple inputs of waste.

This Master Plan will contribute to the City's reduction in greenhouse gas emissions target against 2030 business as usual emissions as follows:

- Reduce greenhouse gas emissions from recycled waste since 2006 across the City's LGA by 0.135 MtCO$_{2-e}$ a year (2.1%) through avoided landfill gas emissions below 2006 levels by 2030 (not included in the Renewable Energy Master Plan).
- Reduce greenhouse gas emissions from residual waste across the City's LGA by 0.196 MtCO$_{2-e}$ a year (3.1%) through avoided landfill gas emissions below 2006 levels by 2030 (not included in the Renewable Energy Master Plan).
- Reduce greenhouse gas emissions across the City's LGA by 0.106 MtCO$_{2-e}$ a year (1.7%) through conversion of non-recyclable waste into renewable gas for the trigeneration network below 2006 levels by 2030 (included in the Renewable Energy Master Plan).
- Together with avoided landfill gas emissions and conversion of non-recyclable waste into renewable gas for the trigeneration network reduce greenhouse gas emissions across the City of Sydney LGA by 0.437 MtCO$_{2-e}$ a year (6.9%) below 2006 levels by 2030.

FIGURE 61: CITY OF SYDNEY LGA ADVANCED WASTE TREATMENT CONTRIBUTION TO 70% GREENHOUSE GAS EMISSION REDUCTION TARGET FOR 2030 (SOURCE: CITY OF SYDNEY)



Therefore, the three Decentralised Energy Master Plans will reduce greenhouse gas emissions by a total of 75.6 against 2030 business as usual emissions%, as follows:

- 31.9% carbon saving from trigeneration;
- 11.7% carbon saving from renewable electricity within the City of Sydney LGA;
- 6.5% carbon saving from renewable electricity beyond the City of Sydney LGA;
- 19.3% carbon saving from renewable gases from waste;
- 2.1% carbon saving from avoided landfill gas emissions for recycling of waste; and
- 3.1% carbon saving from avoided landfill gas emissions for advanced waste treatment of residual waste.

Together, the three Decentralised Energy Master Plans will reduce greenhouse gas emissions by 4.806 MtCO$_{2-e}$ per year ensuring that the City's emissions will not exceed 1.553 MtCO$_{2-e}$ per year by 2030. This far exceeds the 1.631 MtCO$_{2-e}$ per year maximum emissions necessary to achieve the 70% reduction in greenhouse gas emissions below 2006 levels taking account of the forecast rise in emissions by 2030.

Figure 61 summarises the potential relative contribution of each technology or action, if implemented, to the greenhouse gas reduction target.

RENEWABLE ENERGY TARGETS
The target in Sustainable Sydney 2030 for the city to have the capacity to meet 100% of electricity demand by local electricity generation is based on the City of Sydney LGA electricity demand in 2030 This equates to 4,564GWh/year with 70% to be met by trigeneration and 30% to be met by renewable electricity.

The Trigeneration Master Plan would deliver 3,700GWh/year or 81% of the local electricity generation target. The Renewable Energy Master Plan will deliver 1,171GWh/year or 30% of the local electricity generation target and 48.96PJ/year of syngas and biogas of which 37.06PJ/year is renewable gas and 11.9PJ/year is non fossil fuel gas. The renewable gas component of waste gas is more than the 27PJ/year of renewable gas needed to replace 100% of the natural gas supplying 372MWe of trigeneration in the City of Sydney's proposed four low carbon zones or even the 32.7PJ/year needed to supply 477MWe of trigeneration and cogeneration across the City of Sydney's LGA. This renewable gas resource will also supply the 34.7PJ/year, including the 2PJ/year of domestic gas used for domestic heating and cooking, needed to replace 100% of the fossil fuel natural gas in the City's LGA.

Figures 62 and 63 summarise the potential relative contribution of each renewable energy technology, if implemented, to the 100% renewable energy target.

FIGURE 62: CITY OF SYDNEY LGA RENEWABLE ELECTRICITY CONTRIBUTION TO 30% TARGET FOR 2030 (SOURCE: CITY OF SYDNEY)

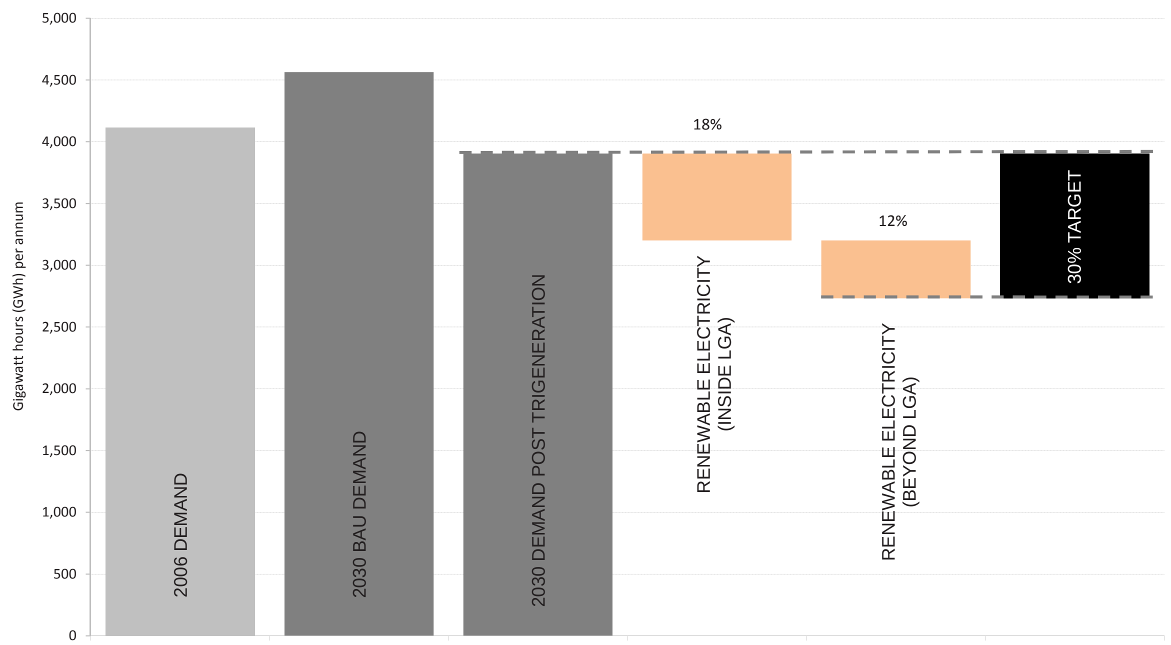
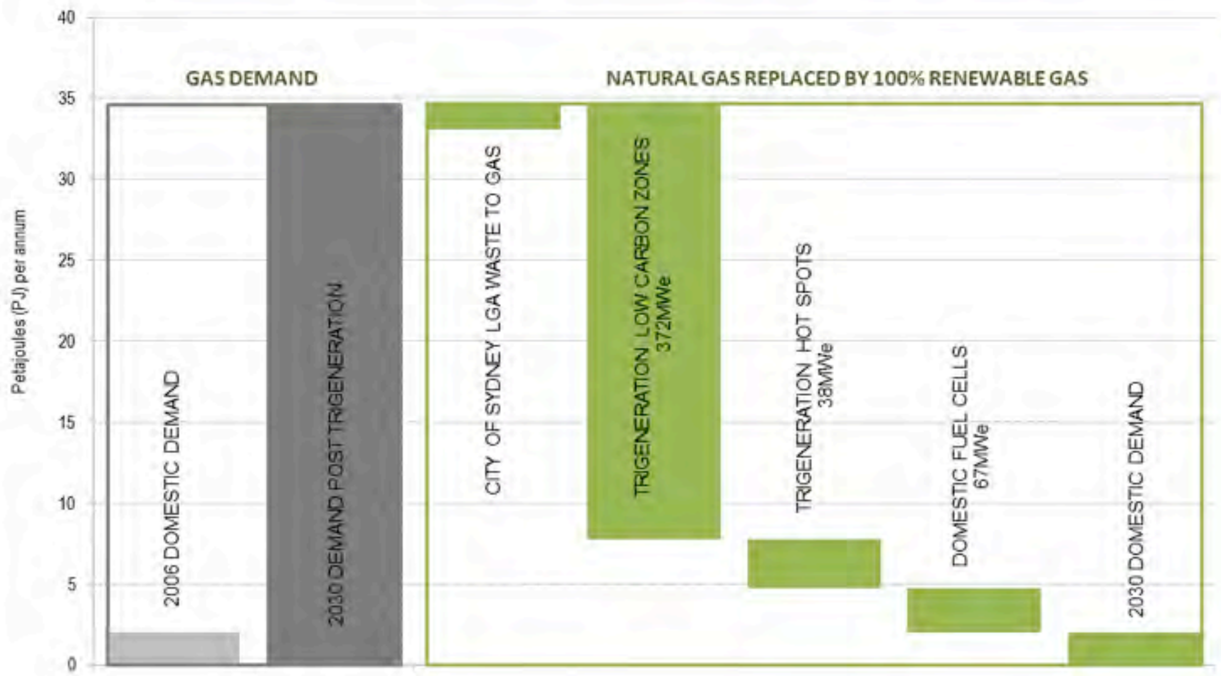


FIGURE 63: CITY OF SYDNEY LGA RENEWABLE GAS CONTRIBUTION TO 100% RENEWABLE ENERGY TARGET FOR 2030 (SOURCE: CITY OF SYDNEY)



MEETING THE 100% RENEWABLE GAS TARGET

Utilising natural gas enables the economic construction of the City's proposed trigeneration network to supply low carbon electricity and zero carbon thermal energy for heating and cooling to the city's buildings. However, Council has resolved to replace natural gas with renewable gases derived from waste to supply the City's proposed trigeneration network by 2030. If the City of Sydney is successful in creating a market for renewable gases to supply the proposed trigeneration network, it could potentially achieve a 100% renewable fuelled trigeneration network by 2030.

To achieve this outcome, the majority of renewable gas will need to be sourced beyond the local government area.

Substitute natural gas, comprising renewable and non fossil fuel gas from waste can provide 48.96PJ/year, 178% of the 27PJ/year gas required to supply the proposed 372MWe of trigeneration in the City of Sydney's four low carbon zones, sourced within 250km of the City of Sydney LGA. Of this amount renewable gas can provide 37.06PJ/year, 145% of the gas required to supply the proposed 372MWe of trigeneration in the City of Sydney's four low carbon zones. Sufficient substitute natural gas and renewable gas resources can be sourced within 50km and just over 100km, respectively.

Other renewable fuels could also contribute towards the City's target to offset 100% of natural gas used for trigeneration by 2030, such as district solar water heating and direct use geothermal heat. Non fossil fuel gas from the inorganic fraction of waste could also be utilised.

The predominant waste streams within the city are residential and commercial waste and sewage streams. The main waste stream sourced from beyond the city will come from waste, livestock manure, forestry, horticulture and broad acre crop residues.

Renewable gases supplying the City's proposed trigeneration network would enable the City to exceed the 30% renewable energy target by more than 300% and make a much greater contribution to reducing greenhouse gas emissions.

FIGURE 64: RENEWABLE GASES – SUPPLY REQUIREMENTS AND RESOURCE POTENTIAL 2029–30 (SOURCE: TALENT WITH ENERGY)

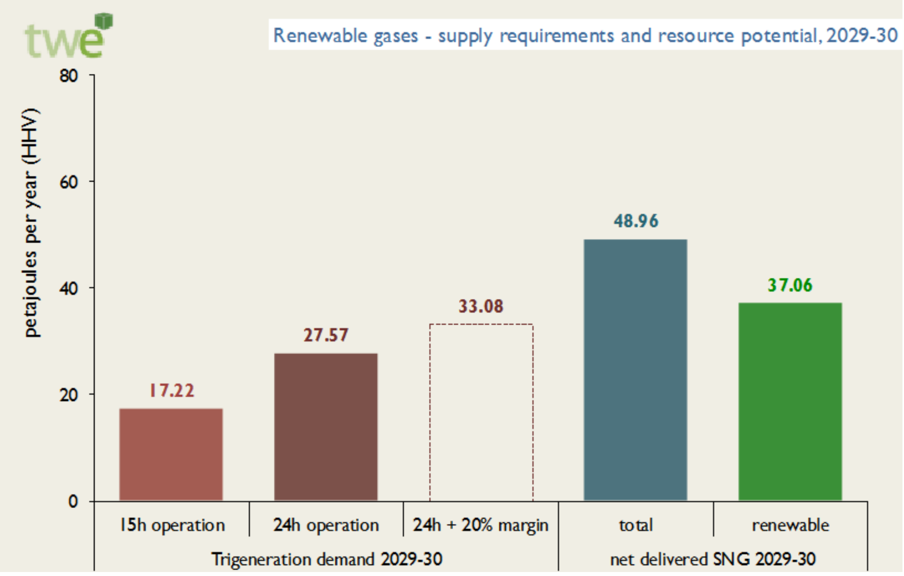


FIGURE 66: RENEWABLE GAS – SUPPLY REQUIREMENT (SOURCE: TALENT WITH ENERGY)

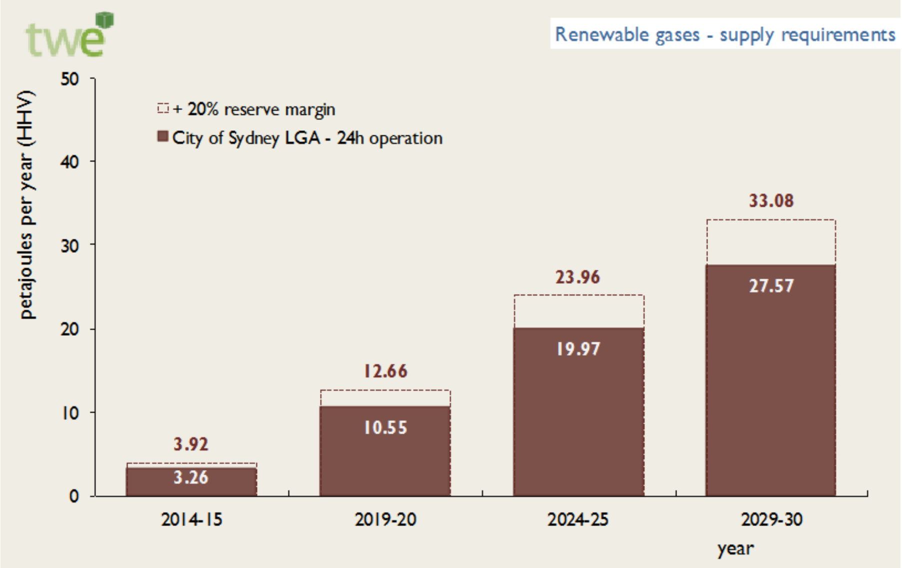


FIGURE 65: TRIGENERATION NATURAL GAS DEMAND IN 2030 (SOURCE: KINESIS)

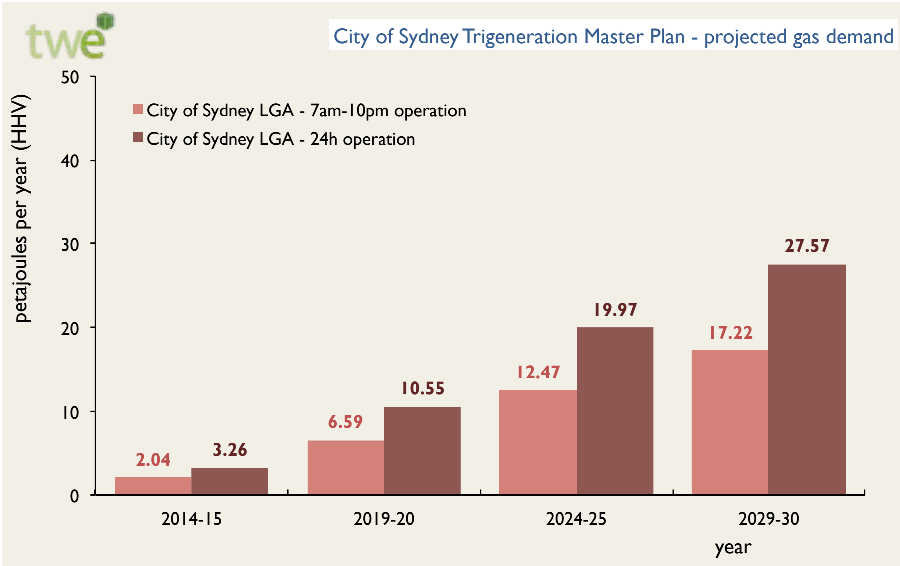
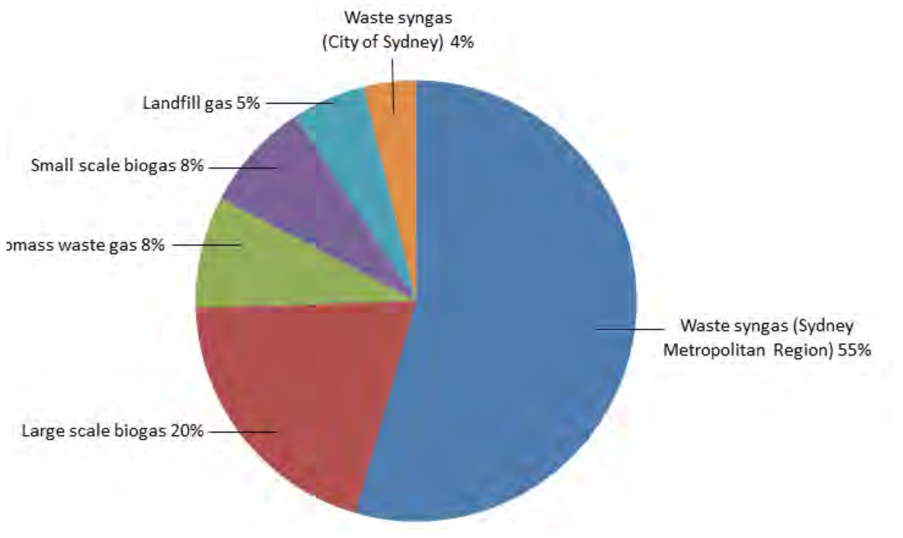


FIGURE 67: RENEWABLE GASES BY WASTE RESOURCES (SOURCE: CITY OF SYDNEY)



RENEWABLE GAS CONTRIBUTION FROM CITY OF SYDNEY WASTE

This Master Plan identifies the potential of renewable gases that can be recovered from the City of Sydney LGA own domestic, commercial and industrial waste that is not otherwise recycled. The renewable gas energy potential for the City's LGA own waste was included in the Renewable Energy Master Plan.

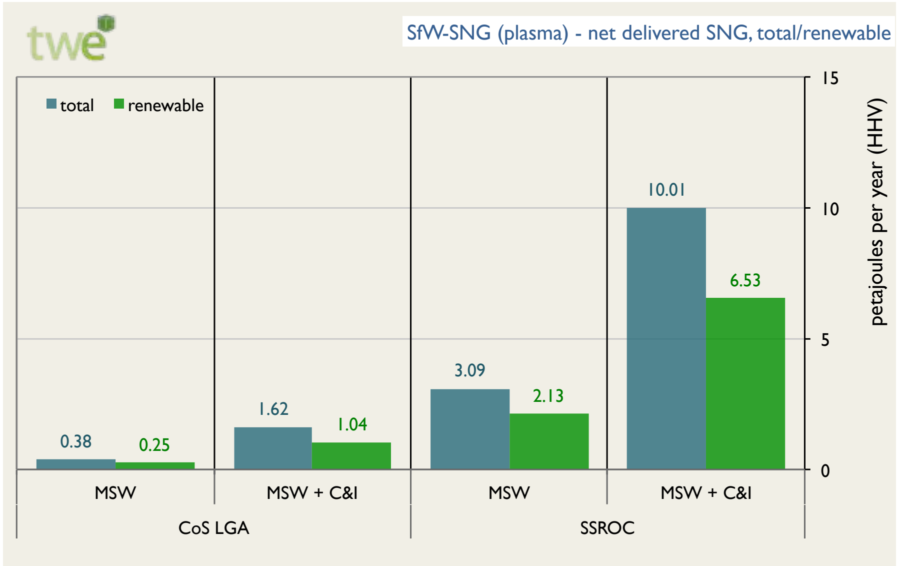
Further energy can be harnessed by converting inorganic waste into syngas. However, for the purposes of the Renewable Energy Master Plan organic waste only was taken into account for the supply of renewable gases to the City's trigeneration network. Gas derived from inorganic waste represents an additional, virtually zero carbon, unconventional non-fossil fuel resource. Both types of gases are included in this Advanced Waste Treatment Master Plan.

Of the total renewable gas resource identified in the Renewable Energy Master Plan the City's LGA own domestic, commercial and industrial waste could contribute 1.62PJ/year of renewable and non-fossil fuel gas towards displacing fossil fuel natural gas. This represents 9.5% and 6% of the gas needed to fuel the trigeneration network in the four low carbon zones for 7am–10pm and 24 hours a day, respectively. In other words, enough renewable and non-fossil fuel gas to supply between 35.5MWe and 22.3MWe of trigeneration, respectively.

Renewable gas injected into the gas grid would recover up to four times the primary renewable energy resource than renewable electricity generation only as well as producing a non-intermittent form of renewable energy from a resource that would otherwise be disposed of in landfill.

The City's plans for precinct trigeneration will create a market for renewable gases which would otherwise not exist, thereby improving the commercial viability of energy from waste projects as well as contributing towards the economy.

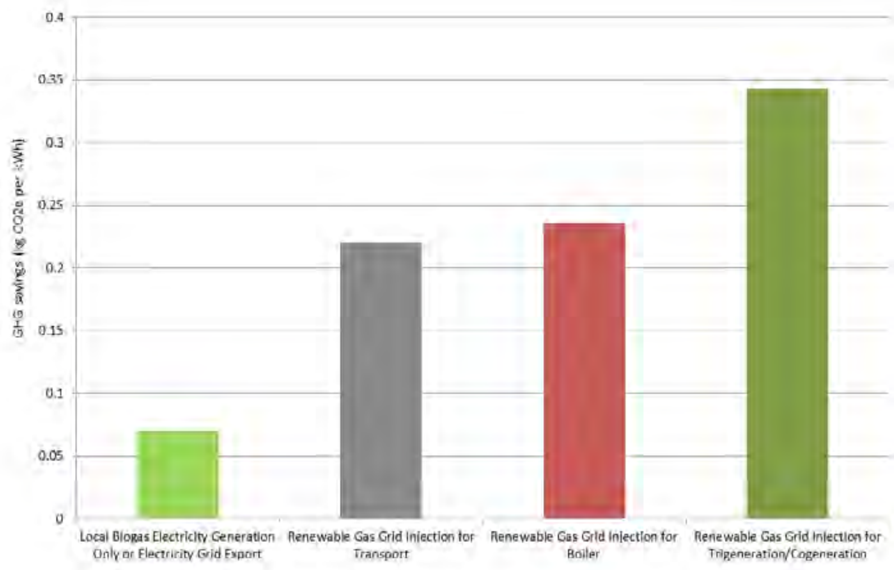
FIGURE 68: SYNGAS FROM WASTE – SUBSTITUTE NATURAL GAS (PLASMA) – NET, DELIVERED SNG, TOTAL/RENEWABLE (SOURCE: TALENT WITH ENERGY)



RENEWABLE GAS V RENEWABLE ELECTRICITY EFFICIENCY

Utilising renewable gas from bioenergy for injection into the gas grid recovers typically 80% of primary renewable energy resource at end use whereas generating electricity only from bioenergy recovers typically 20–35% of primary renewable energy resource for local or on site use, less grid losses if exported into the grid for off-site end use. For renewable gas grid injection some of the gas is normally used for on site plant energy requirements, usually in the form of cogeneration, but the majority of renewable gas is grid injected. Therefore, renewable gas grid injection can deliver up to four times as much renewable energy at end use than electricity generation only.

FIGURE 69: GREENHOUSE GAS EMISSION SAVINGS FOR RENEWABLE GAS GRID INJECTION (SOURCE: CITY OF SYDNEY)



FINANCIAL ANALYSIS

The costs and achievement of the renewable energy and emission reduction targets are dependent on the uptake of the renewable energy technologies as set out in the Renewable Energy Master Plan.

In order to determine the cost of renewable energy the cost per unit of electricity generated over the lifetime of each renewable energy technology was calculated, referred to as the levelised cost of electricity (LCOE) or the levelised cost of gas (LCOG). The delivered costs, the amount of energy generation, and the volume of carbon abated were also analysed.

Renewable electricity generation beyond the city will also be subject to all the above costs. Renewable electricity generated beyond the city will also need to compete with the wholesale price of electricity in the National Electricity Market (NEM). Renewable gas generated will need to be competitive with the wholesale or hub price of natural gas. With the expansion of liquified natural gas for export accelerating, this price may see upward movement making locally sourced gas more competitive in the medium term.

COST OF RENEWABLE GAS

The estimated costs of constructing generating capacity using each type of renewable gas technology and resources are detailed in Figure 70. Natural gas capital cost estimates are drawn from the Australian Energy Technology Assessments (AETA) published by the Australian Government and the four types of renewable gas/substitute natural gas (SNG) were estimated by Talent With Energy.

The four types of renewable SNG analysed are, as follows:

- SNG sourced from municipal solid waste (MSW) and commercial and Industrial (C&I) waste;
- SNG sourced from biomass, such as forestry waste and broadacre crop residue;
- SNG sourced from large scale biogas, such as vegetable crops and horticulture, chicken and cattle manure; and
- SNG sourced from small scale biogas (including sewage gas) and landfill gas.

With the exception of conventional natural gas, the costs of SNG are based on a levelised cost of gas (LCOG).

The economic feasibility of the City's approach to conversion technologies relies on revenue from:

- gate fee charges to users; and
- gas and/or fuel sales.

The major cost components of advanced waste treatment facilities include:

- development (e.g. planning and design, community consultation, development approval and environmental impact assessment);
- site acquisition, buffer zones, etc;
- capital financing;
- feedstock (securing supply; can be income for some feedstocks); and
- operation (e.g. maintenance, administration.

SUBSTITUTE NATURAL GAS (SNG)

LEGEND:

SfW-SNG – Syngas from Waste

SfB-SNG – Syngas from Biomass

LsB-SNG – Large Scale Biogas

SsB-SNG – Small Scale Biogas

LFG-SNG – Landfill gas

FIGURE 70: ESTIMATED DELIVERED COST OF NATURAL GAS AND RENEWABLE GAS, BY TYPE OF GAS, 2012 DOLLARS PER GIGAJOULE (SOURCE: TALENT WITH ENERGY)

	SNG delivered, net PJ_{HHV}/y		Gas prices (Central), AUD_{2012}/GJ_{HHV}			
	total	renewable	2014-15	2019-20	2024-25	2029-30
Natural gas (NSW,ACT) [a]			6.99	8.57	10.14	11.71
Substitute Natural Gas [b]	48.96	37.06				
SNG-SfW (plasma)	33.01	21.60	6.2 - 6.4	4.66 - 4.81	3.46 - 3.57	2.55 - 2.63
SNG-SfB [c]	3.52	3.03	10.69 - 13.85	7.44 - 9.63	5.18 - 6.68	3.6 - 4.62
SNG-LsB [c]	7.43	7.43	6.95 - 18.27	5.07 - 13.04	3.68 - 9.28	2.65 - 6.75
SNG-SsB	2.98	2.98	6.18	4.39	3.11	2.19
SNG-LfG	2.01	2.01	6.84	4.76	3.32	2.31

[a] Projected natural gas prices from (BREE 2012), Table 2.3.2

[b] Estimates from Talent with Energy (2012), include delivery operations (10 km injection pipeline for C-SNG delivery), pipeline T&D charges and 15% retail margin

[c] Estimates from Talent with Energy (2012), high estimates for sites with L-SNG delivery

1 ADVANCED WASTE TREATMENT

2 RE-THINKING WASTE AS A RESOURCE

3 ADVANCED WASTE TREATMENT FOR THE CITY OF SYDNEY

4 PERFORMANCE MEASURES

5 ENABLING THE MASTER PLAN

6 CASE STUDIES

The City's preferred waste to syngas to Substitute Natural Gas pathway for direct delivery of renewable energy reduces the size of the infrastructure needed at a facility location and avoids costly electricity infrastructure grid connection and augmentation issues. This is because the City preferred process "de-couples" the *generation* of gas from the *consumption* of gas for local electricity and other energy needs. It provides opportunity for storage of energy recovered from waste as a gas until the consumers preferred time of demand for the energy.

Energy Storage in the Existing Eastern Australian Gas Market

The existing gas storage facility capacity in the Eastern Australian gas market exceeds 150PJ, which is the equivalent of storing 41,700GWh of renewable electricity, more than Eastern Australia's share of the 20% Renewable Energy target and more than 90% of the entire Australian Mandatory 20% Renewable Energy Target of 45,000GWh by 2020.

This process also removes the conventional electricity generation emissions at the facility that would have otherwise been generated for electricity exported to the electricity grid and replaces this with low substitute natural gas emissions where natural gas is being consumed in the City of Sydney LGA.

Injecting renewable gas, in the form of substitute natural gas, into the gas grid also takes advantage of the inherent energy storage in the existing gas grid and thus providing a non-intermittent form of renewable energy directly competing with and replacing fossil fuel energy.

Electricity once generated has to be immediately consumed regardless of end-use demand or the cost or value of the electricity generated. In NSW, wholesale electricity price fluctuates depending on the time of day and day of the week. Retail electricity prices are charged during peak, shoulder and off peak periods. Off peak electricity prices are very low, representing about 37.5% of the electricity pricing periods.

As gas can be stored and consumed at different times of the day and week than from when the gas was produced there are no time of day or week tariffs, just a single hub price for the volume of gas injected into the gas grid. Gas pricing therefore provides more certainty and less risk than electricity pricing.

The financial viability of conversion technologies relies more heavily on revenue from energy sales through products such as gases or fuels, which are not locked into varying wholesale electricity prices. The ability to operate in these higher value energy markets and the inherent compactness and modularity of conversion technologies, make thermal conversion-based schemes feasible at lower level of throughputs.

The conventional at-facility electricity generation model historically used by energy from waste facilities would typically rely on steam boilers generating steam for steam turbines. Such facilities lose most of the energy generated in the form of waste heat rejected into the atmosphere and are restricted to operating at near constant thermal load, as powering down would require a high use of fuel to reach operational levels again.

Renewable gas grid injection, on the other hand, can recover up to three times the renewable energy resource for end use consumption compared to at-facility electricity generation only. Gasification can also vary its renewable gas output to match the daily changing input of non-recyclable waste materials, but the output still commands a less uncertain daily gas price. This significantly improves the economics of renewable gas grid injection over the inefficient electricity export model and contributes to the City objective to identify a waste technology that can accommodate changes to waste composition and levels over time.

AVOIDED LANDFILL AND TREATMENT COSTS
The avoided costs associated with not transporting and ultimately disposing even current levels of waste to landfill for both residential and commercial sectors is significant. For the City, there will be significant costs avoided from existing MSW processing which still incorporates a significant landfill cost and waste levy component.

Diminishing landfill capacity, the exorbitant capital and social cost of establishing new landfill sites, the rising costs of the NSW waste levy are sufficient to warrant investment in thermal treatment to reduce waste residues requiring landfilling across all waste streams, quite apart from the value of the renewable gases generated.

The capital cost of advanced waste technologies is significant. The pricing structure of energy recovery will be dependent on the variance in operating costs, avoided NSW waste levy and other fees and charges and the income derived from additional recycling (extracted metals from gasification) and renewable gas sales compared with the current and future (by 2030) operating costs in the treatment and disposal of non-recyclable waste.

In addition, gate fees for acceptance of waste material from sources other than the City's residents will help address the ongoing costs of facility operation. The viability of an advanced waste treatment improves as landfill prices rise, allowing for improved gate fees while still remaining competitive.

ENERGY FROM WASTE FUNDING AND SUPPORT
The NSW government has recently published an energy from waste policy. It is expected that with the market certainty offered by an improved understanding of the regulatory environment that technology providers can offer prices factoring in known risk.

Infrastructure funding assistance and support can potentially be sourced from both the Federal and State governments.

At a federal level, the proposed advanced waste treatment approach in this Master Plan should be eligible for Australian Renewable Energy Agency (ARENA) scheme funding.

At the state level, both Infrastructure NSW and funds now specifically allocated from the Waste Levy for waste processing infrastructure could be sought to support the green infrastructure for contributing to both energy and waste targets in the state. These grant funds offer up to $10 million for successful candidate projects.

LARGE-SCALE GENERATION CERTIFICATES (LGCs)
Large-scale Generation Certificates can be claimed for generating electricity from the renewable components of waste for power plants over 1 MW. These can apply to the local generation of electricity in the City by trigeneration utilising substitute natural gas from renewable sources.

Electricity that is generated from fossil fuels, or waste products derived from fossil fuels, is not eligible for LGCs, but energy derived from renewable sources will earn LGCs. As noted earlier in Chapter 2, audits have shown that the renewable component of waste disposed in the City is a significant portion of the total.

The City has also audited the level of renewable energy from this component, as a fraction of the total energy that could be generated. Depending upon the technology selected, around 70% of the gas generated from waste is derived from renewable sources.

However, unlike Europe, the existing Australian guidelines for determining the renewable energy component of electricity generated from waste (provided by the Clean Energy Regulator) is outdated and does not account fully for the materials in the City's waste stream that are from renewable organic sources.

Clarification will need to be sought on the method to be applied to correctly account for Large-scale Generation Certificates claims. These claims will arise from the generation of renewable electricity by trigeneration in the City of Sydney LGA. Alternatively, renewable gas and renewable heat targets and associated renewable energy certificates may be established by Australian or NSW Governments, similar to Europe.

1 ADVANCED WASTE TREATMENT
2 RE-THINKING WASTE AS A RESOURCE
3 ADVANCED WASTE TREATMENT FOR THE CITY OF SYDNEY
4 PERFORMANCE MEASURES
5 ENABLING THE MASTER PLAN
6 CASE STUDIES

1.

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3.

4.

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INDICATIVE FINANCIAL ANALYSIS FOR ADVANCED WASTE TREATMENT FACILITY WITH RENEWABLE GAS GRID INJECTION

The financial analysis for a 100,000 tonnes a year advanced waste treatment facility with renewable gas grid injection is set out in Figure 71 and the financial analysis for a 150,000 tonnes a year advanced waste treatment facility with renewable gas grid injection is set out in Figure 72.

FIGURE 71: INDICATIVE FINANCIAL ANALYSIS FOR 100,000 TONNES A YEAR ADVANCED WASTE TREATMENT FACILITY WITH RENEWABLE GAS GRID INJECTION (SOURCE: CITY OF SYDNEY BASED ON TALENT WITH ENERGY AND ALLENS CONSULTING DATA)

Facility Processing Capacity (per year)	100,000 tonnes
Site Size	5 ha
CPI escalation Rate	3.0%
Wages & Salaries Growth	3.5%
Equipment escalation rate (per TWE)	1.85%
Discount rate (WACC)	9.5%
Life of equipment	35 Years

Note: Financial analysis based on treating 100,000 tonnes of non-recycled domestic, commercial and industrial waste. Assumptions used for cost of capital and ancillary equipment, and gas costs, based on figures used in the Gasification Technology Review (see Appendix). However, the advanced waste treatment facility may be increased to treat up to 150,000 tonnes of non-recycled domestic, commercial and industrial waste depending on the take up of the facility from commercial and industrial businesses in the City of Sydney LGA and/or one or more of adjacent local authorities. All assumptions based on existing NSW and Federal policy settings.

																		Five-year highlights				
Items reported in ($'000s) (Loss)/Surplus	**BASE YEAR**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**Year 11**	**Year 12**	**Year 13**	**Year 14**	**Year 15**	**Year 16**	**Year 21**	**Year 26**	**Year 31**	**Year 36**	
Direct Capital Costs																						
Thermal Conversion Equipment		(60,883)	(60,883)															(35,788)				
Syngas Upgrading Facility		(4,892)	(4,892)																			
Building Cost		(3,289)	(3,289)																			
Indirect Capital Cost																						
Engineering, licences, contingency		(14,716)	(14,716)																			
Estimated Land Cost	(35,000)																					
Capital Investment Total (cumulative)	**(35,000)**	**(118,779)**	**(202,558)**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**(238,346)**	**-**	**-**	**-**	**TOTALS**
Annualised Capital Investment	**(3,470)**	**(11,775)**	**(20,081)**	**(20,081)**	**(20,081)**	**(20,081)**	**(20,081)**	**(20,081)**	**(20,081)**	**(20,081)**	**(20,081)**	**(20,081)**	**(20,081)**	**(20,081)**	**(20,081)**	**(20,081)**	**(20,081)**	**(23,629)**	**(23,629)**	**(23,629)**	**(23,629)**	**(781,948)**
Operating, Maintenance, Employees, Electricity	-	(900)	(9,845)	(9,512)	(9,871)	(10,243)	(10,626)	(10,982)	(11,342)	(11,717)	(12,083)	(12,478)	(12,868)	(13,281)	(13,692)	(14,096)	(14,545)	(16,488)	(19,295)	(22,588)	(26,454)	(589,459)
Waste disposal	-	-	(2,884)	(2,984)	(3,089)	(3,197)	(3,310)	(3,427)	(3,549)	(3,675)	(3,807)	(3,944)	(4,087)	(4,235)	(4,389)	(4,550)	(4,687)	(5,433)	(6,298)	(7,302)	(8,464)	(185,521)
Operating Expenditure	**-**	**(900)**	**(12,729)**	**(12,497)**	**(12,960)**	**(13,440)**	**(13,935)**	**(14,409)**	**(14,890)**	**(15,392)**	**(15,890)**	**(16,422)**	**(16,955)**	**(17,516)**	**(18,082)**	**(18,646)**	**(19,231)**	**((22,447)**	**(26,210)**	**(30,614)**	**(35,769)**	**(774,980)**
Gate fees revenue	-	-	11,758	11,938	12,124	12,308	12,505	12,688	12,872	13,057	13,243	13,468	13,711	13,997	14,298	14,608	14,918	16,534	18,249	19,682	21,902	567,064
Avoided waste disposal costs	-	-	11,929	12,531	13,148	13,797	14,453	15,158	15,890	16,651	17,441	18,206	18,980	19,726	20,485	21,268	22,087	26,677	32,220	37,474	47,003	924,115
Income	**--**	**-**	**23,687**	**24,468**	**25,273**	**26,105**	**26,959**	**27,846**	**28,762**	**29,708**	**30,683**	**31,674**	**32,691**	**33,723**	**34,783**	**35,876**	**37,005**	**43,211**	**50,470**	**57,156**	**68,904**	**1,491,179**
Net Cost of Gas Production – Discounted	(2,894)	(9,654)	(6,346)	(5,151)	(4,507)	(3,929)	(3,415)	(2,936)	(2,506)	(2,125)	(1,780)	(1,484)	(1,219)	(993)	(791)	(610)	(450)	(355)	50	236	302	**(50,896)**
Gas Sales at wholesale rates – Discounted			3,307	3,135	2,972	2,817	2,654	2,501	2,356	2,220	2,092	1,971	1,857	1,749	1,648	1,553	1,463	1,086	807	599	445	50,896
Discounted Net Result (Inc. Gas sales)	**(2,894)**	**(9,654)**	**(3,039)**	**(2,016)**	**(1,535)**	**(1,112)**	**(761)**	**(435)**	**(149)**	**95**	**312**	**487**	**637**	**757**	**857**	**943**	**1,013**	**731**	**856**	**835**	**747**	**0**

KEY ASSUMPTIONS (based on Plasma Gasification)

GATE FEES MINIMUM to achieve "break-even" ($ per tonne)	$181	$186	$192	$198	$204	$210	$216	$223	$229	$236	$243	$251	$258	$266	$274	$282	$290	$337	$390	$439	$525
GAS WHOLESALE PRICE (projected) ($ per GJ)	$7.11	$7.38	$7.66	$7.96	$8.26	$8.57	$8.84	$9.12	$9.41	$9.71	$10.02	$10.34	$10.66	$11.00	$11.35	$11.71	$12.08	$14.12	$16.51	$18.70	$22.55

The indicative financial analysis shows that a facility processing either 100,000 or 150,000 tonnes of waste per year can potentially achieve a net present value of $0.00 (or "break-even") over a 35 year period, whilst offering a competitive gate fee for commercial users, if projected wholesale gas prices are received for synthetic natural gas outputs produced.

This indicative analysis undertaken incorporating an "avoided cost" for the City's existing waste treatment suggests that the treatment facility can achieve positive annual results from year 9, also including an annualised capital charge (based only on stated assumptions in the tables).

FIGURE 72: INDICATIVE FINANCIAL ANALYSIS FOR 150,000 TONNES A YEAR ADVANCED WASTE TREATMENT FACILITY WITH RENEWABLE GAS GRID INJECTION (SOURCE: CITY OF SYDNEY BASED ON TALENT WITH ENERGY AND ALLENS CONSULTING DATA)

Facility Processing Capacity (per year)	150,000 tonnes
Site Size	5 ha
CPI escalation Rate	3.0%
Wages & Salaries Growth	3.5%
Equipment escalation rate (per TWE)	1.85%
Discount rate (WACC)	9.5%
Life of equipment	35 Years

																		Five-year highlights				
Items reported in ($'000s) (Loss)/Surplus	**BASE YEAR**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**Year 11**	**Year 12**	**Year 13**	**Year 14**	**Year 15**	**Year 16**	**Year 21**	**Year 26**	**Year 31**	**Year 36**	
Direct Capital Costs																						
Thermal Conversion Equipment		(76,988)	(76,988)															(45,255)				
Syngas Upgrading Facility		(4,892)	(4,892)																			
Building Cost		(4,094)	(4,094)																			
Indirect Capital Cost																						
Engineering, licences, contingency		(17,590)	(17,590)																			
Estimated Land Cost	(35,000)																					
Capital Investment Total (cumulative)	**(35,000)**	**(138,564)**	**(242,128)**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**(287,383)**	**-**	**-**	**-**	**TOTALS**
Annualised Capital Investment	**(3,470)**	**(13,737)**	**(24,004)**	**(24,004)**	**(24,004)**	**(24,004)**	**(24,004)**	**(24,004)**	**(24,004)**	**(24,004)**	**(24,004)**	**(24,004)**	**(24,004)**	**(24,004)**	**(24,004)**	**(24,004)**	**(24,004)**	**(28,490)**	**(28,490)**	**(28,490)**	**(28,490)**	**(938,102)**
Operating, Maintenance, Employees, Electricity	-	(900)	(11,849)	(11,615)	(12,070)	(12,543)	(13,028)	(13,472)	(13,917)	(14,382)	(14,831)	(15,320)	(15,797)	(16,305)	(16,809)	(17,297)	(17,847)	(20,879)	(24,436)	(28,609)	(33,505)	(722,808)
Waste disposal	-	-	(4,326)	(4,476)	(4,633)	(4,795)	(4,965)	(5,140)	(5,323)	(5,513)	(5,711)	(5,916)	(6,130)	(6,353)	(6,584)	(6,825)	(7,030)	(8,150)	(9,448)	(10,952)	(12,697)	(278,282)
Operating Expenditure	**-**	**(900)**	**(16,175)**	**(16,091)**	**(16,703)**	**(17,338)**	**(17,993)**	**(18,612)**	**(19,240)**	**(19,895)**	**(20,541)**	**(21,236)**	**(21,927)**	**(22,658)**	**(23,393)**	**(24,122)**	**(24,877)**	**(29,029)**	**(33,883)**	**(39,561)**	**(46,201)**	**(1,001,090)**
Gate fees revenue	-	-	15,733	16,080	16,439	16,803	17,183	17,560	17,946	18,339	18,742	19,180	19,639	20,138	20,657	21,191	21,735	24,650	27,915	31,564	35,627	847,747
Avoided waste disposal costs	-	-	11,929	12,531	13,148	13,797	14,453	15,158	15,890	16,651	17,441	18,206	18,980	19,726	20,485	21,268	22,087	26,677	32,220	38,916	47,003	924,115
Income	**--**	**-**	**27,662**	**28,611**	**29,588**	**30,600**	**31,637**	**32,719**	**33,836**	**34,990**	**36,182**	**37,386**	**38,620**	**39,865**	**41,142**	**42,459**	**43,822**	**51,326**	**60,135**	**70,479**	**82,630**	**1,771,863**
Net Cost of Gas Production – Discounted	(2,894)	(11,148)	(8,706)	(7,295)	(6,451)	(5,691)	(5,012)	(4,373)	(3,796)	(3,283)	(2,815)	(2,414)	(2,052)	(1,742)	(1,464)	(1,211)	(988)	(768)	(176)	122	252	**(76,344)**
Gas Sales at wholesale rates – Discounted			7,132	7,403	7,684	7,976	8,229	8,490	8,759	9,036	9,323	9,618	9,923	10,238	10,562	10,897	11,243	13,141	15,361	17,955	20,987	453,632
Discounted Net Result (Inc. Gas sales)	**(2,894)**	**(11,148)**	**(3,746)**	**(2,593)**	**(1,993)**	**(1,466)**	**(1,031)**	**(622)**	**(262)**	**47**	**323**	**542**	**733**	**882**	**1,008**	**1,118**	**1,207**	**862**	**1,034**	**1,020**	**919**	**0**

KEY ASSUMPTIONS (based on Plasma Gasification)

GATE FEES MINIMUM to achieve "break-even" ($ per tonne)	$130	$134	$138	$142	$147	$151	$156	$160	$165	$170	$175	$180	$186	$191	$197	$203	$209	$242	$281	$326	$378
GAS WHOLESALE PRICE (projected) ($ per GJ)	$7.11	$7.38	$7.66	$7.96	$8.26	$8.57	$8.84	$9.12	$9.41	$9.71	$10.02	$10.34	$10.66	$11.00	$11.35	$11.71	$12.08	$14.12	$16.51	$18.70	$22.55

ECONOMIC ANALYSIS

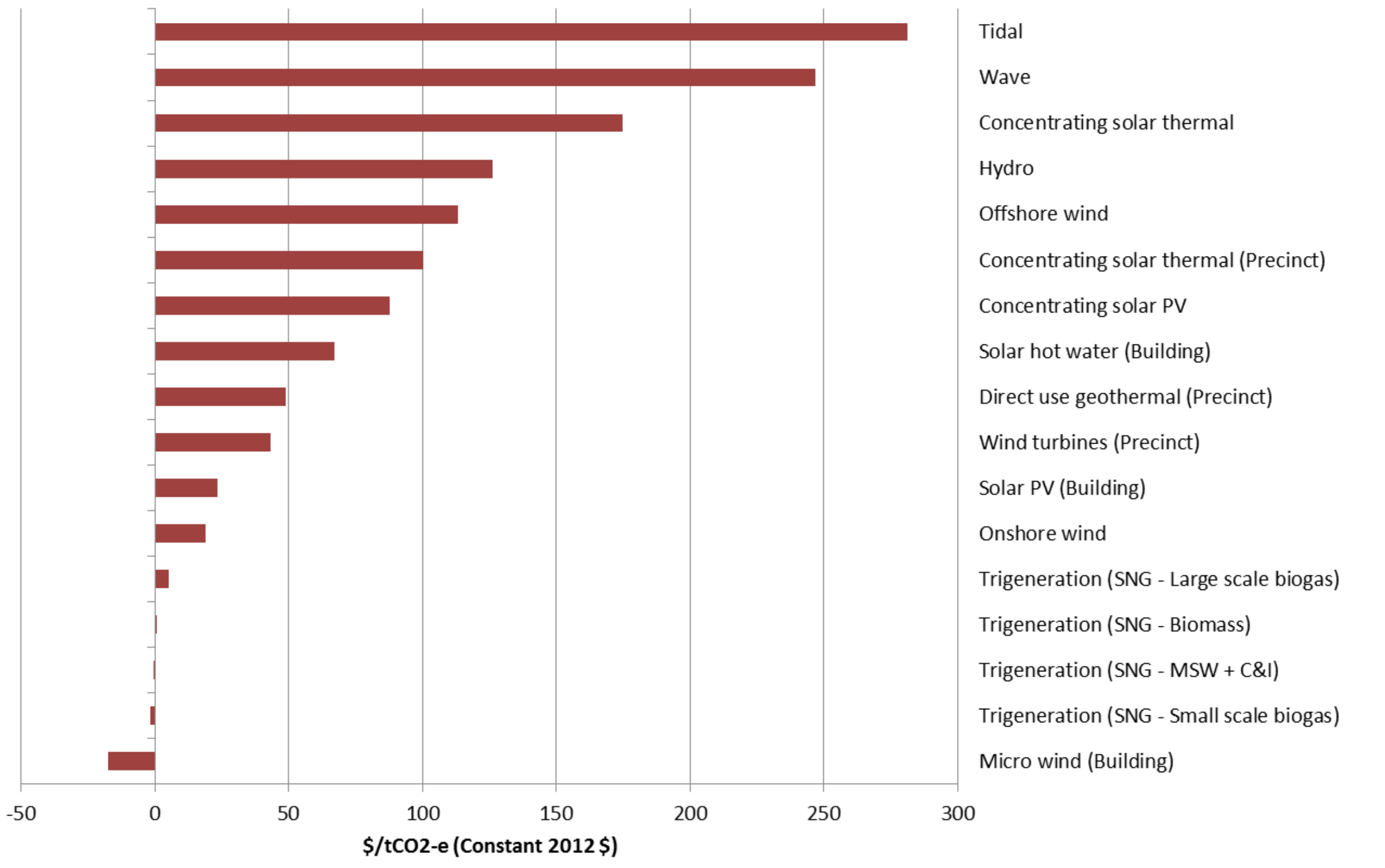
The marginal social cost of greenhouse gas abatement is defined as the marginal or incremental cost to society of the modelled scenario versus business as usual. This analysis involves like-for-like comparison of alternative technologies, based on a common set of assumptions and consistent costing methodology between the alternative technologies.

The cost of abatement approach enables renewable energy and other energy technologies to be valued according to the emissions content (or lack of emissions content) of its generated energy. Therefore, under the economic analysis approach, unlike in the financial analysis model, all of the renewable energy is assumed to be sold at a price that values its lack of emissions intensity, and grid energy is sold at its standard rate.

The City of Sydney commissioned the Allen Consulting Group and Talent With Energy to assess the renewable energy opportunities identified in the Master Plan together with the greenhouse gas abatement potential in order to quantify the marginal social cost of abatement against business as usual, which is high carbon centralised energy generation. The result for the Central Scenario, 2020, is presented in Figure 75. The results for the Central Scenario, 2025 and 2030 are shown as Figures 52 and 53 in the Renewable Energy Master Plan.

The generation of renewable gas from waste for energy purposes allows for low greenhouse emissions intensity generation of electricity locally. Trigeneration supplied with renewable gas (from MSW and C&I) is estimated to have a near zero marginal social cost of abatement, much cheaper than many other renewables. In addition, trigeneration supplied by renewable gases is a non-intermittent renewable energy technology capable of supplying 100% (with solar PV and some large scale onshore wind energy) of the City of Sydney LGA electricity, heating and cooling requirements without interruption by 2030.

FIGURE 73: MARGINAL SOCIAL COST OF ABATEMENT: CENTRAL SCENARIO, 2020 (REAL 2012 DOLLARS PER TONNE OF CO2 EQUIVALENT EMISSIONS ABATEMENT (SOURCE: ALLEN CONSULTING GROUP)



RENEWABLE GAS FROM WASTE RESOURCES BEYOND CITY OF SYDNEY LGA

Although beyond the scope of this Advanced Waste Treatment Master Plan the Renewable Energy Master Plan identified that there was more than enough renewable gas feedstock from waste resource to completely replace fossil fuel natural gas not only for the City's planned trigeneration network but also the City's domestic gas supplies.

More than 90% of the City's requirements for renewable gas supplying the planned trigeneration network would need to be deployed from a range of renewable gas feedstocks from waste beyond the City of Sydney LGA but within the 250km proximity zone to deliver the City's renewable gas target.

The total residual domestic or municipal solid waste resource available within 250km of the City's LGA but excluding the City's LGA is around 1.4 million tonnes a year, forecast to grow to around 1.9 million tonnes a year by 2030.

The total residual commercial and industrial waste resource available within 250km of the City's LGA but excluding the City's LGA is around 2.3 million tonnes a year, forecast to grow to around 2.7 million tonnes a year by 2030.

The Renewable Energy Master Plan showed that at least 48.96PJ/year of renewable and non-fossil gas could be recovered within 250km of the City's LGA. Of this gas 37.06PJ/year is renewable gas and 11.9PJ/year is non-fossil fuel gas.

The City of Sydney LGA represents 25% of NSW gross domestic product (GDP) and 8% of Australia's GDP. This is reflected in the City's LGA energy consumption and electricity peak demand. Local authorities, commercial and industrial businesses as well as the agriculture and farming sectors within 250km of the City's LGA therefore have a significant renewable gas market to export substitute natural gas to via the existing natural gas grid. Although some of this renewable gas is likely to be consumed locally the renewable gas potential of this area is greater than can be consumed locally.

FIGURE 74: DIVERSION OF CITY OF SYDNEY WASTE FROM LANDFILL BY 2030 (SOURCE: CITY OF SYDNEY)

Residual Waste to HTC + Ash Melting Gasification	Diverted from Landfill (Tonnes pa)	Reduction in GHG Emissions (TCO_{2-e} pa)	Avoided NSW Waste Levy ($ million pa)
MSW Gasification	1,900,000	2,257,000	177
C&I Gasification	2,700,000	2,940,000	252
MSW & C&I TOTAL	**4,600,000**	**5,197,000**	**429**

Advantages to other local authorities for advanced waste treatment and renewable gas grid injection plants being developed in their area is the virtual elimination of non-recyclable waste going to landfill and the avoidance of the NSW waste levy. For example, if all of the residual domestic waste within 250km of the City's LGA but excluding the City's LGA was diverted from landfill to advanced waste treatment and renewable gas grid injection plants this could reduce greenhouse gas emissions by 2.257 $MtCO_{2-e}$ a year and avoid around $177 million a year in NSW waste levy payments by 2030. Similarly, for commercial and industrial businesses which could reduce greenhouse gas emissions by 2.94 $MtCO_{2-e}$ a year and avoid around $252 million a year in NSW waste levy payments by 2030.

The potential reduction in greenhouse gas emissions beyond the City's LGA brought about by the City's Renewable Energy Master Plan is equivalent to a 95% reduction below the City's LGA 2006 greenhouse gas emissions demonstrating that where a world city such as Sydney sets an example for others to follow the environmental and economic benefits of such action can spread well beyond the City of Sydney local government area.

The estimated diversion of waste to landfill and avoided NSW Waste Levy, if high temperature conversion with ash melting gasification technologies similar to the City of Sydney advanced waste treatment project were utilised to treat residual waste within 250km of the City of Sydney LGA by 2030, is shown in Figure 74.

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ENABLING THE MASTER PLAN

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ENABLING THE MASTER PLAN

Implementing advanced waste treatment technologies for the City's own domestic waste and commercial and industrial waste in the City of Sydney LGA can be complex. The responsibility of implementing this Master Plan rests with the City of Sydney. However, the current regulatory environment is out of step with modern advanced waste treatment technologies and renewable gas from waste solutions as employed in other jurisdictions around the world. Facilitating the use of renewable gas grid injection technologies for the City of Sydney LGA is over and above current government targets for renewable energy, which contrary to the term, is for renewable electricity only. This requires action on behalf of residential and business communities, and the State and Federal Governments all working in cooperation with the City of Sydney.

This chapter outlines the necessary enabling actions needed to bring about a positive change. These have been framed to be complimentary to the actions in the Renewable Energy and Trigeneration Master Plans.

The City of Sydney does not expect to deliver this Master Plan alone. It requires the support of Sydney's residents and businesses and a modern regulatory environment that allows 21st century methods to treat waste as a resource and not a waste destined for incineration or landfill.

1. **DEVELOP SUCCESS CRITERIA FOR LOCATING AN ADVANCED WASTE TREATMENT FACILITY**
2. **ENGAGE THE LOCAL COMMUNITY**
3. **ESTABLISH RENEWABLE GAS TARGET AND DEVELOP REGULATORY REGIME FOR RENEWABLE GASES**
4. **DEVELOP A NATIONAL ENERGY FROM WASTE POLICY THAT MINIMISES EMISSIONS AND WASTE BEING DISPOSED OF TO LANDFILL**
5. **ESTABLISH AN IMPROVED METHODOLOGY FOR DETERMINING THE RENEWABLE ENERGY COMPONENT FROM WASTE**
6. **ESTABLISH NEW DEFAULT GREENHOUSE GAS EMISSION VALUES FOR POST ADVANCED WASTE TREATMENT WASTE**
7. **MAKE STATE AND FEDERAL FUNDS AVAILABLE FOR ADVANCED WASTE TREATMENT FACILITIES**
8. **STANDARDISE CONNECTION FEES FOR RENEWABLE ELECTRICITY AND GAS NETWORKS**

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1.

DEVELOP SUCCESS CRITERIA FOR LOCATING AN ADVANCED WASTE TREATMENT FACILITY

There are three principal constraints on any location of a gasification type facility:

1\. **Planning Zones** permitting a waste recovery facility. Heavy industrial zones are one of those permitted areas.

2\. **Proximity to gas pipelines of suitable capacity** for reticulating the anticipated supply of renewable gas back into the City. The output of substitute natural gas from the facility must be matched to the ability of a gas injection point and pipeline that can accommodate that level of gas.

3\. **Size of the facility** itself, housing all of the processes that need to be integrated on one site. This includes not only the gasification unit itself, but the inclusion of waste sorting and preparation areas, and the inclusion of SNG methanation technologies will determine the facility footprint. The site must be sufficiently scaled to allow for any staged introduction of additional processes.

Secondary constraints will help determine the optimal location of a facility.

4\. **Proximity to source of waste:** The location of an advanced waste treatment facility will ideally be situated as close as possible to where the major sources of waste supply, to reduce transportation and encourage commercial partners to utilise the facility. Therefore, sites within or in close proximity to the City will be the priority for investigation. Travel distance is a primary consideration for the cost of commercial waste management. Travel distance impacts the economics because it can affect driver costs, vehicle maintenance, and importantly the ability to improve efficiency by collecting greater aggregated volumes of waste in a set period of time.

5\. **Transport Impacts:** Limiting the transport distance and subsequent costs and carbon footprint for waste collection vehicles will greatly influence the suitability of where to locate an Advanced Waste Treatment facility. A location where the re-direction of vehicles from existing waste management facilities to the waste treatment facility does not adversely impact on congestion, transport times and the local community is required.

Finally, there are criteria that will address amenity and compatibility issues concerning a facility location over time, that will influence decisions. The City has identified the determination of all these criteria as an Enabling Action for the Master plan, and will engage the broader community on their final composition (see Chapter 5 Enabling Actions).

Locating an advanced waste treatment facility within Sydney, or inner Sydney, requires careful consideration of perceived amenity issues for communities, and the principal constraints limiting the site options for a facility (see Chapter 3).

The key factors that determine site suitability are grouped into financial, technical, environmental and social impacts. These criteria ensure that risk-based issues are taken into account in the decision making process in a transparent way.

Because the final location will be the subject of a separate process by which the City may choose to acquire a site itself, or elect to take up a technology with a site already chosen, the criteria by which the City will locate an advanced waste treatment are important for either scenario.

High level analysis and community engagement feedback undertaken by the City has enabled the development of some general success criteria for locating a facility. Together with the infrastructure and zoning constraints identified, the following are the minimum criteria for locating an advanced waste treatment facility site.

- **Suitable Zoning:** Approved land use zoning for waste recovery facility, such as Heavy Industrial.
- **Proximity to gas grid pipeline connection**: Of suitable scale and pressure rating for volume of SNG delivered.
- **Accommodate Facility Footprint:** Sufficient land availability at a suitable land cost, allowing for expansion and addition of waste streams for recovery.
- **Proximity to source of waste:** The location should be positioned as close to the sources of waste generation as feasible. This would allow commercial intake by avoiding premium transport costs.
- **Minimise Traffic Impacts:** Consideration of a 'pathway of least impact' for delivery of waste to the facility. Ensure that there are no significant adverse impacts on local traffic congestion, and the re-direction of vehicles from existing waste facilities do not contribute to congestion or on local communities. Direct high traffic access would be preferred, avoiding spill over into residential areas. Impacts on road degeneration from heavy traffic should be considered.
- **Avoid Noise and Odour pollution:** The facility located where noise and odour impacts on nearby residents are minimised and meet relevant EPA standards. Hours of operation need to be considered as part of noise and odour management
- **Buffer Zones:** Sites need to be sufficiently large or removed from residential dwellings to contain possible environmental challenges and to reduce the operational and approval risks of a facility.
- **Aesthetics:** The facility and location need to be able to be landscaped, made attractive and visually appropriate and integrated with the local area.
- **Avoid Urban Encroachment:** Compatibility of current land use and future zoning so as not to be adversely impacted by changes in land use or residential encroachment.
- **Climate Change-Proof:** Coastal or estuary sites must consider sea level rise changes
- **Low Amenity Impact:** Social impacts are considered, such as residential amenity, employment, cultural heritage, health and safety.
- **Local Tourism and Business impacts:** Impacts on potential business opportunities for the local area to be assessed. Impacts that may negatively impact on local tourism or costs to local business should be considered in location assessment.

The City will determine any need to acquire a facility site in order to ensure that what is delivered at procurement and construction stages is the same as what has been approved at planning stage in terms of site footprint, nature and size of facility.

The City will engage with the community to test and review these criteria, as outlined in Enabling Action 2.

2.

ENGAGE THE LOCAL COMMUNITY

The most challenging aspect of delivering advanced waste treatment as part of the City's Green Infrastructure Plan is the acceptance of this technological solution by the community.

Advanced waste treatment facilities require more than capital and regulatory acceptance, they critically need a social licence to operate from the community.

To preserve the City's commitment to sustainability as set out in Sustainable Sydney 2030, the location of a facility must be acceptable to the host community.

The City has already consulted the community in the preparation of this Master Plan, and extensively engaged the business sector and other stakeholders.

The City will prepare community engagement plans for both the City community in general, and the host community directly located near a facility. By engaging the community with frank discussion and increasing understanding of a critical activity such as sustainable waste processing and energy recovery, the decisions regarding energy recovery and material processing would be more transparent.

Community engagement plans will seek to deliver benefits to the host community where appropriate. Example action may include competitive energy local supply, support for sport and educational activities, or opportunities to investment in the facility.

It will be important to improve community understanding of how waste can be used to meet sustainable energy needs as part of the City's Green Infrastructure Plan, by producing renewable gas that can provide renewable electricity, heating and cooling at competitive rates.

While some form of genuine recovery accreditation would be of help in addressing issues in the local community, direct engagement would offer a higher investment of trust.

Internationally, energy recovery from waste facilities host a range of community activities, including sport and educational activities, and provide subsidised energy for these.

Decisions regarding operation of a facility must await potential future procurement processes, but some minimum information that would be provided to the community include:

- Emissions and gas quality monitoring data accessible via the internet or social media.
- Regular publicised audits and recommendations for changing recovery systems for specific materials.
- Community input to assist with development and implementation of any Environmental Management System.
- Assisting local tertiary education institutions to conduct research using the facility.

3.

ESTABLISH RENEWABLE GAS TARGET AND DEVELOP REGULATORY REGIME FOR RENEWABLE GASES

Australian and NSW Governments should establish a target of 20% renewable gas similar to the Renewable Electricity Target and implement gas regulatory reform to enable gas purchase agreements between renewable gas generators and customers and a national accreditation program for GreenGas similar to power purchase agreements and GreenPower for renewable electricity.

Development of a regulatory regime for renewable gases will remove regulatory barriers to renewable gases and enhance the financial, security of supply and reduction in greenhouse gas emissions performance of advanced waste treatment and decentralised energy (cogeneration, trigeneration and fuel cells), renewable heating and cooling, and renewable energy for transport and energy storage.

The regulatory regime for renewable gases should be designed to ensure that renewable gases are preferentially used to supply decentralised energy (cogeneration, trigeneration and fuel cells), renewable heating/cooling and transport applications to maximise the efficiency and reductions in greenhouse gas emissions of the renewable gas market. The preference for renewable gases in highly efficient energy generation systems is borne out by analyses showing large gains in greenhouse gas reduction for uses other than immediate electricity generation (see Figure 68: Greenhouse gas emissions savings).

A renewable energy target for renewable gas should also be adopted by State and Federal Governments in addition to the Renewable Electricity Target.

In order to support this, regulatory reform should also ensure that renewable gas is treated differently to and incentivised over natural gas. Renewable gas should be granted preferred network access to the gas grid, preferred network entry by gas grid operators and extended accounting balance for transport applications to stimulate the renewable gas market.

In the UK, the Government's Renewable Energy Strategy 2008 included renewable gas (biomethane) injection into the gas grid. The UK's National Grid published a paper in January 2009 setting out that renewable gas grid injection, with the right government policies in place, could meet up to 50% of the UK's domestic gas demand. Produced mainly via a process of anaerobic digestion or thermal gasification of the UK's biodegradable waste, renewable gas can deliver greater security of energy supply for the country as well as a solution for waste management as UK landfill capacity declines.

The UK energy regulator, the Office of Gas and Energy Markets (OFGEM) published a renewable gas grid injection fact sheet in 2009 and included special renewable gas charging arrangements for renewable gas grid injection in its eight year gas distribution price control for the period 1 April 2013 to 31 March 2021. Gas distribution network operators will be rewarded for delivering environmental benefits over and above their price control obligations through a Discretionary Reward Scheme, which will be able to fund environment projects including the connection of renewable gas to the gas grid through a new innovation fund of £160 million over the eight year price control period.

In 2011, the UK Government legislated for a Renewable Heat Incentive, the first legislation of its kind in the world. Technologies earmarked for support includes renewable gases derived from waste (biogas from anaerobic digestion and syngas from gasification/pyrolysis) injected into the gas grid. At the same time the UK's energy providers launched the Green Gas Certificate Scheme that tracks renewable gas, or 'green gas' through the supply chain to provide certainty for consumers who buy the gas, confidence in the green gas sector and an incentive for gas producers to inject renewable gas into the gas grid.

In Germany, the Renewable Energy Sources Act 2009 (Erneuerbare-Energien-Gesetz, EEG) and the Renewable Energies Heat Act 2009 set in law that 14% of German heat demand is to be produced from renewable energy sources. This includes renewable gases, biomass and solar thermal and geothermal heat or the cogeneration of heat and electricity from renewable sources. Under German law renewable gas can only be used by decentralised energy (cogeneration/trigeneration), renewable heat or transport applications. Renewable gas cannot be used for electricity generating only power stations or the general domestic gas market. This is to maximise energy efficiency and emissions reduction and to prevent 'price gouging' where renewable gas is cheaper than fossil fuel natural gas.

The Gas Network Access Ordinance was also amended to ensure that the charging of transmission and distribution tariffs do not discriminate against renewable gas and to extend the existing gas grid to facilitate the integration of gas from renewable sources (Article 6 of European Directive 2003/55/EC). The Ordinance also ensures that renewable gas is granted preferred network access to the gas grid, preferred network entry by gas grid operators and extended accounting balance for transport applications.

Germany now has more than 7,000 renewable gas generators and since 2009 more than 170 renewable gas grid injection plants injecting more than 8.5 billion kWh a year of renewable gas into the gas grid network against the EEG target to exploit a minimum 60 billion kWh of renewable gas by 2020 and a minimum 100 billion kWh of renewable gas by 2030. This demonstrates the speed of action that can be delivered with good energy policy and regulation. Notwithstanding the minimum EEG targets the German Government expects that by 2030, up to 650 billion kWh of primary energy could be delivered by renewable gases, with 370 billion kWh from biogas and 280 billion kWh from syngas and other renewable gases.

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DEVELOP A NATIONAL ENERGY FROM WASTE POLICY THAT PROMOTES RENEWABLE ENERGY AND LOWER EMISSIONS

The NSW Government has revised its existing policy settings for energy from waste. The potential benefits of advanced waste treatment are identified within the Federal government's National Waste Policy but a national position on energy from waste is not yet fully developed.

The City will advocate for a National agenda for the promotion of environmentally beneficial energy from waste technologies as part of a suite of resource management strategies.

The development of national guidelines would also enable a consistent approach to waste disposal and best practice waste treatment. National targets and national economic instruments are also essential. A National policy should mean the energy from waste sector will be developed where required and not simply in the jurisdiction with the least restrictive settings.

In terms of delivering for NSW the best available technologies for recovering energy from waste, the new Policy does not sufficiently demarcate between the options for incineration of waste and the increasing international use of conversion by thermal treatment of waste into a wholly or partially renewable gas. The use of waste as an incineration fuel is not an efficient and effective recovery of the energy resource within waste. Conversion of waste to a gas with measurable renewable energy content is a far more commercially flexible and environmentally better and safer option.

On that basis, the efficiency of energy from waste facilities should be determined in relation to the carbon improvement in relation to the existing suite of fossil fuel energy generating facilities rather than nominating material recovery as a privileged resource recovery process without establishing full carbon life cycle analysis for comparison.

The City notes that energy recovery is a tier of the NSW waste hierarchy and its promotion over the continued use of landfill should be supported by the NSW EPA. The City considers that given the complex technical nature of this industry sector that a designated waste infrastructure strategy should be provided by the NSW government to assist supporting energy from waste projects.

Extended producer responsibility programs should be implemented on a national basis that target a range of materials and products that cause hazardous impacts in waste management. This should move to a co-regulatory rather than simply voluntary platform and be directed at chemical waste, such as batteries and mercury containing products such as compact fluorescent lamps. Container deposit schemes should also be implemented to lower the level of inert category waste, such as low value glass, to minimise the impact on the energy value of the non-recycled materials.

In addition, national policy should address hazardous materials such as polyvinyl chloride that can generate acidic gases and a range of chlorine based hazardous chemicals under thermal processing operations. National policy should remove such materials from the production chain by restricting their application, reducing toxins such as phthalates and heavy metal stabilisers.

5.

ESTABLISH AN IMPROVED METHODOLOGY FOR DETERMINING THE RENEWABLE ENERGY COMPONENT FROM WASTE

Determining the eligibility of any renewable energy component generated from the gas provided by advanced waste treatment facilities is critical to obtaining Large-scale Generation Certificates (LGCs).

Municipal Solid Waste is included in the Renewable Energy (Electricity) Act 2000 as an eligible renewable energy source. The MSW waste stream contains both renewable and non-renewable components, and therefore the level of renewable components needs to be clearly determined. This determination establishes the level of LGCs when using waste as a feedstock for generating electricity, such as via co-generation or trigeneration. The work carried out by the City to determine its renewable energy component showed that the renewable content of gas from Municipal Solid waste could be calculated based on audited composition of the components in the waste, or by measuring directly the renewable content of the gas produced, such as by analysing samples for levels of carbon isotopes which provides the means for discriminating between "fossil" carbon and "new" carbon.

The Clean Energy Regulator absorbed the previous Office of the Renewable Energy Regulator (ORER) in April 2012. Publication of new guidelines was promised shortly after the merger of the two regulators but the new guidelines have still not been published.

Currently the methodology is provided as the "Guideline for Determining the Renewable Components in Waste for Electricity Generation" originally prepared for the ORER in 2001.

The Clean Energy Regulator Guideline documents the procedure to be followed in determining the eligibility for renewable energy certificates based on the energy value of components of solid waste. This Guideline is now very outdated and needs to be revised to take account of revised waste audit categories, obsolete publications referenced, and renewable gas grid injection and the renewable electricity, heating and cooling outputs via cogeneration and trigeneration.

6.

ESTABLISH NEW DEFAULT GREENHOUSE GAS EMISSION VALUES FOR POST ADVANCED WASTE TREATMENT WASTE

Although "waste" is really a non-homogenous group of materials, default greenhouse gas emission factors are currently assigned to waste per tonne sent to landfill based on the sector of origin. The sector of origin of any waste load must be identified by the landfill operator and the greenhouse gas emission factors applied. The originating sector for solid waste will most typically be MSW, C&I or C&D.

The factors convert the total of potential greenhouse gas emissions to an equivalent of CO_2. For instance, one tonne of waste from residential collection (MSW) is assigned a default value of 1.2 tonnes of CO_2 equivalent when determining potential emissions, while one tonne of commercial and industrial waste is assigned a default value of 1.1 tonnes CO_2 equivalent. If default values are used, variations between loads in terms of composition are ignored for reporting purposes.

When waste is processed through advanced waste treatment, the relative composition of individual materials contributing to the overall factor will change. For example, the level of organics contributing to methane generation is significantly reduced after advanced waste treatment of any type. However, under current reporting requirements, the default value remains the same as the value for unprocessed material from the original sector.

This determination does not provide a clear market signal to encourage processing of waste by removing materials contributing to methane to minimise greenhouse gas emissions and must be reformed. Additional default values for greenhouse gas emissions must therefore, be developed for post-advanced waste treatment residues that need to be landfilled. This would provide a clear and rational incentive to seek out the highest level of treatment and diversion technology.

7.

MAKE STATE AND FEDERAL FUNDS AVAILABLE FOR ADVANCED WASTE TREATMENT FACILITIES

The City notes that the burden of contracting major waste infrastructure facilities still falls mainly to the local government sector. But it is the levels of non-recyclable commercial waste that continue to fill up landfill. State and Federal funding for waste infrastructure should ensure that the private sector waste is addressed in a way that minimises the financial burden on local government. Subsidies and co-investment grants should be aligned with the need for more private sector waste to be processed for resource recovery, allowing local government to make up any shortfall to help establish a facility.

This would be a competitive process based on the public sector's grant or contribution cost of carbon abatement. Subsidies and grants should be targeted to those technologies or mix of technologies that address:

- Maximisation of diversion of waste disposed to landfill.
- Additional recovery of recycled materials via advanced waste treatment technologies such as gasification or pyrolysis.
- Maximisation of the production of renewable and non-fossil fuel gases and/or electricity and/or heat.
- Reduction in greenhouse gas and pollutant emissions.
- Reduction in transport movements for the recycling, treatment and disposal of waste.

8.

STANDARDISE CONNECTION FEES FOR RENEWABLE ELECTRICITY AND GAS NETWORKS

Establish standards for grid transmission and distribution connection fees. Uncertainty regarding potential fees for connecting to the electricity and gas networks is a barrier to greater adoption of renewable energy technologies. This provides a simple way to reduce that uncertainty.

Additional charges for augmentation when connecting renewable energy to the electricity and gas networks may place high financial burdens on renewable electricity and gas connections, and ultimately to the connected customers as the cost is passed on.

CASE STUDIES

CASE STUDIES

ADVANCED GASIFICATION TECHNOLOGIES

GENERAL
The case studies in this chapter detail how existing gasification technologies can significantly reduce waste going to landfill and produce renewable gases and other useful by-products.

The case studies demonstrate various gasification technologies and their capacity to recover renewable gases and by-products that can be re-used. In some parts of the world cities have been operating gasification of waste plants for at least 25 years but research and development continues to improve the technology and efficiency of operation.

For the City of Sydney, there are choices and investments to be made and a range of methods of conversion of waste to energy and usable by-products that can be used.

The City's approach to the conversion of renewable and non-fossil fuel gases derived from the gasification of non-recyclable waste into a substitute natural gas for injection into the gas grid for high efficiency end uses such as precinct trigeneration, instead of combusting the untreated gases to generate low efficiency electricity for export to the electricity grid is a step change from most existing configurations of thermal conversion technologies and infrastructure. Therefore, the case studies set out the potential of the gasification of waste into renewable gases to deliver the City's renewable energy and diversion of waste objectives rather than identifying gasification case studies that operate in exactly the same way as set out in this Advanced Waste Treatment Master Plan.

The case studies include advanced gasification technologies operating at high temperature with ash melting, which are capable of gasifying combustible, non-combustible and hazardous mixed waste. These gasification technologies are able to generate the highest levels of syngas for conversion into substitute natural gas via the methanation process for injection into the gas grid for use by the City's trigeneration networks as well as maximum diversion of waste going to landfill.

GOBIGAS BIOMASS GASIFICATION RENEWABLE GAS GRID INJECTION, GOTHENBURG, SWEDEN (METSO/REPOTEC)

Background

With 45% of its proportion of energy use provided from renewable sources Sweden can be considered as a mature low carbon economy compared to other countries. Renewable energy sources include hydro power, wind energy and renewable gases. District heating has been used in Sweden since the 1950s and is the commonest form of heating in apartment buildings with about 82% of apartments being heated in this way. District heating and cooling is also the main source of thermal energy supplying offices, commercial premises and public buildings. District cooling has been used in Sweden since the 1990s. Together, they represent more than 40% of the country's energy use.

Sweden has ambitious targets to provide 50% renewable energy by 2020, transport independent of fossil fuels by 2030, 40% reduction in greenhouse gas emissions by 2020 and zero net greenhouse gas emissions by 2050.

Electricity production is 51% renewable energy and 37% nuclear energy with the remaining 12% being made up of fossil-fuelled and biofuel-based production. However, electricity prices reached record levels in 2009/10 primarily due to low availability of the nuclear power stations which led to increased oil-fired power generation and imports from the Nord Pool. Sweden is moving away from fossil fuel power and nuclear energy and is likely to phase out nuclear energy by 2035. This will have to be replaced by renewable energy.

Natural gas was first introduced to Sweden in 1985 and has increased rapidly since the 1990s. The use of biofuels and renewable gases in the Swedish energy system has also increased from 10% of total energy supply in the 1980s to over 25% today. Most of the increase in bioenergy or renewable gases has occurred in industry and for cogeneration district heating, although use is also increasing in the residential and transport sectors. More than 230 renewable gas plants and more than 30 renewable gas grid injection plants are currently in operation. In addition, more than 110 public renewable gas refuelling stations are available for transport fuel gas.

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ADVANCED GASIFICATION TECHNOLOGIES

Biomass is considered as a carbon neutral fuel as the amount of CO_2 released on burning biomass equals the uptake of CO_2 from the atmosphere during the growth of the biomass. Fuels like hydrogen, methane, Fischer-Tropsch diesel and methanol produced from biomass have the potential to become a carbon negative fuel, because part of the biomass carbon is separated as CO_2 in a concentrated steam during the production process. If this pure CO_2 stream is sequestered, these fuels can become CO_2 negative. If natural gas is replaced by biomethane or substitute natural gas produced by gasification there would be up to a 70% reduction in CO_2 emissions. If the pure CO_2 steam is not vented into the atmosphere but sequestered in, for example, a depleted natural gas field, the net CO_2 emissions would become negative by 70%.

Thermal gasification involves the production of a synthesis gas or syngas in a gasifier through the thermal breakdown of solid biomass into non-condensable gases. Gasification uses chemical reactions with steam and oxygen often added to promote the desired reactions. The raw syngas is a mixture composed mostly of hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2), water vapour (H_2O) and methane (CH_4) as well as smaller amounts of hydrogen sulphide (H_2S) and light hydrocarbons such as ethane. Syngas cleaning removes the particulates, tars, H_2S and any other trace elements. To produce renewable gas, H_2 and CO are converted to methane via a process called 'methanation'. The CO_2 is then removed.

Methane produced from biomass or municipal or agriculture or farming waste is referred to as biomethane, renewable gas or bio-substitute natural gas (Bio-SNG). The composition of biomethane is similar to natural gas, making replacement of natural gas by biomethane straightforward.

GoBiGas Biomass Gasification Renewable Gas Grid Injection

The GoBiGas thermal gasification of biomass for renewable gas grid injection into the gas grid project was developed and implemented by Goteborg Energi. The gasification plant was located adjacent to the Gothenburg cogeneration/district heating plant at Rya near Gothenburg harbour.

The Phase 1 gasification plant consumes 3MW of electricity supplied from the cogeneration plant but generates 11MW of heat which is injected into the district heating grid and heat pumps with a net saving in greenhouse gas emissions of 5,800 tonnes a year. The gasification plant generates syngas which is converted into biomethane or substitute natural gas and injected into the gas grid by Goteborg Energi to supply the city and its customers.

Goteborg Energi is an energy services company owned by the City of Gothenburg providing utility services to more than 300,000 customers in Greater Gothenburg, including cogeneration/trigeneration, electricity, natural and renewable gases, fibre optic cabling and technologies for consumers not connected to the district heating network. Goteborg Energi supply heating to 90% of all apartment blocks in Gothenburg with 1,000km of district heating networks with decentralised cooling for commercial customers. Prior to the GoBiGas project the district heating network was 17% renewable fuelled. Goteborg Energy also supplies gas to 50 refuelling stations for gas powered vehicles.

Phase 1 of the GoBiGas project gasifies 100,000 tonnes of low quality pulpwood and forestry residues and became operational in 2013 and produces 20MW of biomethane or substitute natural gas which is injected into the gas grid with a reduction in greenhouse gas emissions of 37,760 tonnes a year. The total efficiency of the Phase 1 plant is 90% and operates for 8,000 hours a year. The overall cost of the facility was €100 million ($135 million).

Phase 2 of the GoBiGas project will produce a further 80MW of renewable gas for injection into the gas grid gasifying an additional 400,000 tonnes of low quality pulpwood and wet forestry residues. The Phase 2 gasification plant is expected to become operational in 2016.

The market for GoBiGas renewable gas is cogeneration district heating, renewable methane for industrial purposes and transport fuel.

The GoBiGas project partners comprises Goteborg Energi who own the plant, Metso who built the plant under licence from Repotec who own the twin fluidised bed gasification technology that was developed by the University of Vienna, Haldor Topsøe who designed and supplied the 'TREMP' methanation and gasification portions of the project, including the supply of catalysts for the process reactors, tar, sulphur and carbon dioxide removal, and Jacobs who built the Haldor Topsøe equipment. Chalmers University of Technology also assisted Goteborg Energi in developing the project.

The indirect gasification Hofbauer Reactor or fast internally circulating fluidised bed (FICFB) reactor was first demonstrated in 2001 at Gussing, Austria which produced 8MW of syngas which was used for a cogeneration system generating 2MW of electricity and 7MW of heat.

The core of the plant is formed by two interconnected fluidised bed systems of the fluidised bed steam gasifier (reactor).

ADVANCED GASIFICATION TECHNOLOGIES

In the gasification zone the reduced biomass is whirled up and gasified in anaerobic conditions at approximately 850ºC in the shortest time possible by introducing steam. The bed material (olivine sand) has the function of a heat transfer medium and provides a stable temperature in the reactor.

In the next step the resultant product gas is purified and cooled. The heat emitted during cooling is used for the generation of thermal energy to inject into the district heating network. Subsequently the gas is filtered and tar scrubbed with biodiesel. At this stage all resulting residual materials are captured and recycled.

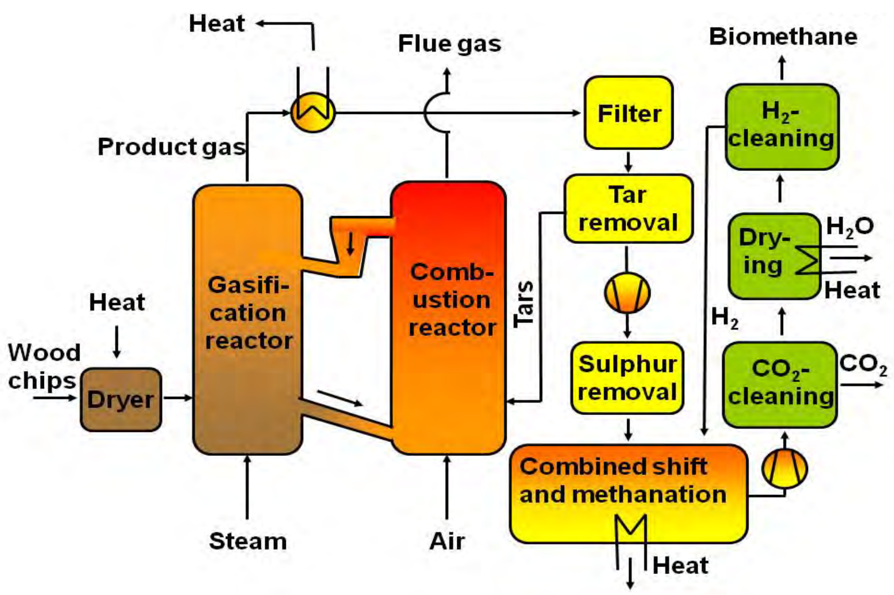
In the gas purification stage neither solid waste nor waste water arises and the product gas is completely free of nitrogen.

The Haldor Topsøe 'TREMP' process converts the pure syngas produced into hydrogen H_2 and carbon monoxide CO in the ratio of 3/1 into methane CH_4. The result is biomethane or substitute natural gas. Approximately, 80% of the energy in the feed gas is converted into methane in a gas with up to 98% methane. The rest of the energy (heat released during the process) can be delivered in the form of pressurised steam for electricity generation or used in the gasification process.

Feedstock:	*100,000 tonnes/yr low quality pulpwood and forestry residues*
CHP Capacity:	*11MW heat*
CHP Annual Output:	*88GWh heat*
Gas Grid Injection Capacity:	*2,000m³/hour (20MW)*
Annual Gas Grid Injection:	*160GWh (0.576PJ)*
Annual saving:	*45,560 tonnes CO_{2-e}*
Energy from Waste Ratio:	*2.5MWh/tonne of waste (renewable gas and heat output)*
CO_{2-e} Saving to Waste Ratio:	*0.46 tonnes/tonne of waste*

FIGURE 75: GOBIGAS BIOMASS GASIFICATION RENEWABLE GAS GRID INJECTION – PHASE 1, GOTHENBURG, SWEDEN (SOURCE: REPOTEC)

FIGURE 76: FAST INTERNALLY CIRCULATING FLUIDISED BED (FICFB) INDIRECT GASIFICATION PROCESS (SOURCE: SWEDISH GAS COUNCIL)



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ADVANCED GASIFICATION TECHNOLOGIES

KYLMÄJÄRVI 2 MUNICIPAL WASTE GASIFICATION RENEWABLE GAS FUELLED COGENERATION NETWORK, LAHTI, FINLAND (METSO)

Background

Finland is a world leader in precinct scale decentralised energy accounting for 50% of the total heating market of which 80% is produced by cogeneration or trigeneration. Over 90% of apartment blocks, more than 50% of all terraced houses and the bulk of public buildings and business premises are connected to a district heating and/or cooling network.

Renewable energy accounts for 25% of primary energy consumed which is the third highest in the European Union. Finland is also among the leading countries in the use of biomass in energy production. Renewable gases and other bio energy accounts for 20% of all primary energy consumption, currently the second highest in the European Union. A new feed-in tariff was established in 2011 to promote the production of electricity based on wind power, renewable gases and biofuels to deliver Finland's 38% renewable energy target by 2020.

The Finnish Government's long term aim is to reduce greenhouse gas emissions by 80% below 1990 levels by 2050 – "Low Carbon Finland 2050".

The City of Lahti is located 100km north-east of Helsinki and has a population of 102,000 people but serves an economic region with 200,000 inhabitants. Through a combination of recycling of waste and waste to energy only 6% of all waste is disposed to landfill. As part of its policies to reduce waste being disposed to landfill, to increase renewable energy and to reduce greenhouse gas and other noxious emissions the City, through the City owned Lahti Energia, built its first gasification plant, Kylmäjärvi 1, in 1998. This is a hybrid cogeneration plant using coal and gasified wood solid waste in an 85:15 ratio. This reduced the need to import 700,000 tonnes of coal a year and reduced carbon dioxide and sulphur dioxide by 10%, nitrogen oxides by 5% and particulates by 40%.

The Kylmäjärvi cogeneration district heating network covers the entire Lahti city area and supplies 7,600 customers with almost every building in Lahti connected to the network. The district heating network also supplies Nastola and Hollola city centre areas. Biogas is also generated by anaerobic digestion at Lahti's sewage treatment works which is converted into thermal energy and fed into Lahti's district heating network. Cogenerated electricity is supplied to 87,000 customers in the Lahti area and nationwide.

Consideration was later given to replace the hybrid gasification system with a renewable gas only gasification system since a syngas only plant would generate 40% more electricity per tonne of solid, mainly household waste, than hybrid firing. In addition, using such a gasification system would reduce the import of a further 170,000 tonnes of imported Siberian coal.

Kylmäjärvi 2 Municipal Waste Gasification

The Kylmäjärvi 2 municipal waste gasification renewable gas fuelled cogeneration plant began operation in 2012 and is operated as the primary cogeneration plant. The Kylmäjärvi 1 plant was retained for back-up in peak demand periods such as winter, when temperatures can drop to –30ºC.

The plant's feedstock is waste collected within a 200km radius from households, industry and construction sites and then processed by waste management companies to meet detailed standards set by Lahti Energia. Households separate waste into three recyclable wastes (waste carton, glass and metal + biowaste + energy waste). Finns do not regard waste as waste but as recyclable energy waste. The separately sorted energy waste is collected and shredded by waste management companies. Those waste management companies collecting industrial waste use BMH Technology's Tyrannosaurus solid recovered fuel separator-shredders to do both jobs. Processed waste is delivered to the plant's fuel depot as well as industrial and forestry wood waste.

The sorted waste or solid recovered fuel primarily consists of plastic, wood and paper that cannot be recycled and is sufficiently energy-rich to be gasified to produce syngas from mainly renewable fuels. After delivering the waste, suppliers are required to cut it into a size of about 6 cm and reduce any moisture content to below 20–30%. A sample from each truckload is tested by a laboratory at the entrance to Lahti Energia's weigh station. The economics of the project is such that Lahti Energia pays suppliers for delivering waste in this way which also incentivises waste management companies to comply with Lahti Energia's requirements.

After approval and unloading, the solid fuel is fed into two 7,500m^3 silos from where it is conveyed 240 metres to two Metso 80MW circulating fluidised bed gasifiers where it mixes with sand, limestone and air at a temperature of 900ºC in the gasifier reactors. Under these conditions solid fuel breaks down into a synthesis gas or syngas. The hot syngas rises to the top of the gasifier and then onto a cooling system where the temperature is reduced to 400ºC.

ADVANCED GASIFICATION TECHNOLOGIES

The syngas does not burn in the reactor since there is insufficient oxygen for combustion. Cooling is used to clean the syngas of unwanted particles such as metal compounds and alkilis that re-solidify and fall to the bottom of the chamber which are then removed. This process purifies the syngas so that emissions are practically zero except for carbon dioxide produced during gasification. The gas impurities are removed inside 12 cooling chambers containing 300 ceramic candle filters each collecting unwanted particles while allowing the syngas to pass through. A nitrogen pulse every minute ejects collected dust which falls to the chamber floor for removal. Studies are under way to recycle the ash for agriculture or re-combustion.

The clean syngas is fed into the cogeneration station's boiler to produce steam which in turn produces electricity and district heating hot water via two 25MWe turbines, operating at 540°C under 121 bars, delivering nearly 90% overall efficiency. Unlike incineration, the temperature and pressure can be run at these levels because the corrosive metals and alkilis have been extracted during cleaning, generating nearly three times as much electricity than incineration or nearly twice as much electricity than hybrid fossil fuel/solid recovered fuel gasification.

FIGURE 77: KYLMÄJÄRVI 2 MUNICIPAL WASTE GASIFICATION RENEWABLE GAS FUELLED COGENERATION NETWORK, LAHTI, FINLAND (SOURCE: LAHTI ENERGIA)

Feedstock:	*250,000 tonnes of municipal waste*
Capacity:	*50MW electricity* *90MW heat*
Annual Output:	*300GWh pa electricity* *600GWh pa heating*
Fuel Storage:	*15,000m^3 (two 7,500m^3 silos)*
Annual saving:	*180,000 tonnes CO_{2-e}*
Energy from Waste Ratio:	*3.6MWh/tonne of waste (renewable electricity and heat output)*
CO_{2-e} Saving to Waste Ratio:	*0.72 tonnes/tonne of waste*

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ADVANCED GASIFICATION TECHNOLOGIES

AOMORI MUNICIPAL AND INDUSTRIAL WASTE GASIFICATION, JAPAN (EBARA TWINREC)

Background

Japan is a world leader in the gasification of waste with around 130 gasification plants from 17 companies employing different gasification processes gasifying around eight million tonnes of waste a year. Ebara is the second largest gasification technology company in Japan with 15% of the Japanese gasification market.

Aomori is located at the southern end of Mutsu Bay in the far north of Honshu Island. With a population of nearly 300,000 inhabitants, 17th century Aomori is the capital of the Aomori Prefecture. Aomori is a major services sector city with some manufacturing. Aomori is connected to Hokkaido Island by an undersea railway tunnel.

Established in 1912, the Ebara Corporation manufactures environmental and industrial machinery, including wind turbines, hydro-electric turbines and gasification systems.

The Ebara TwinRec process is a fully commercial process that combines gasification with an ash melting furnace.

The Ebara TwinRec gasification technology was first developed in the early 1990s.

The TwinRec process accepts a wide range of waste materials, including municipal solid waste, automotive shredder residues, plastics, electronics waste and other industrial residues, refuse-derived fuels and sewage sludge. Minimal pre-processing is required.

Estimates of its construction costs range between $14 and $21 million USD, based on a 40 tonnes per day (tpd) TwinRec facility.

Technology Development and Commercialisation

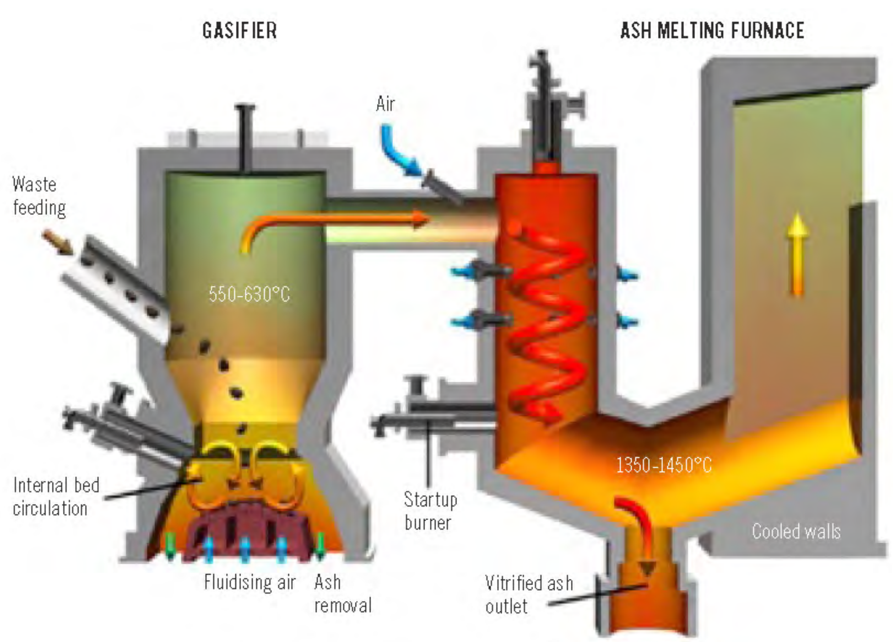
A small to medium scale operation was piloted as a demonstration facility at Fujisawa, Japan in 1997. The Fujisawa plant successfully operated on a single 100-days continuous test run.

Commercial operation started in 2000 with the commissioning of the Aomori plant, followed by ten more commercial facilities. The eleven commercial plants currently operated in Japan collectively process 1,462 tonnes of MSW, 1,063 tonnes of industrial waste and 16 tonnes of sewage sludge per day, for a total installed thermal capacity of 371 MW.

FIGURE 78: AOMORI MUNICIPAL AND INDUSTRIAL WASTE GASIFICATION, JAPAN (SOURCE: EBARA CORPORATION)

ADVANCED GASIFICATION TECHNOLOGIES

FIGURE 79: THE EBARA TWINREC PROCESS (SOURCE: EBARA CORPORATION)



Feedstock:	*160,000 tonnes of municipal and industrial waste*
Capacity:	*5.5MW electricity*
Annual Output:	*37,500MWh pa electricity*
Estimated Diversion: from Landfill	*99.9%*
Annual saving:	*27,375 tonnes CO_{2-e} (based on Japan grid emissions)* *39,750 tonnes CO_{2-e} (based on NSW grid emissions)*
Energy from Waste Ratio:	*0.23MWh/tonne of waste (renewable electricity output only)*
CO_{2-e} Saving to Waste Ratio:	*0.17 tonnes/tonne of waste (based on Japan grid emissions)* *0.25 tonnes/tonne of waste (based on NSW grid emissions)*

Process Description

The TwinRec process combines a fluidized-bed gasifier, operating at high temperatures (550 –600°C) and atmospheric pressure, with a secondary combustion and ash-melting furnace.

Features of the Conversion Process

The low gasification temperature and high-turbulence of the primary chamber bed allow for easy process control and limited air requirements, resulting in a compact design for both the primary gasification chamber and for the energy recovery and air pollution control (APC) systems downstream.

Energy Recovery

The raw synthesis gas produced is burnt at very high-temperature in a secondary combustion chamber. Heat from the syngas generates steam for industrial processes or power generation in steam turbine. Due to the overall low excess air intake, the steam boiler can be compact, maximising recovery of the energy content of the waste. All TwinRec plants integrate steam power generation.

Process By-product Recovery

Steel, aluminium, copper and iron are easily recovered from the waste stream. Mineral dust and metal oxide powder are vitrified into the glass granulate and can be separated and recycled afterward.

In the ash-melting furnace, the tars, fine char, and ash residue are melted in the furnace and accumulate on the walls of the furnace where they are vitrified.

Vitrification of ash enables the plant to achieve a high diversion rate of residuals from landfill, at around 95%.

The air pollution control system controls nitrous oxide. Performance test results confirm the plant's ability to operate within safe permit limits, including dioxin emissions.

ADVANCED GASIFICATION TECHNOLOGIES

CHIBA CITY RECYCLING CENTRE MUNICIPAL WASTE PYRO GASIFICATION AND ASH MELTING, GREATER TOKYO, JAPAN (THERMOSELECT)

Background

Chiba City is located 40km southeast of the centre of Tokyo. With a population of nearly 1 million inhabitants, 11th century Chiba City is the capital of the Chiba Prefecture. Chiba City is a major seaport with many factories and warehouses located along the coast. Chiba is famous for the Chiba Urban Monorail, the longest suspended monorail in the world.

The Thermoselect High Temperature Reactor is a fully commercial process combining slow pyrolysis with high-temperature gasification and ash melting.

The high temperature reactor process was developed by a private Swiss company, in the late 1980's.

The Thermoselect process accepts unsorted municipal solid waste, and a range of industrial wastes, with minimal or zero feedstock preparation/pre-processing and integrates an extensive array of material recovery steps.

The overall cost of the facility is estimated to be \$80 and \$120 million USD.

Technology Development and Commercialisation

The Thermoselect gasification and ash melting process was originally developed in Switzerland between 1985 and 1992. A demonstration plant with a capacity of 110 tonnes per day was built at Fondotoce, Italy to validate the technology and operated between 1992 and 1999. A larger commercial facility with a capacity of 792 tonnes per day was built at Karlsruhe, Germany in 1999 but was 'mothballed' in 2004, pending the outcome of a dispute between the project partners.

In the 1990s, Kawasaki Steel Corporation of Japan became interested in the Thermoselect process and, in 1999 built the first Thermoselect plant in Japan at Chiba City. Chiba became the testing ground of the Thermoselect technology in Japan where many minor problems were overcome through design and operating changes which were adopted in the following Thermoselect plants built throughout Japan. The average availability of the Thermoslect operating plants is about 80% but with accumulating operating experience availability is increasing.

Process Description

The Thermoselect HTR process consists of slow-pyrolysis followed by high-temperature gasification (around 1200°C) in a fixed-bed reactor with melting of the inorganic component of the feedstock (ashes, metals) to form a vitrified slag.

FIGURE 80: CHIBA CITY RECYCLING CENTRE MUNICIPAL WASTE GASIFICATION, GREATER TOKYO, JAPAN (SOURCE: JFE GROUP/THERMOSELECT)

Features of the Conversion Process

The raw synthesis gas is moved from the degassing channel to the upper sections of the heating chamber which is maintained at high temperature. The inorganic portion of the waste has remained virtually unaffected

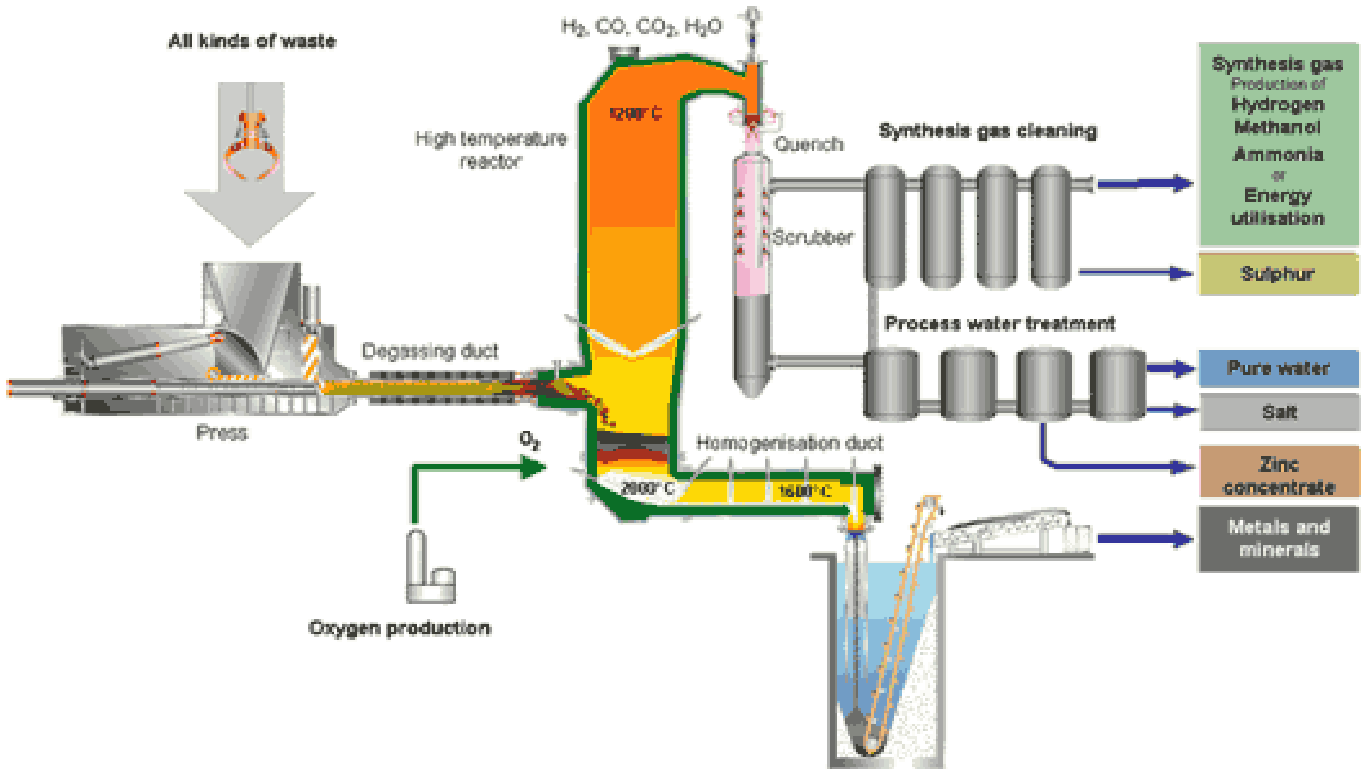
Control of the temperature allows it to perform as a smelter, where the high temperature provides the necessary conditions to melt the inorganic fraction, composed primarily of glass products and various metals.

The resultant synthesis gases exiting the chamber at 1200°C are immediately cooled down to temperatures below 70°C, and the gases cleaned from impurities.

At the Chiba facility, this cleaned syngas is exported offsite via pipeline to a nearby industrial facility. It is used for generation of electricity and heat at that separate location.

ADVANCED GASIFICATION TECHNOLOGIES

FIGURE 81: PYRO GASIFICATION PROCESS
(SOURCE: THERMOSELECT)



Feedstock:	*94,000 tonnes of municipal and industrial waste*
Capacity:	*1.5MW electricity*
Annual Output:	*6,160MWh pa electricity*
Estimated Diversion: from Landfill	*99.9%*
Annual saving:	*4,500 tonnes CO_{2-e} (based on Japan grid emissions)* *6,530 tonnes CO_{2-e} (based on NSW grid emissions)*
Energy from Waste Ratio:	*0.07MWh/tonne of waste (renewable electricity output only)*
CO_{2-e} Saving to Waste Ratio:	*0.05 tonnes/tonne of waste (based on Japan grid emissions)* *0.07 tonnes/tonne of waste (based on NSW grid emissions)*

Process By-product Recovery

The Thermoselect technology is well suited solution for energy from waste applications with one of the highest waste diversion performances of almost 100%.

The mineral and metal melt flow is cooled and as the temperature drops a vitrified mineral stream. The glass-like material is suitable for a variety of uses, including aggregates and raw components for construction materials, mineral and insulation fibres.

Metal granules are recovered, and the use of the metal residues for metallurgical processes is also being investigated.

Sulphur is recovered at a saleable quality.

The recovery of water generated from the gas-cleaning process complies with sewerage discharge guidelines. Alternatively, the water is cleaned and distilled to be returned for use in the process-water loops and cooling towers.

ADVANCED GASIFICATION TECHNOLOGIES

MUTSU INDUSTRIAL WASTE GASIFICATION, AOMORI, JAPAN (THERMOSELECT)

Background

Mutsu is a city located on Mutsu Bay in the Aomori Prefecture. With a population of 60,000 inhabitants, Mutsu is the northernmost city on Honshu Island. The economy is heavily dependent on agriculture, forestry and fishing.

In 2001, following the commissioning of the Chiba City gasification and ash melting plant Kawasaki Steel Corporation merged with NKK Corporation to form JFE, the fifth largest steelmaker in the world and a major engineering company within Japan in the construction of more than 80 waste to energy plants. JFE built the Thermoselect plant at Mutsu followed by the construction of further Thermoselect plants which today amounts to a total of 16 Thermoselect units with a total daily capacity of 2,000 tonnes.

Mutsu Industrial Waste Gasification

The gasification and ash melting plant at Mutsu was commissioned in 2003 and was the second Thermoselect gasification plant installed in Japan. The gasification plant is owned by the Sumokita Local Authority and gasifies 50,000 tonnes a year of municipal and industrial waste. The clean syngas produced by the gasification plant generates 10,000MWh a year of electricity via two generators (steam cycle and gas engine) and exports 9,500MWh a year of electricity to the grid. Other by-products that are recycled comprise sulphur, metallic slag and glassy slag. The slag particles are used as a substitute for stone aggregate and other applications.

Due to the process, a definite aesthetic advantage of the Thermoselect gasification plant is the absence of a tall stack or chimney.

FIGURE 82: MUTSU INDUSTRIAL WASTE GASIFICATION, AOMORI, JAPAN (SOURCE: JFE GROUP/THERMOSELECT)

Feedstock:	*50,000 tonnes of municipal and industrial waste*
Capacity:	*2.2MW electricity*
Annual Output:	*9,560MWh pa electricity*
Estimated Diversion: from Landfill	*99.9%*
Annual saving:	*6,980 tonnes CO_{2-e} (based on Japan grid emissions)* *10,135 tonnes CO_{2-e} (based on NSW grid emissions)*
Energy from Waste Ratio:	*0.19MWh/tonne of waste (renewable electricity output only)*
CO_{2-e} Saving to Waste Ratio:	*0.14 tonnes/tonne of waste (based on Japan grid emissions)* *0.20 tonnes/tonne of waste (based on NSW grid emissions)*

ADVANCED GASIFICATION TECHNOLOGIES

MIHAMA-MIKATA MUNICIPAL WASTE PLASMA GASIFICATION, JAPAN (ALTER NRG)

Background

Mihama is a town located in Mikata District, Fukui Prefecture on the west coast of Honshu Island. With a population of more than 13,000 inhabitants, Mihama's economy is mainly rural, tourism and the local nuclear power station.

The Plasma Gasification Vitrification Reactor (PGVR) is a plasma-assisted gasification process commercialized by Alter NRG, a Canadian company.

In the 1990s, applications of the technology for processing municipal solid waste and biosolids were developed and a demonstration facility in Japan was commissioned in 1999.

In 2007, Alter NRG acquired Westinghouse Plasma Corporation which was regarded by many as a leader in MSW plasma gasification. Buying Westinghouse immediately positioned Alter NRG as one of several key contenders in the potentially large embryonic market for plasma processing of household waste. Commercial operating plasma gasification facilities include MEPL at Pune, India, Ecovalley at Utashinai, Japan and Mihama-Mikata, Japan. Projects under construction in 2014 include the plasma gasification facilities at Shanghai, China, Wuhan, China and the Tees Valley Renewable Energy Facility at Teesside, UK.

The company is actively pursuing opportunities for a range of potential applications of plasma technology, including waste-to-energy (municipal solid waste, biosolids and hazardous waste), co-gasification with coal, waste-to-ethanol from MSW and gasification of petcoke and other refinery residuals.

FIGURE 83: MIHAMA-MIKATA MUNICIPAL WASTE GASIFICATION, JAPAN (SOURCE: HITACHI LTD/ALTER NRG)

Technology Development and Commercialisation

Following the experience at Yoshi, Hitachi Metals developed two commercial facilities in Japan: Mihama-Mikata (25 tpd, started in 2002) and Utashinai (150 –220 tpd, started in 2003). The Mihama-Mikata plant, a commercial success, has ten years of operation at full capacity.

Utashinai (150 –220 tpd) had commissioning issues affecting its profitability. It is possible that the plant will shut down in 2013.

The second generation PGVR design, currently being installed at two sites in India and being commercialized worldwide by Alter NRG is yet to be tested in full commercial operation.

A substantial pipeline of other commercial prospects also includes a:possible waste-to-energy plant in Kwinana,in Western Australia valued at around $32 million

Process Description

The PGVR furnace is the core component of AlterNRG plasma gasification system. The current generation design features a number of improvements based on the lessons learned at the Utashinai facility.

In a typical plant waste-to-energy configuration the PGVR is combined with a waste pre-processing and feed system, a molten residue removal and handling system, a steam power generation system (boiler, turbine, condensers), and air-pollution control (APC) for flue-gas clean-up and handling.

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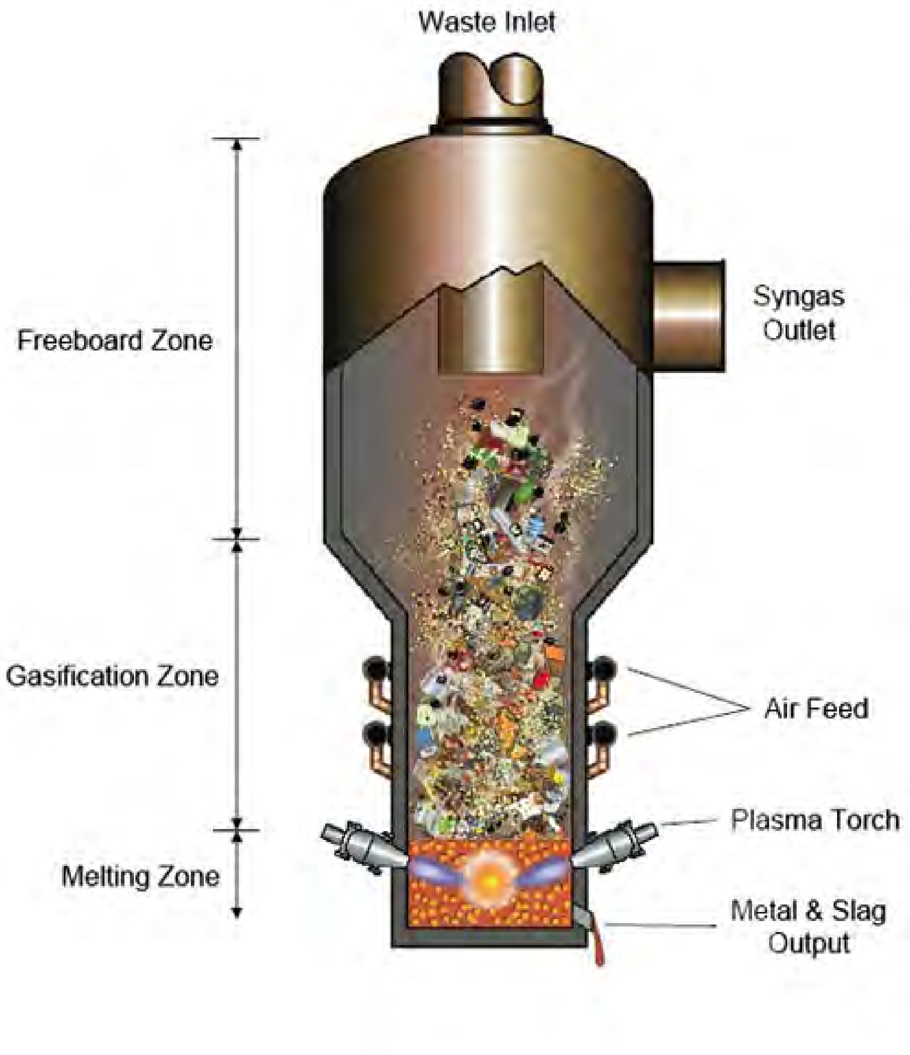
ADVANCED GASIFICATION TECHNOLOGIES

FIGURE 84: ALTER NRG/ WESTINGHOUSE PLASMA GASIFICATION REACTOR (SOURCE: WESTINGHOUSE PLASMA CORPORATION)



Heating and Conversion

The water-cooled plasma torches superheat air into plasma. The plasma-heated gas stream is mixed with coke. The superheated combustion products from the coke transfer heat to the incoming waste feedstock and bring its temperature to gasification conditions.

Energy Recovery

The syngas exiting the PGVR is burned in a combustor at the entrance of an adjacent boiler, where the hot flue gases generate steam for power generation in a steam turbine. Exhaust travels through an Air Pollution Control (APC) system comprised of a caustic scrubber to remove acid gases and activated carbon filters before being vented to the stack.

Process By-product Recovery

Inorganic components of the feed waste, the coke, and the fluidizing agent are fused and percolate down to a slag pool at the bottom of the gasifier chamber. The vitrified residue formed from the molten slag has very limited solubility and is used as an aggregate or other 'clean fill' material.

Feedstock:	*10,220 tonnes of municipal and industrial waste*
Capacity:	*0.35MW electricity*
Annual Output:	*1,520MWh pa electricity*
Estimated Diversion: from Landfill	*97%*
Annual saving:	*1,110 tonnes $CO_{2\text{-}e}$ (based on Japan grid emissions)* *1,610 tonnes $CO_{2\text{-}e}$ (based on NSW grid emissions)*
Energy from Waste Ratio:	*0.15MWh/tonne of waste (renewable electricity output only)*
$CO_{2\text{-}e}$ Saving to Waste Ratio:	*0.11 tonnes/tonne of waste (based on Japan grid emissions)* *0.16 tonnes/tonne of waste (based on NSW grid emissions)*

ADVANCED GASIFICATION TECHNOLOGIES

TEES VALLEY RENEWABLE ENERGY FACILITY – PLASMA GASIFICATION, TEESSIDE, UK (ALTER NRG/WESTINGHOUSE)

Background

Teesside is a conurbation in the north east of England made up of Middlesbrough, Stockton-on-Tees, Thornaby, Billingham and surrounding settlements near the River Tees. The Teesside urban area has a population of around 375,000 people. Teesside is an important centre for heavy industry, primarily steel making (British Steel), chemical manufacture (Imperial Chemical Industries or ICI) and more recently high technology activities, science development and the services sector.

One of the companies based in Teesside is US company, Air Products who employ more than 2,000 people in the UK and 18,900 people around the world. Air Products serves customers in industrial, energy, technology and healthcare markets worldwide with a portfolio of atmospheric gases, process and speciality gases, performance materials, and equipment and services.

Tees Valley Renewable Energy Facility Waste Gasification

Air Products is currently constructing the world's largest advanced gasification plant at Tees Valley Renewable Energy Facility, adjacent to the North Tees Chemical Complex near Billingham. The facility, scheduled for completion in 2014, is based on a $21 million 50MW Alter NRG/Westinghouse plasma gasification plant that will supply 50,000 homes with renewable electricity in the North East. The plant will divert 350,000 tonnes of household, commercial and industrial non-recyclable waste from landfill and provide an environmentally-friendly solution for the production of renewable electricity. Longer term, Air Products plan to generate renewable hydrogen for commercial applications, for example to fuel public transport.

Following completion of the £300 million ($450 million) Phase 1 gasification plant Air Products will build a second 50MW plasma gasification plant processing an additional 350,000 tonnes of non-recyclable waste scheduled for completion in 2016. Arising out of the Phase 2 gasification plant Air Products has signed a 20 year power purchase agreement with the UK Government's Cabinet Office which will save UK taxpayers £84 million ($126 million) over the life of the contract through a fixed agreement that will provide stability in what the UK Government pays for energy.

FIGURE 85: WORLD'S LARGEST PLASMA GASIFIER BEING DELIVERED TO TEES VALLEY RENEWABLE ENERGY FACILITY (SOURCE: WESTINGHOUSE PLASMA CORPORATION)

ADVANCED GASIFICATION TECHNOLOGIES

FIGURE 86: TEES VALLEY RENEWABLE ENERGY FACILITY (SOURCE: AIR PRODUCTS)

Tees Valley Renewable Energy Facility – Phase 1

Feedstock:	*350,000 tonnes of municipal solid waste*
Capacity:	*50MW electricity*
Annual Output:	*416,000MWh pa electricity*
Estimated Diversion: from Landfill	*97%*
Annual saving:	*291,625 tonnes CO_{2-e} (based on UK grid emissions)* *440,975 tonnes CO_{2-e} (based on NSW grid emissions)*
Energy from Waste Ratio:	*1.19MWh/tonne of waste (renewable electricity output only)*
CO_{2-e} Saving to Waste Ratio:	*0.83 tonnes/tonne of waste (based on UK grid emissions)* *1.26 tonnes/tonne of waste (based on NSW grid emissions)*

ADVANCED GASIFICATION TECHNOLOGIES

OTTAWA MUNICIPAL WASTE PLASMA GASIFICATION, CANADA (PLASCO ENERGY)

Background

Ottowa is the capital of Canada and the fourth largest city in the country. The city stands on the south bank of the Ottowa River in the eastern portion of Southern Ontario. Ottowa borders Gatineau, Quebec and together they form the National Capital Region (NCR). The city's population is around 900,000 and the metropolitan area around 1.25 million. The economy is based primarily on the Public Service of Canada and the high-tech industry where it has built a reputation similar to Silicon Valley in California.

The City of Ottowa is a single-tier or unitary municipality and has no county or regional municipality above it. As such, the City is responsible for all municipal services, including waste. Ottowa's population is expected to grow by 300,000 by 2042 and at the current consumption and disposal rates will generate about 1 million tonnes a year. At this rate the City's landfill would run out unless action is taken to reduce waste going to landfill.

In 2011, the City adopted its Waste Management Master Plan which set out its vision, guiding principles, goals, objectives and targets. As part of its vision the City adopted the principles of reduce, re-use, recycle/compost, energy from waste and disposal/landfill. The City put in place the tools to divert upwards of 70% of residents waste from landfill but currently, only 44% is diverted from landfill. Local businesses and institutions face similar challenges with commercial and industrial waste and are further encumbered by the lack of affordable diversion services, particularly for demolition and construction wastes and organics.

In 2007, Plasco Energy built a plasma arc gasification demonstration plant at the City's Trail Road waste facility where the City already generates 6MW of renewable electricity from landfill gases. The demonstration plant processes 27,300 tonnes a year of municipal waste and generates 24,570MWh a year of electricity from the syngas produced.

The Trail Road gasification plant was based on the pilot gasification plant at Castellgali, Spain, a joint venture between Plasco Energy and HERA, one of the largest waste managers in Spain, processing five tonnes a day of waste since 2003.

FIGURE 87: PLASCO TRAIL ROAD PLASMA GASIFICATION FACILITY – PHASE 1, OTTOWA, CANADA (SOURCE: PLASCO ENERGY GROUP)

Following the success of the demonstration gasification plant the City signed a 20 year contract with Plasco Energy in December 2012, for the construction of a three train commercial plasma gasification plant. The plant will process up to 405 tonnes a day of municipal solid waste, generate 130,000MWh a year of electricity from the syngas produced, 300 litres a year of water suitable for irrigation and 19,500 tonnes of non-leachable aggregate. Plasco Energy has until December 2014 to raise the $200 million finance for the project with construction commencing shortly after.

The Phase 2 facility will be built to the Plasco Conversion System (PCMTM) design and will incorporate three proprietary Integrated Converting and Refining System (ICARSTM) modules. Effective throughput of the facility will be 130,000 tonnes a year. Under the terms of the contract the City will pay Plasco Energy $CAN 9.1 million ($9.5 million) a year to process 300 tonnes of waste a day – 109,500 tonnes a year, or roughly a third of the City's municipal solid waste. The City also has the right of first refusal to supply the balance of plant capacity.

As part of the contract the City will lease land to Plasco at the Trail Road waste facility at a peppercorn rent and will pay Plasco Energy a tipping fee of $CAN 83.25 per tonne, escalating annually at the rate in the Consumer Price Index. Other than this obligation, the City takes on no other risk or commitment.

The City estimates that the contract will extend the life of the City's landfill by at least 28 years saving the City approximately $CAN 250 million ($260 million) in future landfill costs.

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ADVANCED GASIFICATION TECHNOLOGIES

Technology Development and Commercialisation

The Plasco Trail Road Commercial Demonstration Facility is a 100 tonne per day design, and is operated on a scheduled basis. This schedule enables maintenance and modifications to be performed economically, while providing a platform to directly demonstrate and improve Plasco's technology. Plasco Trail Road is permitted under specific regulations that allow operations and testing to proceed within defined limits and controls.

Since the facility first began processing post-recycled MSW from the City of Ottawa in January 2008, operations at the Plasco Trail Road facility have successfully demonstrated:

- Delivery of engine-quality syngas that supports 1.0 MWh/tonne of electricity production.
- Conversion efficiencies at or above expectations.
- Compliant environmental performance.
- Generation of electricity that can be sold to the local utility.
- Production of commercially acceptable vitrified slag.
- Water treatment for production of potable quality water.

Process Description

The PCS breaks down waste using Plasco's patented ICARS system, which gasifies the waste and refines the resulting gas using plasma technology.

There are no emissions to atmosphere in the conversion process. The synthesis gas is consumed as fuel by the gas engines with any unused gas sent to a flare. Exhaust from the engines and flare have emission levels significantly below the most stringent standards in the world.

Heating and Conversion

Plasco uses a process which heats and gasifies sorted MSW in a primary conversion chamber. This primary chamber relies on excess heat from the system to provide thermal input. Metals are recovered in this chamber.

Syngas and particulate matter are then fed into a secondary carbon recovery chamber where the syngas is refined using plasma torches and any remaining particulates are fused and melted into a vitreous slag for recovery.

Energy Recovery

The clean syngas produced by the plasma gasification process is used to supply specially converted internal combustion gas engines to generate electricity. In addition, steam recovered from the gasification process is used to drive a steam turbine to generate further electricity. Together, the generators will produce 16MW of net electricity for export to the electricity grid.

Process By-product Recovery

Plasco has achieved a 95% diversion of waste from landfill for the Plasco Trail Road – Phase 1 facility as a whole.

Residual solids are refined using plasma to produce slag which meets the requirements for a range of applications, including construction aggregates and abrasives. Moisture in the waste is recovered, cleaned and made available for reuse in the community.

For every tonne of waste processed by the Plasma Conversion System the following is produced:

- 1.0 MWh of electricity (net value);
- 300 litres of water for reuse;
- 7–15 kilograms of metal; and
- 150 kilograms of construction aggregate.

Based on municipal solid waste prepared feedstock with a calorific value of 14.2 MJ/Kg.

ADVANCED GASIFICATION TECHNOLOGIES

FIGURE 88: PLASCO ENERGY PROCESS (SOURCE: PLASCO ENERGY GROUP)

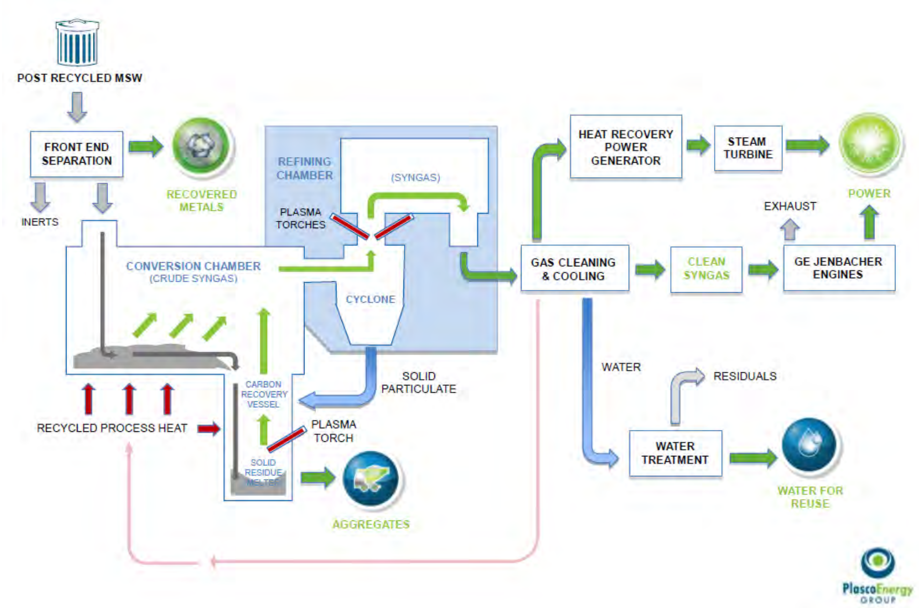
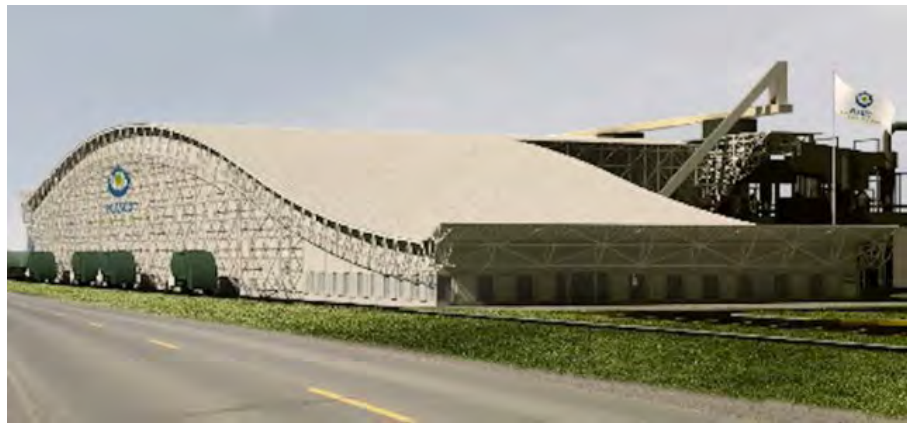


FIGURE 89: PLASCO TRAIL ROAD PLASMA GASIFICATION FACILITY – PHASE 2, OTTOWA, CANADA (SOURCE: PLASCO ENERGY GROUP)



Plasco Trail Road Plasma Gasification Plant – Phase 1

Feedstock:	*27,300 tonnes of municipal solid waste*
Capacity:	*3MW electricity*
Annual Output:	*24,570MWh pa electricity*
Estimated Diversion: from Landfill	*95%*
Annual saving:	*21,525 tonnes $CO_{2\text{-}e}$ (based on Canada grid emissions)* *26,045 tonnes $CO_{2\text{-}e}$ (based on NSW grid emissions)*
Energy from Waste Ratio:	*0.90MWh/tonne of waste (renewable electricity output only)*
$CO_{2\text{-}e}$ Saving to Waste Ratio:	*0.80 tonnes/tonne of waste (based on Canada grid emissions)* *0.95 tonnes/tonne of waste (based on NSW grid emissions)*

Plasco Trail Road Plasma Gasification Plant – Phase 2

Feedstock:	*130,000 tonnes of municipal solid waste*
Capacity:	*16MW electricity*
Annual Output:	*130,000MWh pa electricity*
Estimated Diversion: from Landfill	*95%*
Annual saving:	*113,880 tonnes $CO_{2\text{-}e}$ (based on Canada grid emissions)* *137,800 tonnes $CO_{2\text{-}e}$ (based on NSW grid emissions)*
Energy from Waste Ratio:	*1.00MWh/tonne of waste (renewable electricity output only)*
$CO_{2\text{-}e}$ Saving to Waste Ratio:	*0.90 tonnes/tonne of waste (based on Canada grid emissions)* *1.06 tonnes/tonne of waste (based on NSW grid emissions)*

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ADVANCED GASIFICATION TECHNOLOGIES

TYSELEY MUNICIPAL WASTE PLASMA GASIFICATION, BIRMINGHAM, UK (ADVANCED PLASMA POWER)

Background

Birmingham is a city and metropolitan borough in the West Midlands of England. It is the second largest city in the United Kingdom with around 1.1 million residents. Birmingham's metropolitan area has a population of around 3.7 million residents. Although the city grew to prominence as a manufacturing and engineering centre, its economy today is dominated by the services sector, which accounts for 86% of its employment. Tourism is also an increasing part of the local economy. With major facilities such as the International Convention Centre and National Exhibition Centre the Birmingham area accounts for 42% of all UK conference and exhibition trade.

As a single-tier or unitary authority, Birmingham City Council is responsible for running nearly all municipal services, with the exception of those run by joint boards. In addition to being responsible for the collection and disposal of domestic waste the City also owns Birmingham Commercial Waste Services, a 'not-for-profit' waste collection service offered to all businesses in Birmingham. Although Birmingham's population is expected to grow by 150,000 by 2031, total waste is not expected to increase beyond existing levels at 3.2 million tonnes a year. Current recycling rates are 31.5% but the City has set a targets to increase this to 50% by 2020 and to 60% by 2026.

There are no active landfills left in the city and the existing Tyseley Energy Recovery Facility primarily accepts municipal waste of about 350,000 tonnes a year, generating 25MW of electricity. The City's draft Birmingham Plan 2031 identifies a shortfall in recycling facilities and the Birmingham Waste Capacity Study shows that over 27,000 tonnes of waste will still need to be exported outside Birmingham. The City is committed to reducing greenhouse gas emissions by 60% by 2027 from 1990 levels, promoting the use of cogeneration and district heating schemes and encouraging the use of waste as a resource. In support of this, the draft Plan sets out the City's support for gasification and pyrolysis technologies which can generate electricity and heat for district heating schemes in appropriate locations.

Advanced Plasma Power

Advanced Plasma Power was established in 2005 to develop and commercialise Gasplasma technology which had been invented by Tetronics, a well established supplier with over 50 years experience in the application of plasma technology to metals and waste treatment and recovery.

Since 2008, a 1/100th scale Gasplasma plant has been operating in Swindon on a wide range of feedstocks. The Gasplasma technology is a plasma arc gasification or two stage thermal process generating electricity from a gas engine. Since its inception, Advanced Plasma Power has developed a number of innovative uses of the Gasplasma technology such as landfill mining and renewable gas grid injection into the gas grid.

FIGURE 90: GASPLASMA PLASMA GASIFICATION PLANT, SWINDON, UK (SOURCE: ADVANCED PLASMA POWER)

1 ADVANCED WASTE TREATMENT

2 RE-THINKING WASTE AS A RESOURCE

3 ADVANCED WASTE TREATMENT FOR THE CITY OF SYDNEY

4 PERFORMANCE MEASURES

5 ENABLING THE MASTER PLAN

6 CASE STUDIES

ADVANCED GASIFICATION TECHNOLOGIES

Renewable Gas Grid Injection from Gasification, Swindon, UK

In 2013, Advanced Plasma Power announced that the joint venture formed with the National Grid and Progressive Energy had been awarded £1.9 million ($3 million) funding from UK Energy Regulator –the Office of Gas and Electricity Markets to contribute to the £4.2 million ($6.7 million) Swindon-based plasma gasification demonstration project to convert the syngas produced into a bio-substitute natural gas (Bio-SNG) or substitute natural gas (SNG).

The National Grid is the UK's electricity and gas transmission network operator as well as operating the electricity and gas networks in the North Eastern USA, including New York, and has since 2010 be working to develop renewable gas grid injection from waste in both countries.

Tyseley Municipal Waste Plasma Gasification

In 2013, Birmingham City Council granted Advanced Plasma Power planning consent for a 6MW Gasplasma waste to energy plant at Hay Hall Road, Tyseley, Birmingham. The consent replaces an existing 2010 planning consent for a waste to energy incineration plant which will also reduce the area of land required for waste to energy from 3.9 hectares to 2.66 hectares, freeing up 1.24 hectares for other development. Emissions and transport movements will also be significantly reduced from the original planning consent.

The site would process 50,000 tonnes of mixed waste a year with 35,000 tonnes of waste processed by the Gasplasma plant after the recyclates, moisture and rejects have been removed. The plant would operate for 24 hours a day, seven days a week with a planned maintenance shutdown of 18 days a year. The syngas produced would be used to supply Organic Rankine Cycle electricity generation, generating 49,970MWh a year at an efficiency of 35%.

The Gasplasma project is one of three projects commissioned by the Energy Technologies Institute (ETI) with £2.8 million ($4.6 million) of funding to design the most cost-effective, economically viable and efficient commercial energy from waste demonstrator plant possible. The ETI is a public/private partnership between BP, Caterpillar, EDF Energy, E.ON, Rolls Royce, Shell and the UK Government. The project must deliver a net electrical efficiency of at least 25%. The design will be completed in early 2014 with construction completed by 2015.

FIGURE 91: CONSENTED ENERGY RECOVERY FACILITY, HAY HALL ROAD, TYSELEY, BIRMINGHAM, UK (SOURCE: BIRMINGHAM CITY COUNCIL)

Process Description

The Gasplasma plant comprises one or more plasma arc gasification units and may incorporate a Materials Recovery Facility (MRF) where residual waste is processed to recover any metals, glass and dense plastics as recyclable material. The residue is shredded and dried (using recovered process heat) to produce a refuse derived fuel (RDF) which is supplied to the Gasplasma process. Alternatively, the MRF process can be conducted off site and the RDF transported to the Gasplasma plant.

The core of the Gasplasma process comprises a fluidised bed gasifier which transforms the organic material in the RDF into a raw syngas containing tars and chars. It does this by heating the RDF to a high temperature, around 800°C, in a highly controlled reduced oxygen environment. The fluidised bed gasifier allows for the production of a consistent syngas and achieves high conversion efficiencies.

The raw syngas exiting the gasifier is then passed into the separate, secondary Gasplasma plasma conversion unit. The intense heat from the plasma arc – in excess of 8,000°C – and the strong ultraviolet light of the plasma result in complete

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ADVANCED GASIFICATION TECHNOLOGIES

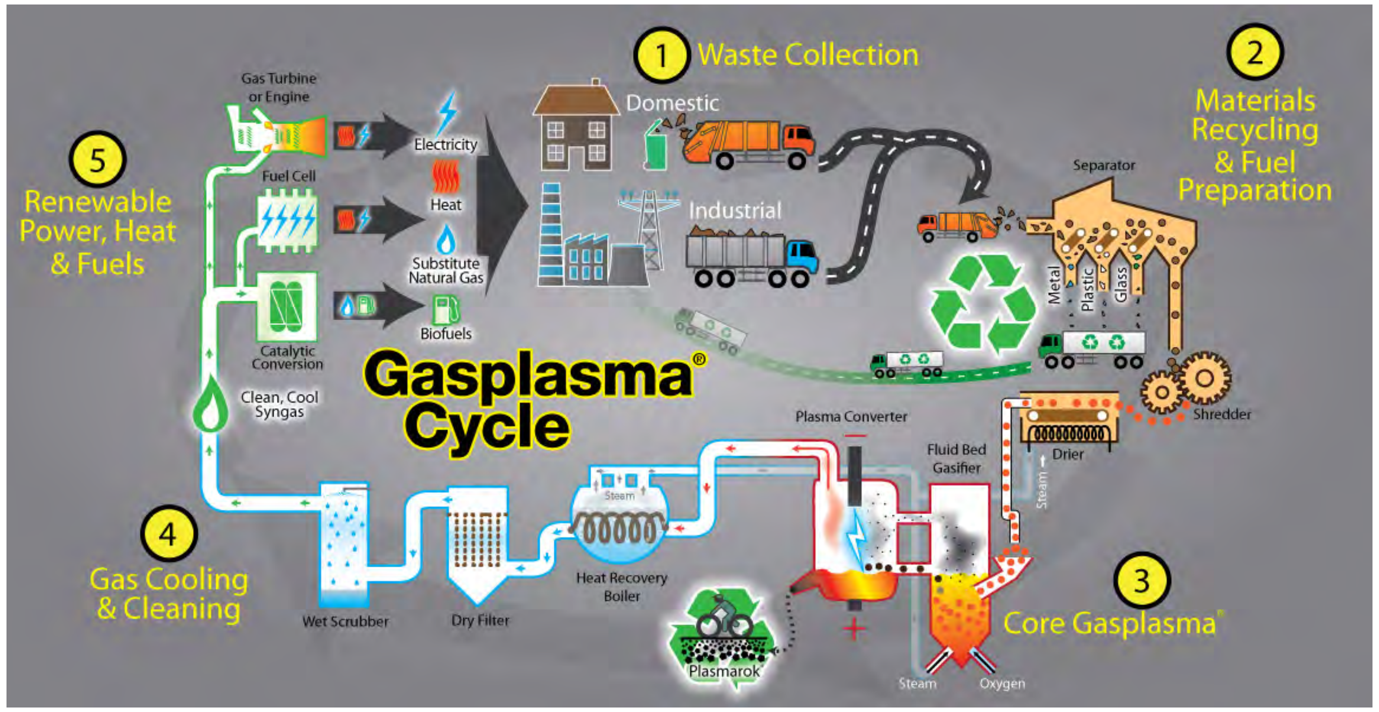
cracking of tar substances and the breakdown of char materials. The cracking creates a clean syngas, whilst the inorganic elements in the ash carried over from the gasifier are vitrified into a product called Plasmarock.

The clean syngas exiting the plasma converter is then cooled and conditioned through wet and dry scrubbers before being used directly in reciprocating gas engines or gas turbines to generate renewable electricity or through the methanation process to generate renewable gas for injection into the gas grid as a substitute natural gas. Residual heat is also recovered in the process to be used in cogeneration mode within the process itself as well as other users in the vicinity.

The key element of plasma gasification is the plasma converter which is able to achieve highly effective and energy efficient cracking of the complex tars and char products in the raw syngas exiting the gasifier. It is the presence of these contaminants in waste gasification processes which has, in the past, been the major obstacle in deploying more efficient energy generation. Converting waste to a clean gas to generate electricity directly in gas engines, gas turbines and fuel cells dramatically improves energy conversion efficiency and maximises electrical output or by the even more efficient conversion into liquid fuels, hydrogen or substitute natural gas for distribution to end demand energy uses such as cogeneration, trigeneration, homes and businesses in existing gas grids.

Feedstock:	*50,000 tonnes of municipal solid waste*
Capacity:	*6MW electricity*
Annual Output:	*49,970MWh pa electricity*
Estimated Diversion: from Landfill	*99%*
Annual saving:	*35,030 tonnes $CO_{2\text{-}e}$ (based on UK grid emissions)* *52,970 tonnes $CO_{2\text{-}e}$ (based on NSW grid emissions)*
Energy from Waste Ratio:	*1.00MWh/tonne of waste (renewable electricity output only)*
$CO_{2\text{-}e}$ Saving to Waste Ratio:	*0.70 tonnes/tonne of waste (based on UK grid emissions)* *1.06 tonnes/tonne of waste (based on NSW grid emissions)*

FIGURE 92: GASPLASMA PROCESS
(SOURCE: ADVANCED PLASMA POWER)



TECHNICAL APPENDIX

Gasification Technologies Review