Section 5. Advanced Waste Treatment in the Green Infrastructure Strategy

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Pictured: Energy recovery at Kymijärvi II gasification facility, Lahti, Finland.
Credits: Metso Power, 2012

efficiency | renewables | innovation

Overview

In previous sections of this study we have provided a comprehensive review of commercially available platforms for the generation of synthesis gas from residual waste resources and upgrading of the resulting raw syngas into a pipeline-quality substitute natural gas (SNG) product; and a detailed assessment of the potential for energy recovery and waste minimization deriving from establishment of an integrated Syngas from Waste SNG (SfW-SNG) facility converting post-recycling residues from domestic, commercial and industrial waste resources collected within the City of Sydney LGA and surrounding Councils in the Southern Sydney Regional Organization of Councils (SSROC).

The *Renewable Gas Supply Infrastructure* study (TWE 2013), developed by Talent with Energy within the scope of the City of Sydney *Renewable Energy Master Plan* (City of Sydney 2013a), has evaluated the potential associated with a range of renewable gas resources – from thermal or biological conversion of waste and biomass residues – available within a 250-km radius from the City of Sydney LGA, to meet gas supply requirements from the network of precinct-scale trigeneration facilities proposed under the City's *Trigeneration Master Plan* ((City of Sydney 2013b).

In this section we introduce the key elements of integration between the Trigeneration and Renewable Energy Master Plans, and highlight the key contribution of the SfW-SNG platform in providing a secure and robust renewable substitute natural gas supply for the City's proposed trigeneration network.

Based on the results presented in Section 4, this analysis focuses on the High-Temperature Conversion + Melting (HTCM) family of thermal conversion technologies, and adopts plasma gasification as the reference technology for the purpose of modelling.

Decentralised Energy Network

A central element of the City's Green Infrastructure Strategy, the City's *Decentralised Energy Master Plan – Trigeneration* (hereinafter referred to as the *Trigeneration Master Plan*) seeks to improve the supply of energy services to businesses and residents in the City of Sydney through the deployment of a network of 15 precinct-scale trigeneration facilities – for a total installed capacity of 372 MWe by 2030 – connected to form a reticulated heating and cooling network, servicing buildings within four *low-carbon infrastructure zones*[19]:

Figure 66. Trigeneration Master Plan – Decentralised Energy Network[20]

[19] *City of Sydney Decentralised Energy Master Plan - Trigeneration*. Prepared by Kinesis for City of Sydney, June 2012. http://www.cityofsydney.nsw.gov.au/.../TrigenerationReport.pdf

[20] adapted from (City of Sydney 2012), Figure 21, p. 25.

Key highlights

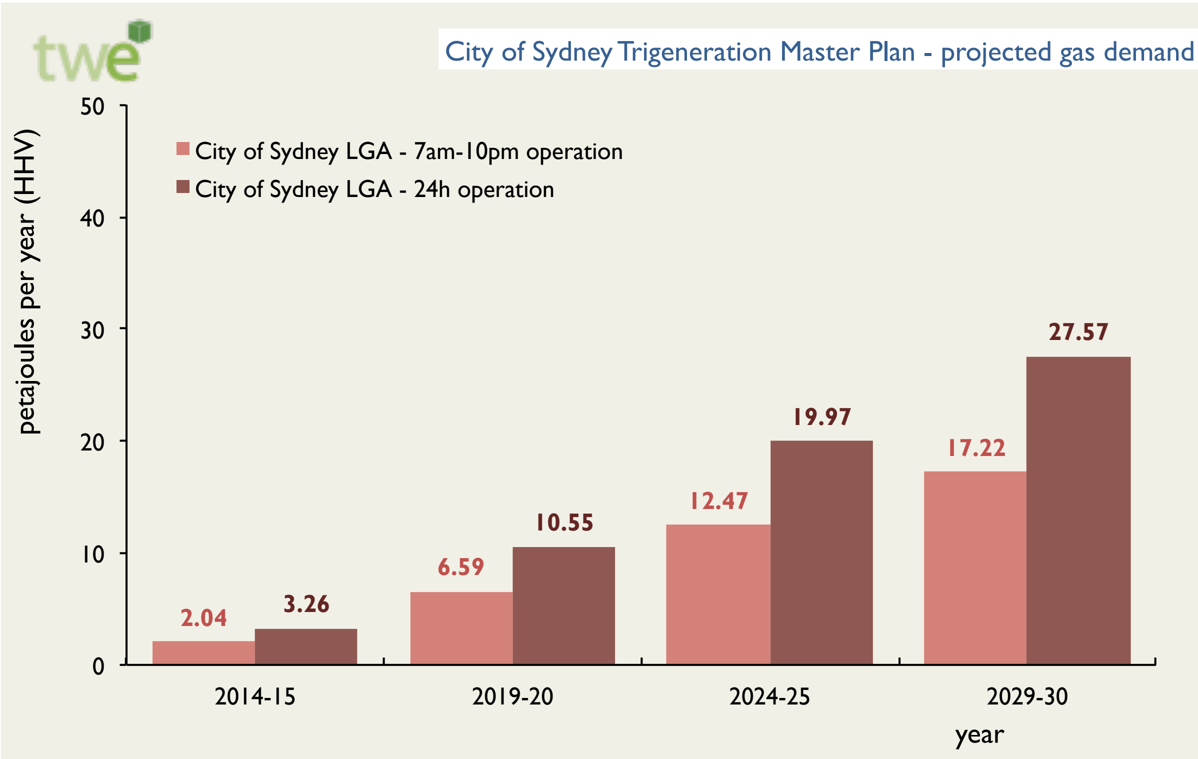
Gas demand

Within the scope of the Trigeneration Master Plan, Kinesis has provided an estimate of the projected gas demand from this network, through to the 2029-30 timeframe, on the basis of two utilization scenarios: 15 h (7am-10pm) operation; and 24h operation.

The chart below illustrates the resulting projected annual demand for natural gas through to 2029-30, expressed in petajoules per year (PJ/y, HHV basis[21]).

This is projected to grow up to 17.22 PJ/y in 2029-30 in the 15hr (7am-10pm) operation scenario, and up to 27.57 PJ/y in the 24h operation scenario (City of Sydney 2012).

Figure 67. Proposed trigeneration network, projected natural gas demand to 2029-30



In addition to this demand, the Master Plan estimates that the network of small-scale trigeneration facilities in the four 'hotspots' areas could reach a total installed capacity of 38 MW_e, adding 2.5 to 3 PJ/y to the annual demand for natural gas in 2029-30.

The proposed network of trigeneration facilities, suitably re-named by the City as *Green Infrastructure*, will deliver power to residents at a higher system-level efficiency, and substantially reduced greenhouse gas intensity than conventional, coal-fired, base-load

[21] throughout this study, energy quantities are reported on a higher heating value (HHV) basis

power plants (accounting for over 90% of capacity installed in New South Wales) due to the combined effect of:

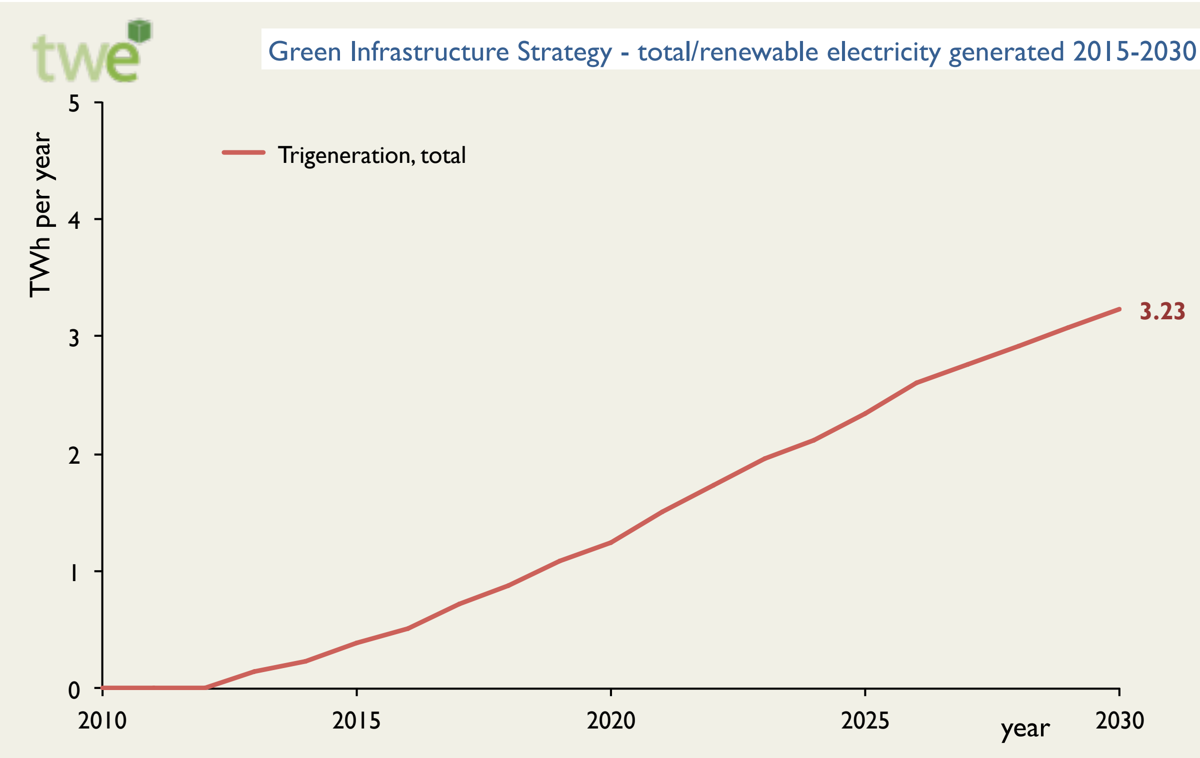
- **increased generation efficiency** versus both established coal-fired steam generation and new, state-of-the art combined cycle gas turbine power plants;
- **lower greenhouse gas emissions** per unit of energy delivered; and
- **reduced transmission and distribution (T&D) losses**.

In addition, waste heat from generation equipment installed at these facilities is used in heat exchangers and absorption chillers to provide heating and cooling as well as water heating services to the cluster of commercial buildings that will be connected to the trigeneration precincts.

Electricity generation

Under the mid-growth, 24h operation scenario total electricity generation from the decentralised energy network is projected by Kinesis to grow to 3.23 TWh per year in 2029-30.

Figure 68. Green Infrastructure Strategy (Trigeneration) – total electricity generated, 2010-30



Greenhouse gas mitigation

Modelling developed by Kinesis for the Trigeneration Master Plan, has estimated the cumulative greenhouse gas (GHG) reduction potential resulting from implementation of the decentralised energy network to be between 8 and 19 million tonnes of CO_2 equivalent (Mt_{CO2-e}) between 2010 and 2030, based on a range of roll-out and operational scenarios.

The analysis presented in our study takes the mid-growth trigeneration roll-out scenario, with 24h operation, as the starting point.

When this scenario is considered, the implementation of the trigeneration master plan brings total 2029-30 emissions down to 1.25 Mt_{CO2-e} per year, a reduction of 1.68 Mt_{CO2-e} per year – or 57.2% – against the 2029-30 baseline of 2.93 Mt_{CO2-e} per year, as illustrated by the emission trajectories presented in the diagram below.

The resulting cumulative emission reductions against the baseline scenario amount to 15.17 Mt_{CO2-e} in the 2010-2030 timeframe.

Figure 69. Green Infrastructure Strategy (Trigeneration) – net annual GHG emissions, 2010-30

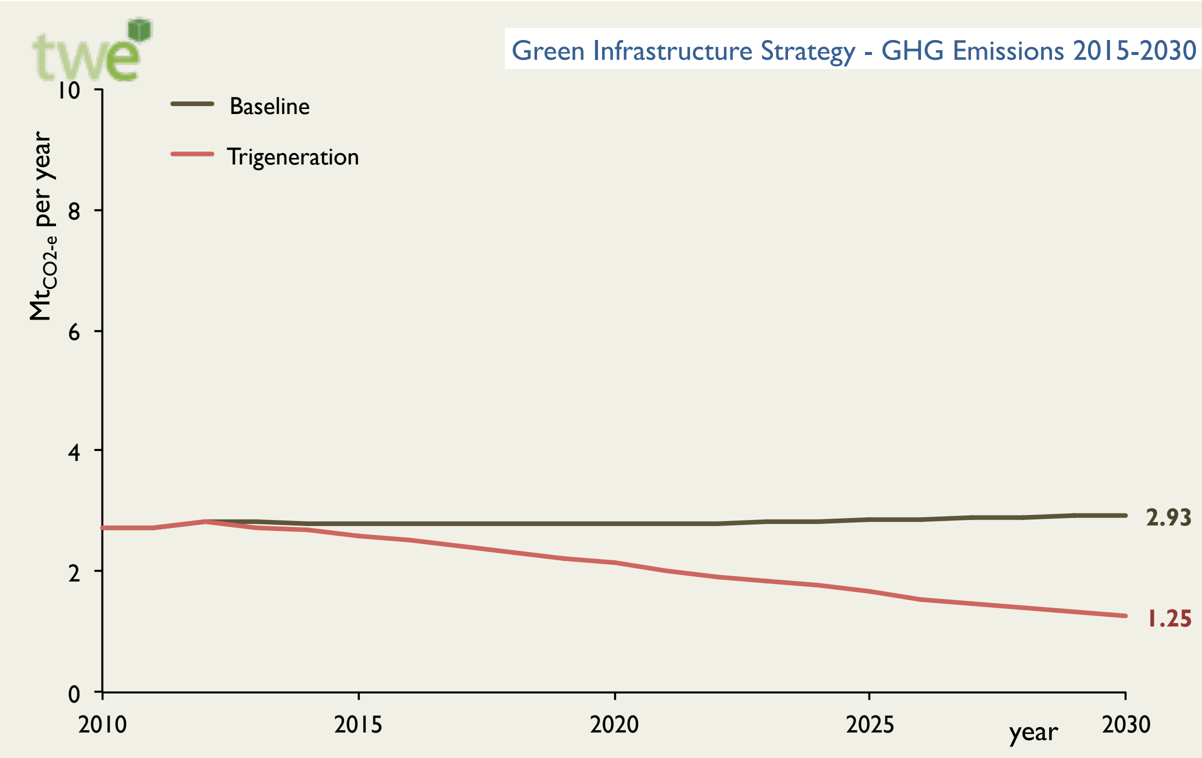
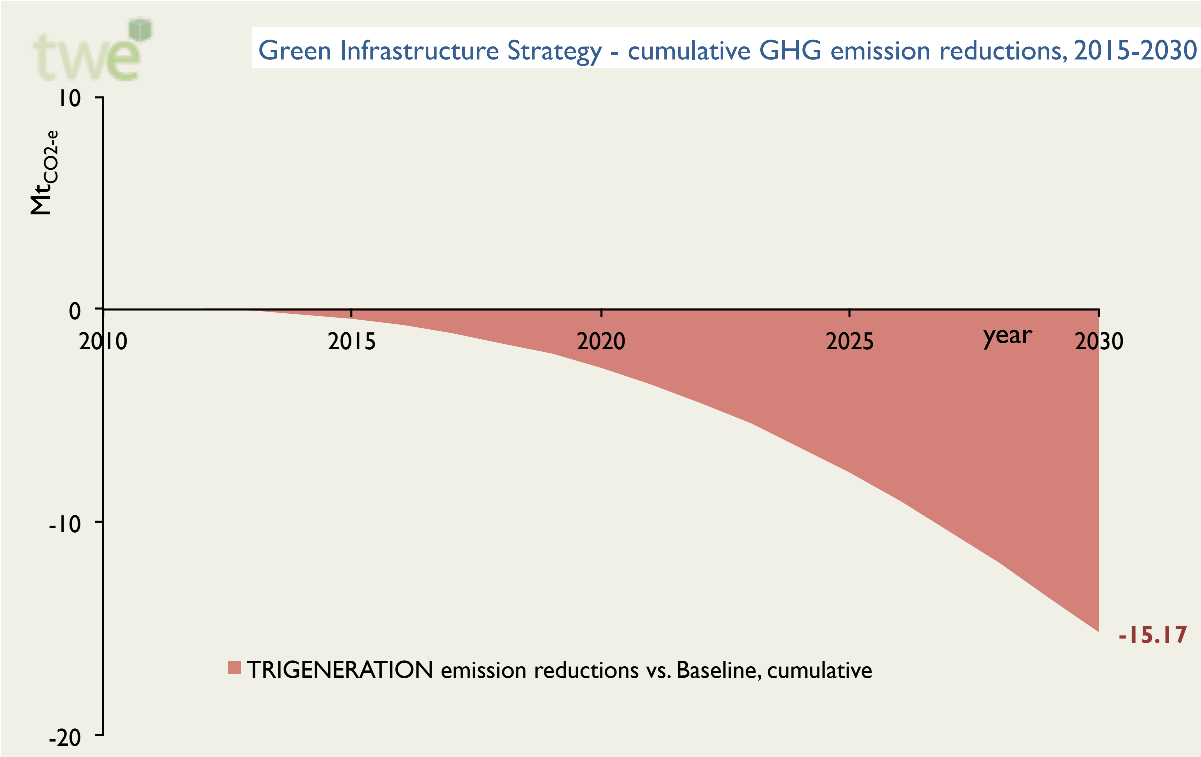


Figure 70. Green Infrastructure Strategy (Trigeneration) - cumulative net GHG emission reductions, 2015-30

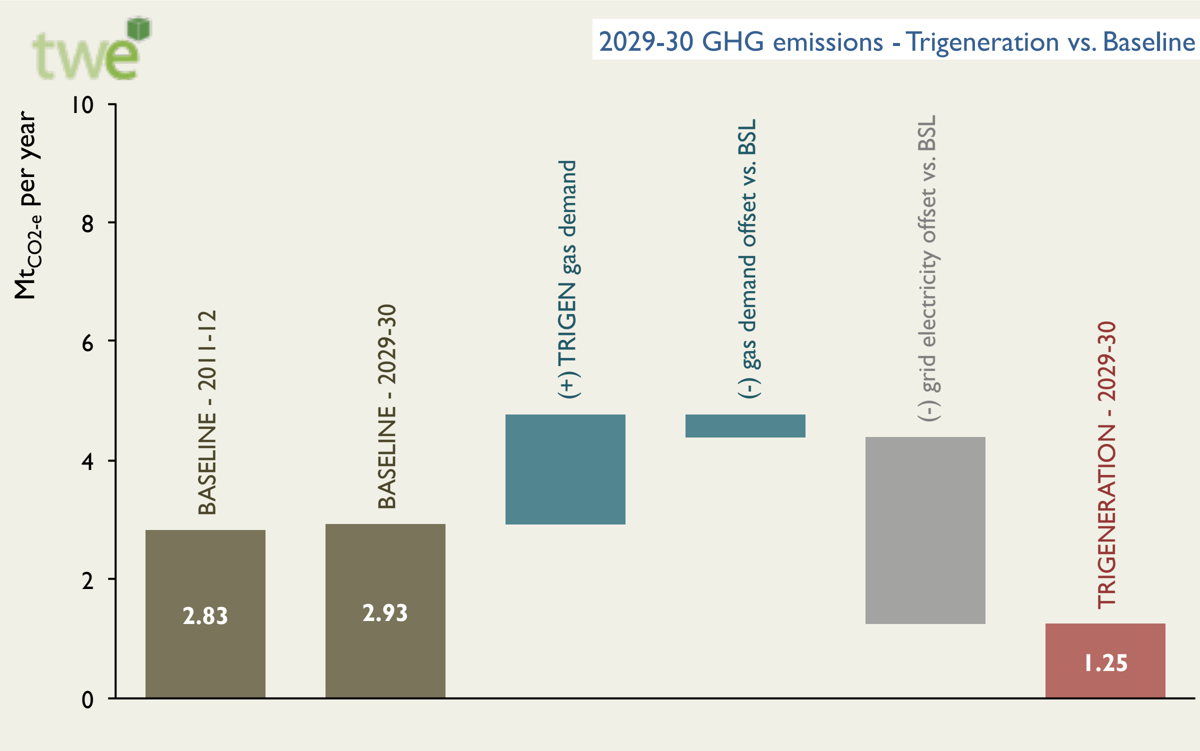


Reductions in GHG emissions, are broken down as follows:

- an increase in GHG emissions of 1.84 Mt_{CO2-e} per year, associated with additional consumption for natural gas from the decentralised energy network;
- a decrease in GHG emissions of 0.38 Mt_{CO2-e} per year, associated with baseline gas consumption displaced by the provision of reticulated heating services through the decentralised energy network; and
- a decrease in GHG emissions of 3.14 Mt_{CO2-e} per year, associated with grid electricity consumption offset through electricity generated and the provision of reticulated heating and cooling services through the decentralised energy network.

The individual contribution of each of these elements and the variation from the baseline are illustrated in the waterfall diagram below.

Figure 71. 2029-30 GHG emissions –Trigeneration vs. Baseline



Advanced Waste Treatment and Renewable Gas Supply

Renewable gases from conversion of residual waste and biomass resources available within the Greater Sydney and the surrounding regions represent the key element of integration between the Trigeneration and Renewable Energy components of the *Decentralised Energy Master Plan*.

To cater for the novel nature of these platforms, the *Renewable Gas Supply Infrastructure Study*, developed by Talent with Energy within the scope of the City of Sydney Renewable Energy Master Plan, has following a unique, *pathway-based* perspective, providing an in-depth assessment of alternative renewable gas supply pathways along the key pathway operations: from resource harvesting to delivery of upgraded renewable gas products to end-users. The study integrates several elements of analysis, including:

- characterization of residual waste and biomass resources;
- residual waste and biomass resource assessment;
- technology performance, cost and emissions survey;
- renewable gas generation and delivery scenarios;
- direct (scope 1) and life-cycle (scope 3) GHG emission profiles;
- levelized cost of gas (LCoG) and least-cost gas supply scenarios;
- marginal cost of abatement and marginal abatement cost curves (MACCs).

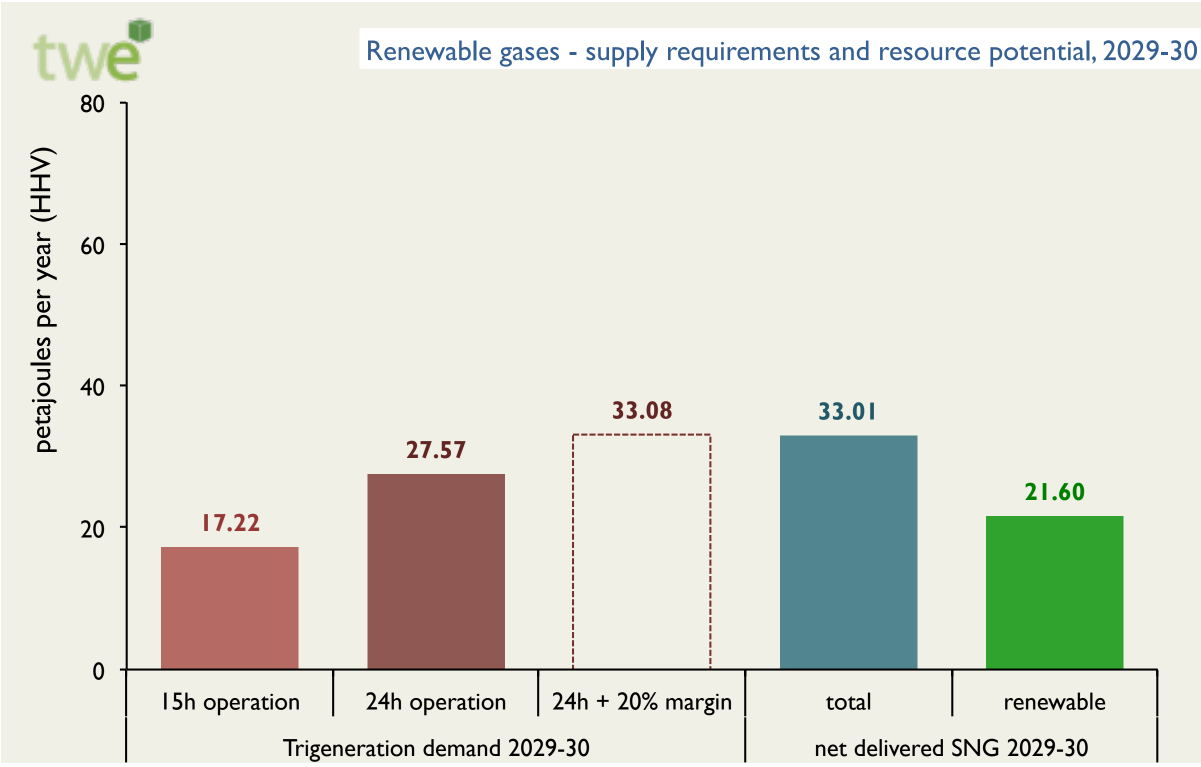
In the remainder of this section we present a summary of the result of this analysis highlighting the key contribution of Syngas from Waste SNG (SfW-SNG) pathways to the establishment of a secure renewable energy supply for the City's proposed trigeneration network.

Security of gas supply

The modelling presented has identified an available resource well in excess of the requirements from the proposed trigeneration network, even in the most demanding 24h operation scenario.

The Syngas from Waste component of SNG supply, 33.01 petajoules per year in 2029-30, compares well with the 2029-30 supply requirement, derived as the projected gas demand plus a 20% reserve margin, of 33.08 petajoules per year. The renewable energy component of the SfW-SNG supply is 21.60 PJ/y by 2029-30.

Figure 72. Syngas from Waste SNG - total/renewable net delivered SNG and supply requirements



Competitiveness of renewable gas supply

The analysis presented in Section 4 has determined, for 79 supply resources across five renewable gas generation pathways, the levelized cost of gas as the minimum selling price that would meet capital and operating costs for the proposed schemes, inclusive of upgrading and delivery operations (connection pipelines and transmission and distribution charges) and a 15% retail margin.

These cost figures, reported in real AUD_{2012} per GJ_{HHV} have been estimated across three timeframes, 2015-20, 2020-25 and 2020-25 for new build renewable gas generation facilities.

The table below compares summarizes the resulting range of LCoG for each pathway with the latest projected cost of gas from the Bureau for Resources and Energy Economics (BREE 2012b).

Table 22. Delivered renewable gas price estimated and natural gas price projections

	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

The price escalation trend in natural gas prices, determined by increasing exposure to international gas hub prices with the commissioning of large-scale LNG export terminals in Queensland, is matched by a decreasing price trend for renewable gases, determined by escalation in waste management revenues and decreasing equipment costs deriving from large-scale deployment of renewable gas generation, upgrading and delivery technologies and the associated technology and operational learning mechanisms.

The Syngas from Waste SNG, by far the largest resource, is also one of the most competitive resource, after small-scale biogas and landfill gas, with projected costs, delivered to the City, lower than projected prices for natural gas supply from the 2015-20 timeframe.

Contribution to the City's Green Infrastructure targets

The contribution to the City's renewable electricity generation and GHG mitigation targets has been estimated for the least-cost roll-out determined under Section 4.

The table below summarizes the least gas supply resource mix for the 2015-20, 2020-25 and 2025-30 timeframe and the resulting weighed average renewable energy fraction and greenhouse gas emission factors.

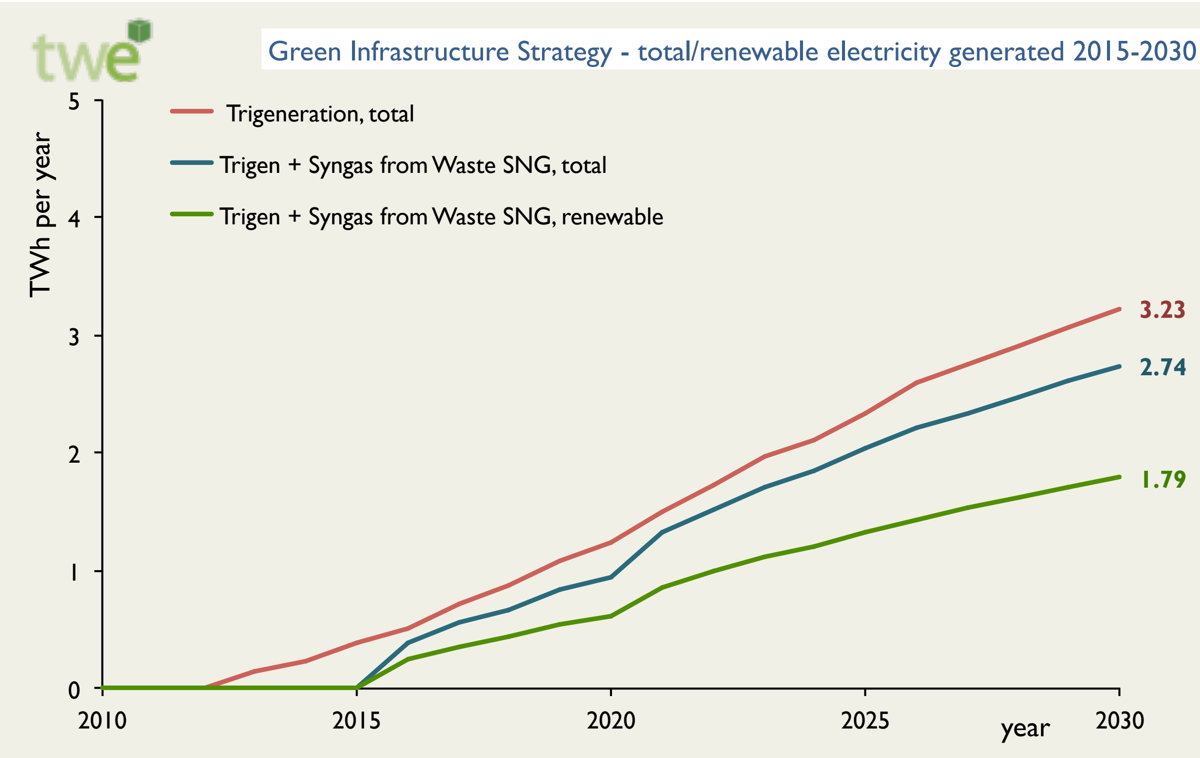
Table 23. Least-cost renewable gas supply – gas resource mix, renewable energy fraction and emission factors

Pathway/timeframe	Conversion strategy SfW-SNG	SfB-SNG	LsB-SNG	SsB-SNG	LfG-SNG	ALL GASES w. average
SHARE of TOTAL SNG generated (HHV basis)						
2015-20	76.44%			23.56%		
2020-25	87.55%			12.45%		
2025-30	84.90%			9.02%	6.08%	
RENEWABLE ENERGY FRACTION (HHV basis)						
2015-20	64.85%			100.00%		73.13%
2020-25	65.15%			100.00%		69.49%
2025-30	65.24%			100.00%	100.00%	70.48%
LIFE-CYCLE EMISSION FACTOR, $kg_{CO2\text{-}e}/GJ_{HHV}$						
2015-20	-26.501			11.499		-17.548
2020-25	-26.660			11.499		-21.909
2025-30	-26.825			11.499	-269.553	-38.124

Renewable electricity generation

The diagram below illustrates the total and renewable electricity generation resulting from the Syngas from Waste SNG component of the least-cost roll-out of renewable gas supply for the trigeneration network (under the 24 h operation scenario.

Figure 73. Syngas from Waste SNG - total and renewable electricity generation

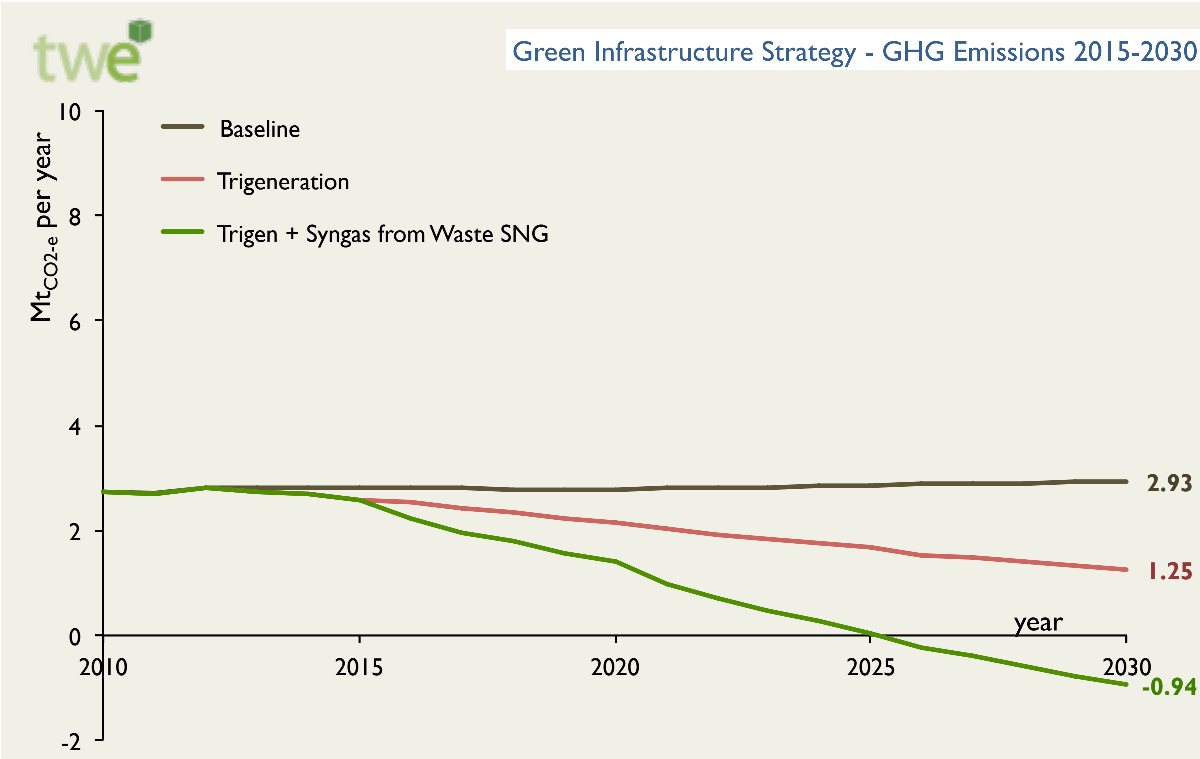


GHG emissions

The chart below illustrates the emission trajectories for the Baseline, Trigeneration (mid-growth, 24h operation) and Trigeneration + Syngas from Waste SNG (least-cost roll-out) scenarios.

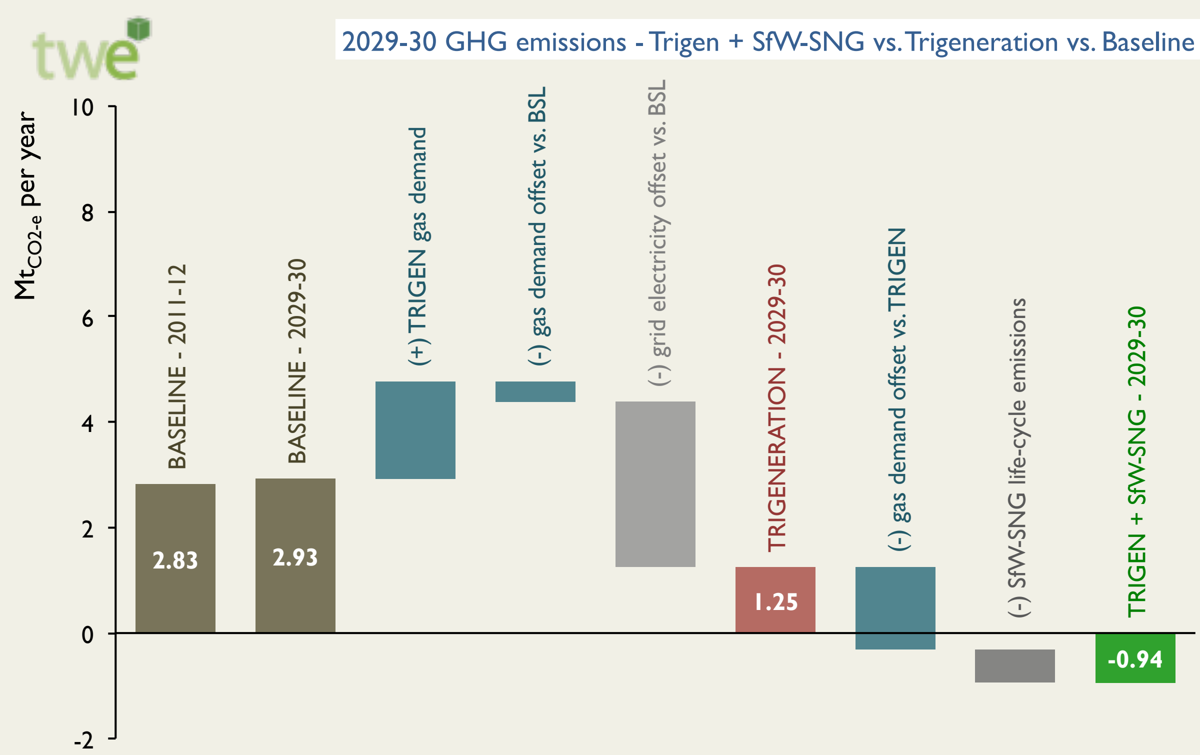
The Trigeneration + Renewable Gases strategy brings about additional GHG emission reductions versus trigeneration of 2.89 Mt_{CO2-e} per year by 2029-30, bringing the emissions from the Low Carbon Infrastructure Zones down to -1.64 Mt_{CO2-e} per year by 2029-30.

Figure 74. Green Infrastructure Strategy (Trigen + Syngas from Waste SNG) – net GHG emissions, 2010-30



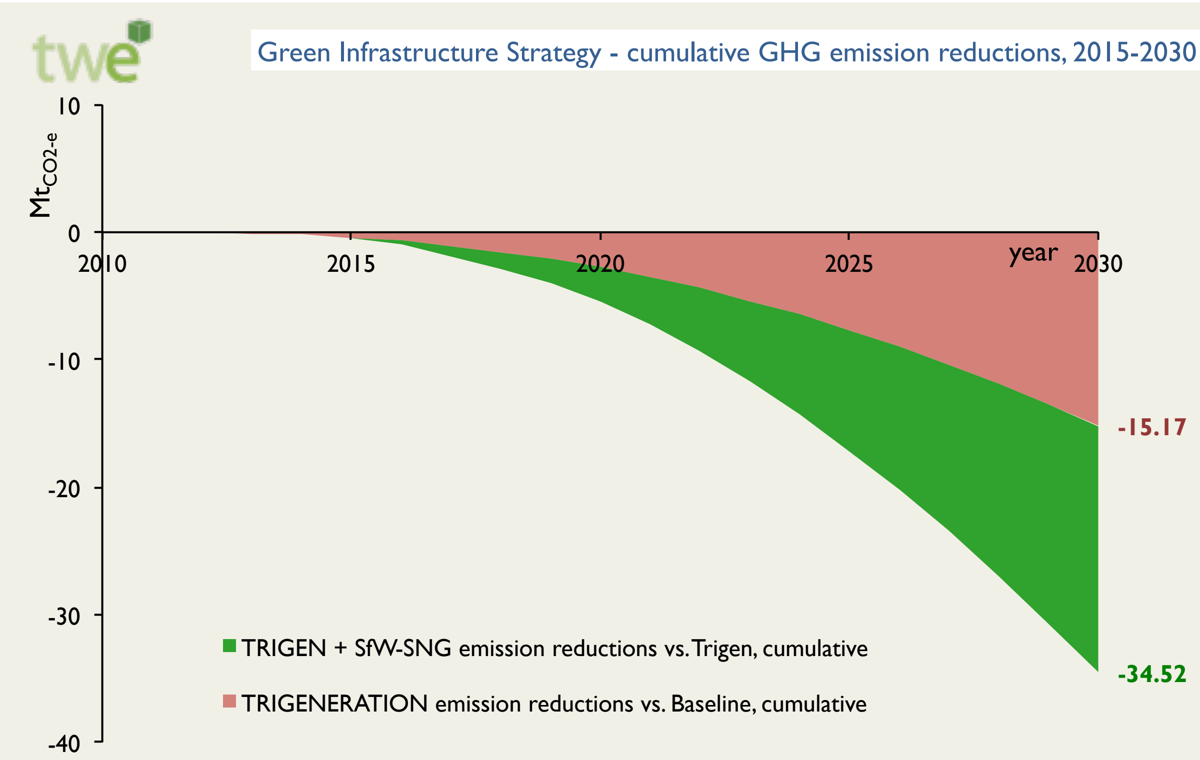
The breakdown of emission reductions, from the baseline 2029-30 emission figure of 2.93 Mt_{CO2-e} per year, to the 1.25 Mt_{CO2-e} per year achieved through implementation of the trigeneration strategy and finally down to -0.94 Mt_{CO2-e} per year achieved through implementation of the trigeneration + syngas from waste SNG strategy is explained in the waterfall diagram below.

Figure 75. 2029-30 GHG emissions – Trigen + Syngas from Waste SNG vs. Trigeneration vs. Baseline



The cumulative emission reductions over the 2015-2030 timeframe, increase from the 15.17 Mt$_{CO2-e}$ brought about by the *trigeneration* strategy to 34.52 Mt$_{CO2-e}$.

Figure 76. Green Infrastructure Strategy (Trigen + SfW-SNG), cumulative net GHG emission reductions



Section 6. Enabling Actions

Pictured: Energy recovery at Kymijärvi II gasification facility, Lahti, Finland.
Credits: Metso Power, 2012

Overview

Successful commissioning of a Syngas from Waste (SfW) plant is heavily dependent on execution of a well planned *project development pathway* – from preliminary planning activities to plant testing and commissioning.

While some aspects of the process are not unlike those required for any energy conversion project, the very nature and variability of the waste resource, the multitude of stakeholders involved, the higher degree of technology and operational risk associated with waste conversion processes and, in some constituencies, issues arising from public perception of waste-to-energy schemes and lack of a clear and comprehensive regulatory framework, do require adoption of a development strategy very specific to this type of facilities.

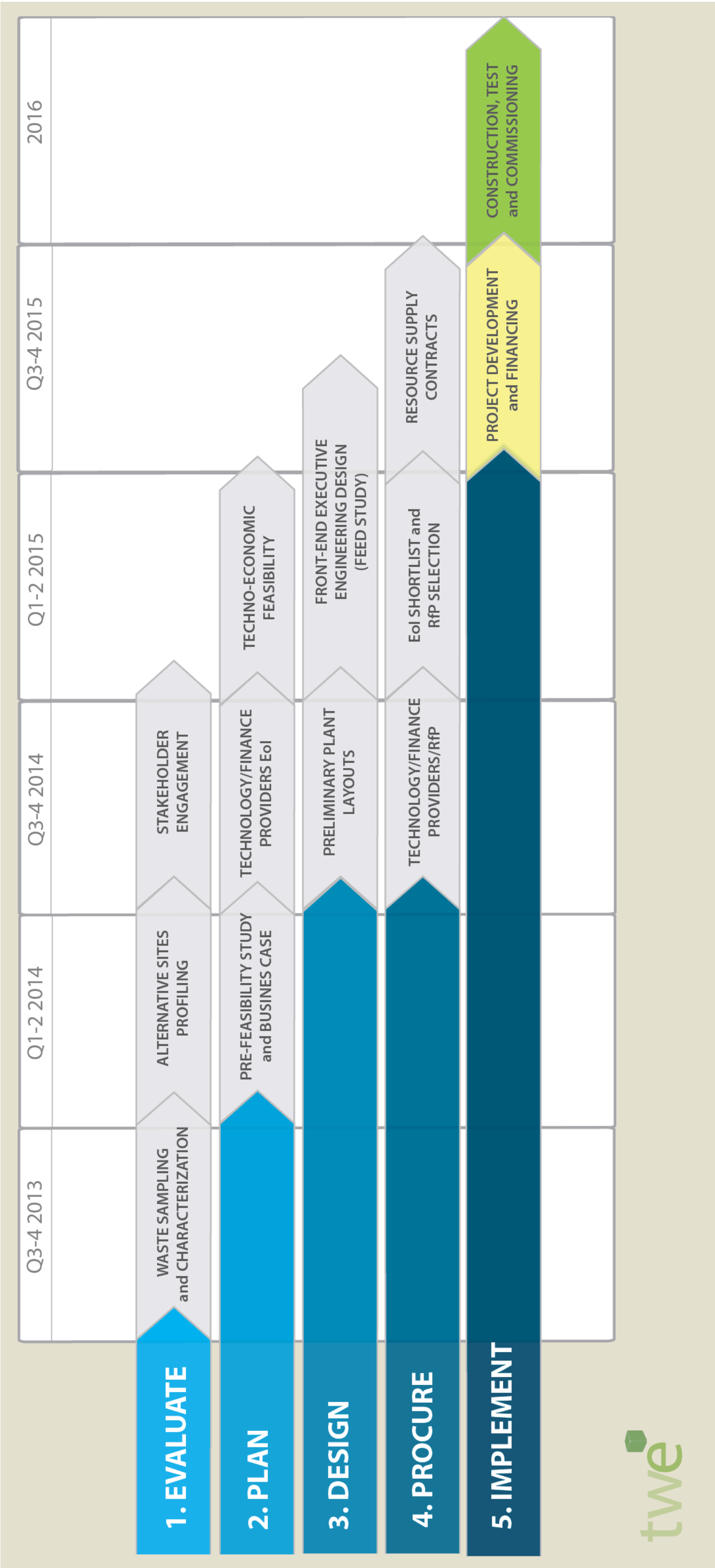
To put this in the context of the proposed EfW facility, presented here is a sketch of such a *project development pathway*, with the aim to highlight the key activities involved, and provide a preliminary timeline for their planning and execution.

These are grouped as follows:

- Preliminary planning: including waste audit, sampling and characterization, Commercial and Industrial (C&I) waste resource assessment, alternative sites profiling, and preliminary feasibility assessment;
- Stakeholder engagement: including stakeholder engagement strategy, institutional stakeholder engagement and broader stakeholder consultation activities;
- Market approach: including an expression of interest for technology and finance providers and subsequent request for proposal,
- Partnership development: negotiations towards the establishment of a project development partnership.
- Project design: including full feasibility study and detailed engineering and construction plans;
- Project development: resource contracts, power purchase and/or gas off take agreements and plant manufacturing and project development contracts;
- Project construction and commissioning.

The project pathway presented below has been built assuming construction and commissioning of the plant (from breaking ground to full commissioning) will take 15 months, from Q3 2014, with ongoing testing and commissioning to carry for at least one year from the plant first firing, with full commercial operation to commence in Q4 2016.

Figure 77. Preliminary SfW project development pathway



The early activities grouped under preliminary planning, stakeholder engagement and market approach are seen as key enabling activities and are described in detail below.

Preliminary planning activities

Waste audit

Knowledge of fractional waste composition is key to determine the likely amounts of waste feedstocks available for the development of the proposed SfW plant under the different conversion strategy scenarios and determine the incremental improvements in resource recovery and landfill diversion rates associated with implementation of such a facility.

The figures presented in the SfW scenario are based on audits conducted in 2011 for the City of Sydney (APC 2011a), and the Southern Sydney Regional Organization of Councils (APC 2011b).

A new audit commissioned by the City for 2011-12, has been conducted at quarterly intervals from Q3 2011 to help characterize the seasonal variability of the waste streams. Results of this audit were not available at the time this report was completed.

It is recommended that the modelling figures here presented be updated to reflect the most recent audit data available, and that new audit campaigns be conducted in conjunction with detailed sampling and characterization campaigns (see below) for at least two years to support planning activities towards establishment of a Syngas from Waste facility.

Domestic waste sampling and characterisation campaign

Waste sampling and characterization campaign

Knowledge of the chemical composition and other physical parameters for the waste resource are key to the development of robust process models supporting preliminary feasibility assessments and detailed project design.

While the estimates presented in this report have provide a preliminary assessment of the likely syngas yield and composition associated with alternative conversion technology strategies, it should be stressed that these are based on internationally benchmarked waste characterization data.

A detailed characterization of the waste streams available within the City of Sydney is thus a key enabling factor for subsequent planning activities including:

- Revision of syngas yield and composition estimates,
- Preliminary feasibility studies,

- Estimation of energy conversion efficiencies for the purpose of renewable energy certification, and
- Enabling detailed process modelling from perspective technology suppliers.

A waste sampling and characterization campaign should be carried out by the City in alignment with the waste audit work currently under way.

The campaign should be carried for at least one year at quarterly intervals, with selection of a statistically significant sample of mixed waste, and other streams of interest, and compositional analysis for the following:

- Moisture content, as received basis (ISO 5068 standard, or equivalent),
- Ash Constituent Analysis (ASTM D1102 standard, or equivalent),
- Ultimate Analysis (ASTM D2439 standard, or equivalent),
- Gross Calorific Value (ISO 1928 standard, or equivalent),
- Proximate Analysis (ISO 562 standard, or equivalent).

Commercial and Industrial waste resource assessment and characterization

The City of Sydney does not hold direct responsibility for the Commercial and Industrial (C&I) waste stream and as such holds no detailed data on the quantities, composition and characteristics of this resource.

The analysis presented in the *EfW Scenarios* sections identifies this resource as a significant additional feedstock to a proposed EfW facility, however C&I waste quantities and composition figures used in this analysis, derived from a low level visual assessment, recently published by the State Government (DECCW 2010), need to be replaced by a more robust resource assessment focused on this stream.

Alternative sites profiling

The selection of a potential site for the proposed EfW facility has not been covered as part of this study, a detailed site profiling and selection analysis is a key enabling activity.

The analysis should consider technical and economic aspects of the site (land availability and cost, access to existing infrastructure, etc.) as well as address the social dimension of the sites considered, allowing factoring in the knowledge developed in the set of downstream stakeholder engagement and project design activities.

Preliminary feasibility study

A pre-feasibility study supporting the AWT Business Case should be completed to enable a preliminary techno-economic assessment of the proposed facility and inform the City of

Sydney on the key economic performance parameters under the different conversion technology and project implementation scenarios considered for this study.

Stakeholder engagement activities

The set of activities the City intends to develop under the AWT Master Plan have a distinct character of novelty in the Australian context, and as such require development of a robust and comprehensive set of stakeholder engagement activities.

Development of a stakeholder engagement strategy, aligned with the broader Green Infrastructure Strategy is a key enabling factor.

A two-pronged strategy, aimed at institutional (State and Federal Government Regulatory Authorities, neighboring Local Government Authorities, Industry Associations, etc.) and public opinion stakeholders should at minimum identify and map key organization on the basis of their perceived position on the City of Sydney's plans and their ability to influence, promote or block the activities the City intends to carry out under the AWT stream of its Green Infrastructure Strategy.

Engagement of institutional stakeholders will be key to assist them develop the regulatory infrastructure required for obtaining adequate operational permits for the proposed facility and will help securing access to funding mechanism developed under the Carbon Tax legislation and other State and Federal Government clean technology funding mechanisms.

Public opinion stakeholders will need to be informed of the key benefits of conversion technologies and engaged in the promotion of the proposed facility.

Funding opportunities

In addition to the wide array of funding opportunities available from State and Federal Agencies, the establishment of the Australian Renewable Energy Agency (ARENA) and the broader program of initiatives established within the framework of the Carbon Tax legislation, open a number of opportunities for supporting renewable energy and energy efficiency research development and demonstration (RD&D) initiatives linked with the proposed scope of initiatives for the City's Advanced Waste Treatment Master Plan, including:

- feasibility studies;
- resource assessment; and
- pilot demonstrations.

Approach to market

A robust and comprehensive market approach will allow the City to refine its understanding of the portfolio of conversion technology solutions and inform the selection of preferred technology, service and finance partners for the proposed facility.

It is important for the City to recognize that the required scope of supply for a Syngas from Waste facility includes elements (syngas upgrading and delivery) that are not usually integrated in the offering of most traditional gasification technology providers, and would require them to team up with industrial gas technology providers, or even have the industrial gas providers stepping in as the leading proponent, much like the case of Air Products in the Tees Valley developments in the UK.

For this reason, we recommend that the market approach be carried out in two stages.

Expression of Interest

The first stage will be an expression of interest (EoI) process designed to engage the shortlist of suppliers presented earlier in this report, and gather additional data on their system based on a matrix of selection criteria capturing the key economic, energy and environmental performance dimensions of interest for the proposed facility.

Following an approach demonstrated by the City and County of Los Angeles (and reviewed in the Appendixes), we recommend that a second parallel EoI should be aimed at perspective finance and waste management services partners, to gauge market interest in engaging with the City of Sydney on the development of a city-wide Waste Management Services Company (WASCo) or similar public-private partnership mechanism for the development and operation of the proposed facility.

Request for Proposals

Following completion of the EoI processes, a detailed request for proposal (RfP) should be issued to the successful participants with full technical specification for the proposed facility, including site selection, detailed waste composition data and waste management fee structure across the City’s LGA and surrounding region.

Submission from the successful RfP respondent will inform the basis for subsequent project design activities, including full feasibility and detailed engineering construction and manufacturing design.

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Appendix A. Waste Resource Assessment and Characterization

Overview

In order to support energy recovery and GHG emission modelling activities presented in Section 4. Advanced Waste Treatment Scenarios, TWE has developed a framework for detailed waste resource assessment and characterization, including the following:

- **elemental analysis**
- **energy content**
- **biomass content**
- **renewable energy content**
- **biogenic carbon content**

The framework builds on a combination of elemental analysis data for the range of materials typically found in the domestic and commercial and industrial waste streams, sourced from (Niessen 2010), and data from the following activities:

- a regional audit of domestic waste fractions collected within the LGAs of the Southern Sydney Regional Organization of Councils (SSROC), carried out in 2011 by APC Environmental (APC 2011b); and
- a kerbside audit of the domestic waste stream collected within the City of Sydney LGA, carried out in 2011 by APC Environmental Management (APC 2011a);
- a disposal based survey of the Commercial and Industrial waste streams collected in the Sydney Metropolitan Area (SMA), carried out in 2008 by the New South Wales Government's Department of the Environment, Climate Change and Water (DECCW 2010).

In this Appendix we present the framework developed, with details of source data and estimation methods used. Throughout this Appendix and the Study we aggregate data according to a *Waste Breakdown Structure*, organized in four levels:

- **streams,** aggregating waste materials by source (eg. domestic, commercial and industrial, etc.);
- **fractions,** aggregating waste materials into homogeneous fractions for the purpose of processing (eg. recyclable, combustible, putrescible, inert, hazardous, etc.);
- **categories,** aggregating waste materials with similar production methods or characteristics (eg. Oils, Paper, Plastics, Wood, Food wastes, etc.); and
- **materials**, the individual materials typically defined in waste audit activities (eg. for Paper and Paper Newspapers, Magazines, Timber, Leather, Rubber, Glass,etc.);

Reference waste materials

Detailed knowledge of the physico-chemical characteristics of the different materials in the waste stream is key to provide accurate estimates of the resulting moisture content and elemental analysis, and thus energy content of the incoming feedstock for a waste conversion facility. In this regard, the development of a waste sampling and characterization campaign, carried out at quarterly intervals for a minimum period of 12 months horizon is a critical activity in the project development pathway, and has been included in the set of enabling actions recommended to the City in Section 6 of this study.

In the absence of detailed sampling data collected within the Sydney Region, for the purpose of the analysis presented under Section 3 (Feedstock Resource Assessment) and 4 (AWT Implementation Scenarios), we resort here to use in the interim an internationally benchmarked database of physico-chemical characteristics for waste materials and categories, sourced from (Niessen 2010), including the following:

- **moisture content** of homogeneous waste categories;
- **proximate analysis**, to determine fraction composition, by weight as received basis, in terms of moisture content, volatile matter, combustible and inert fractions by weight;
- **ultimate analysis**, to determine elemental composition, by weight dry basis, in terms of key elements (Carbon, Hydrogen, Nitrogen, Oxygen and Sulphur) and inert residuals (Ash).

Physico-chemical characteristics

Moisture content data

Table 24. Typical moisture contents of waste categories (wt%, as received)

	Moisture content, wt%	
Waste category	As-fired	As-discarded
Oils	0	0
Paper	24.3	8
Plastics	13.8	2
Wood	15.4	15
Food wastes	63.6	70
Yard wastes	37.9	55.3
Rubber	13.8	2
Leather	13.8	2
Textiles	23.8	10
Glass	3	2
Metal	6.6	2
Miscellaneous	3	2

Adapted from: (Niessen 2010), Table 4.7, p.111

Proximate analysis data

Table 25. Proximate analysis of waste materials, paper and paper products (wt%, as received)

Category/material	Proximate analysys (as received), wt % Moisture	Volatile matter	Fixed carbon	Non comb.
Paper and Paper Products				
Paper, Mixed	10.24	75.94	8.44	5.38
Newsprint	5.97	81.12	11.48	1.43
Brown Paper	5.83	83.92	9.24	1.01
Trade Magazine	4.11	66.39	7.03	22.47
Corrugated Boxes	5.2	77.47	12.27	5.06
Plastic-Coated Paper	4.71	84.2	8.45	2.64
Waxed Milk Cartons	3.45	90.92	4.46	1.17
Paper Food Cartons	6.11	75.59	11.8	6.5
Junk Mail	4.56	73.32	9.03	13.09

SOURCE: (Niessen 2010), Table 4.32, pp.132-133.

Table 26. Proximate analysis of waste materials, food and food wastes (wt%, as received)

Category/material	Proximate analysys (as received), wt % Moisture	Volatile matter	Fixed carbon	Non comb.
Food and Food Wastes				
Vegetable Food Wastes	78.29	17.1	3.55	1.06
Citrus Rinds and Seeds	78.7	16.55	4.01	0.74
Meat Scraps (cooked)	38.74	56.34	1.81	3.11
Fried Fats	0	97.64	2.36	0

SOURCE: (Niessen 2010), Table 4.32, pp.132-133.

Table 27. Proximate analysis of waste materials, green waste (wt%, as received)

Category/material	Proximate analysys (as received), wt % Moisture	Volatile matter	Fixed carbon	Non comb.
Green Waste				
Green Logs	50	42.25	7.25	0.5
Rotten Timbers	26.8	55.01	16.13	2.06
Demolition Softwood	7.7	77.62	13.93	0.75
Waste Hardwood	12	75.05	12.41	0.54
Furniture Wood	6	80.92	11.74	1.34
Evergreen Shrubs	69	25.18	5.01	0.81
Balsam Spruce	74.35	20.7	4.13	0.82
Flowering Plants	53.94	35.64	8.08	2.34
Lawn Grass	75.24	18.64	4.5	1.62
Ripe Leaves	9.97	66.92	19.29	3.82
Wood and Bark	20	67.89	11.31	0.8
Brush	40	--	--	5
Mixed Greens	62	26.74	6.32	4.94

SOURCE: (Niessen 2010), Table 4.32, pp.132-133.

Table 28. Proximate analysis of waste materials, domestic wastes (wt%, as received)

Category/material	Proximate analysys (as received), wt % Moisture	Volatile matter	Fixed carbon	Non comb.
Domestic Wastes				
Upholstery	6.9	75.96	14.52	2.62
Tires	1.02	64.92	27.51	6.55
Leather	10	68.46	12.49	9.1
Leather Shoe	7.46	57.12	14.26	21.16
Shoe, Heel & Sole	1.15	67.03	2.08	29.74
Rubber	1.2	83.98	4.94	9.88
Mixed Plastics	2	--	--	10
Plastic Film	3-20	--	--	--
Polyethylene	0.2	98.54	0.07	1.19
Polystyrene	0.2	98.67	0.68	0.45
Polyurethane	0.2	87.12	8.3	4.38
Polyvinyl Chloride	0.2	86.89	10.85	2.06
Linoleum	2.1	64.5	6.6	26.8
Rags	10	84.34	3.46	2.2
Textiles	15-31	--	--	--
Oils, Paints	0	--	--	16.3
Vacuum Cleaner Dirt	5.47	55.68	8.51	30.34
Household Dirt	3.2	20.54	6.26	70

SOURCE: (Niessen 2010), Table 4.32, pp.132-133.

Table 29. Proximate analysis of waste materials, municipal wastes (wt%, as received)

Category/material	Proximate analysys (as received), wt % Moisture	Volatile matter	Fixed carbon	Non comb.
Municipal Wastes				
Street Sweepings	20	54	6	20
Mineral	2-6	--	--	--
Metallic	3-11	--	--	--
Ashes	10	2.68	24.12	63.2

SOURCE: (Niessen 2010), Table 4.32, pp.132-133.

Ultimate analysis data

Table 30. Ultimate analysis of waste materials, paper and paper products (wt%, dry basis)

Category/material	Ultimate analysis (dry basis), weight % C	H	O	N	S	Ash
Paper and Paper Products						
Paper, Mixed	43.41	5.82	44.32	0.25	0.2	6
Newsprint	49.14	6.1	43.03	0.05	0.16	1.52
Brown Paper	44.9	6.08	47.34	0	0.11	1.07
Trade Magazine	32.91	4.95	38.55	0.07	0.09	23.43
Corrugated Boxes	43.73	5.7	44.93	0.09	0.21	5.34
Plastic-Coated Paper	45.3	6.17	45.5	0.18	0.08	2.77
Waxed Milk Cartons	59.18	9.25	30.13	0.12	0.1	1.22
Paper Food Cartons	44.74	6.1	41.92	0.15	0.16	6.93
Junk Mail	37.87	5.41	42.74	0.17	0.09	13.72

Adapted from: (Niessen 2010), Table 4.28, p.127

Table 31. Ultimate analysis of waste materials, food and food wastes (wt%, dry basis)

Category/material	Ultimate analysis (dry basis), weight %					
	C	H	O	N	S	Ash
Food and Food Wastes						
Vegetable Food Wastes	49.06	6.62	37.55	1.68	0.2	4.89
Citrus Rinds and Seeds	47.96	5.68	41.67	1.11	0.12	3.46
Meat Scraps (cooked)	59.59	9.47	24.65	1.02	0.19	5.08
Fried Fats	73.14	11.54	14.82	0.43	0.07	0

Adapted from: (Niessen 2010), Table 4.28, p.127

Table 32. Ultimate analysis of waste materials, green waste (wt%, dry basis)

Category/material	Ultimate analysis (dry basis), weight %					
	C	H	O	N	S	Ash
Green Waste						
Green Logs	50.12	6.4	42.26	0.14	0.08	1
Rotten Timbers	52.3	5.5	39	0.2	1.2	2.8
Demolition Softwood	51	6.2	41.8	0.1	<.1	0.8
Waste Hardwood	49.4	6.1	43.7	0.1	<.1	0.6
Furniture Wood	49.7	6.1	42.6	0.1	<.1	1.4
Evergreen Shrubs	48.51	6.54	40.44	1.71	0.19	2.61
Balsam Spruce	53.3	6.66	35.17	1.49	0.2	3.18
Flowering Plants	46.65	6.61	40.18	1.21	0.26	5.09
Lawn Grass	46.18	5.96	36.43	4.46	0.42	6.55
Ripe Leaves	52.15	6.11	30.34	6.99	0.16	4.25
Wood and Bark	50.46	5.97	42.37	0.15	0.05	1
Brush	42.52	5.9	41.2	2	0.05	8.33
Mixed Greens	40.31	5.64	39	2	0.05	13

Adapted from: (Niessen 2010), Table 4.28, p.127

Table 33. Ultimate analysis of waste materials, domestic wastes (wt%, dry basis)

Category/material	Ultimate analysis (dry basis), weight % C	H	O	N	S	Ash
Domestic Wastes						
Upholstery	47.1	6.1	43.6	0.3	0.1	2.8
Tires	79.1	6.8	5.9	0.1	1.5	6.6
Leather	60	8	11.5	10	0.4	10.1
Leather Shoe	42.01	5.32	22.83	5.98	1	22.86
Shoe, Heel & Sole	53.22	7.09	7.76	0.5	1.34	30.09
Rubber	77.65	10.35			2	10
Mixed Plastics	60	7.2	22.6	--	--	10.2
Plastic Film	67.21	9.72	15.82	0.46	0.07	6.72
Polyethylene	84.54	14.18	0	0.06	0.03	1.19
Polystyrene	87.1	8.45	3.96	0.21	0.02	0.45
Polyurethane	63.27	6.26	17.65	5.99	0.02	4.38 [a]
Polyvinyl Chloride	45.14	5.61	1.56	0.08	0.14	2.06 [b]
Linoleum	48.06	5.34	18.7	0.1	0.4	27.4
Rags	55	6.6	31.2	4.12	0.13	2.45
Textiles	46.19	6.41	41.85	2.18	0.2	3.17
Oils, Paints	66.85	9.63	5.2	2		16.3
Vacuum Cleaner Dirt	35.69	4.73	20.08	6.26	1.15	32.09
Household Dirt	20.62	2.57	4	0.5	0.01	72.3

Adapted from: (Niessen 2010), Table 4.28, p.127

Table 34. Ultimate analysis of waste materials, municipal wastes (wt%, dry basis)

Category/material	Ultimate analysis (dry basis), weight % C	H	O	N	S	Ash
Municipal Wastes						
Street Sweepings	34.7	4.76	35.2	0.14	0.2	25
Mineral	0.52	0.07	0.36	0.03	0	99.02
Metallic	4.54	0.63	4.28	0.05	0.01	90.49
Ashes	28	0.5	0.8	--	0.5	70.2

SOURCE: (Niessen 2010), Table 4.32, pp.132-133.

Waste stream characterization

In order to develop representative moisture content and ultimate analysis data for the waste streams considered in Section 3, we have reviewed data from recent audit activities conducted within the Sydney region and combined them with the physico-chemical characteristics of the individual waste materials presented earlier, to obtain a dataset of physico-chemical characteristics at the level of the following process fractions (combustible, putrescible, inert and hazardous).

In this chapter we present the raw audit data used, the waste breakdown structure adopted for the aggregation and the resulting dataset of fraction elemental analysis.

Waste audit data

Data presented in this section are sourced from the following audit activities:

- **Domestic wastes**, collected within the City of Sydney LGA, and the SSROC region, sourced from (APC 2011a), and (APC 2011b), respectively; and
- **Commercial and Industrial wastes**, collected within the Sydney Metropolitan Area (SMA), sourced from (DECCW 2010).

Domestic wastes

Table 35. Domestic waste composition, 2011 audit – City of Sydney LGA and SSROC

		CoS LGA - 2011 Audit		SSROC - 2011 Audit	
AWD Code	Material	kg/wk	wt%	kg/hh-wk	wt%
A01	Newspapers	12.7	0.80%	0.112	1.15%
A02	Magazines	54.3	3.43%	0.124	1.28%
A03	Paper Packaging	12.6	0.79%	0.010	0.10%
A04	Corrugated Cardboard	21.8	1.38%	0.066	0.68%
A05	Flat Cardboard	26.9	1.70%	0.159	1.64%
A06	Liquid Paperboard	4.6	0.29%	0.026	0.27%
A07	Disposable Paper Products	6.8	0.43%	0.025	0.26%
A08	Paper Paper	31.7	2.00%	0.103	1.06%
A09	Composite (mainly paper)	11.4	0.72%	0.051	0.52%
A092	Nappies Disposable	85.0	5.37%	0.642	6.60%
A90	Contaminated	115.7	7.31%	0.765	7.87%
B01	Food	485.7	30.69%	3.639	37.43%
B02	Vegetation	51.7	3.27%	0.593	6.10%
B03	Other Putrescible	29.8	1.88%	0.190	1.95%
C01	Wood/Timber	28.6	1.81%	0.121	1.24%
C02	Textile/Carpet	53.0	3.35%	0.330	3.39%
C03	Leather	1.0	0.06%	0.027	0.28%
C04	Rubber	3.5	0.22%	0.035	0.36%
C05	Oils	0.2	0.01%	0.006	0.06%
D0121	Glass Drink Containers	66.1	4.17%	0.143	1.47%
D0122	Other Packaging Glass	25.8	1.63%	0.118	1.21%
D0123	Other Glass	8.0	0.50%	0.045	0.46%
D050	Glass Fines	1.7	0.10%	0.006	0.06%
D02	PET Drink Containers	8.8	0.56%	0.039	0.40%
E01	PET Packaging	7.0	0.44%	0.046	0.47%
E02	PET Other			0.001	0.01%
E03	HDPE Drink Containers	4.6	0.29%	0.014	0.14%
E04	HDPE Packaging	4.7	0.30%	0.028	0.29%
E05	HDPE Other	0.0	0.00%	0.003	0.03%
E06	PVC Drink Containers			0.001	0.01%
E07	PVC Packaging	1.1	0.07%	0.003	0.03%
E071	PVC Other	0.0	0.00%	0.005	0.05%
E072	LDPE Packaging			0.003	0.03%
E073	LDPE Other	0.0	0.00%	0.003	0.03%
E08	PP Packaging	19.0	1.20%	0.060	0.62%
F01	PP Other	1.1	0.07%	0.013	0.13%
F011	EPS Packaging	3.5	0.22%	0.026	0.27%
F012	PS & EPS Other	0.4	0.02%	0.008	0.08%
F03	PS Packaging	2.7	0.17%	0.027	0.28%
F02	Other Plastic	23.5	1.48%	0.122	1.25%
G01	Composite (mostly plastic)	29.3	1.85%	0.124	1.28%
G03	Plastic Bags	32.9	2.08%	0.222	2.28%
G02	Plastic Film	56.4	3.57%	0.371	3.82%
H01	Steel Drink Containers	0.0	0.00%	0.005	0.05%
H02	Steel Packaging	18.9	1.19%	0.102	1.05%
H03	Steel Other	9.0	0.57%	0.052	0.53%
H04	Composite (mostly ferrous)	4.0	0.25%	0.034	0.35%
H05	Aluminium Drink Containers	4.2	0.26%	0.014	0.14%
H06	Aluminium Packaging	1.4	0.09%	0.009	0.09%
H07	Aluminium Other	3.3	0.21%	0.028	0.29%
	Non – Ferrous (specify)	0.5	0.03%	0.003	0.03%
	Composite (mostly non-ferrous)	1.0	0.06%	0.007	0.07%

… continues

SOURCES: City of Sydney LGA data from (APC 2011a), Table 13, p..37-38; SSRoC data from (APC 2011b) Table 18, pp.55-56.

Table 36. Domestic waste stream composition, 2011 audit – City of Sydney LGA and SSROC (continued)

AWD Code	Material	CoS LGA - 2011 Audit kg/wk	CoS LGA - 2011 Audit wt%	SSROC - 2011 Audit kg/hh-wk	SSROC - 2011 Audit wt%
continued …					
I01	Paint	2.6	0.16%	0.015	0.15%
I02	Fluorescent Tubes	0.4	0.03%	0.002	0.02%
I03	Single use batteries	0.7	0.04%	0.011	0.11%
Q53	Rechargeable batteries	0.2	0.01%	0.001	0.01%
Y57	Vehicle Batteries			0.005	0.05%
	Household Chemicals	2.5	0.16%	0.012	0.12%
	Asbestos			0.007	0.07%
	Clinical	0.0	0.00%	0.008	0.08%
XX00	Gas Bottles				
	Hazardous Other				
	Building materials	11.7	0.74%	0.181	1.86%
	Ceramics, Dust, Dirt, Rock, Inert, Ash	77.9	4.92%	0.241	2.48%
	Computer Equipment	1.4	0.09%	0.015	0.15%
	TVs				
	Mobile Phones			0.001	0.01%
	Electrical Items and Peripherals	11.0	0.70%	0.095	0.98%
	Toner Cartridges	0.1	0.01%	0.003	0.03%
	Containerised Food & Liquid	72.9	4.60%	0.362	3.72%
	Other	25.9	1.64%	0.054	0.56%
	Total	1,582.8	100.00%	9.722	100.00%

SOURCES: City of Sydney LGA data from (APC 2011a), Table 13, p..37-38; SSRoC data from (APC 2011b) Table 18, pp.55-56.

Commercial and Industrial wastes

Table 37. Commercial and Industrial waste composition, 2008 audit – Sydney Metropolitan Area

Material	SMA - 2008 Audit	
	t/y	wt%
Food/kitchen	282,735.0	16.27%
Food – dense	20,429.0	1.18%
Wood – pallets/ other	142,079.0	8.18%
Wood – mdf/chipboard	77,329.0	4.45%
Wood – furniture	37,512.0	2.16%
Wood – fencing/board/pole (untreated)	14,587.0	0.84%
Wood – fencing/board /pole (treated)	11,911.0	0.69%
Sawdust	4,948.0	0.28%
Plastic – bags & film	136,102.0	7.83%
Plastic – hard	84,727.0	4.88%
Plastic – other	40,766.0	2.35%
Plastic – recyclable containers	22,414.0	1.29%
Polystyrene/foam	9,732.0	0.56%
Paper – all other	128,969.0	7.42%
Paper – office	48,531.0	2.79%
Compacted dry cardboard	77,499.0	4.46%
Loose dry cardboard	25,998.0	1.50%
Compacted wet cardboard	13,224.0	0.76%
Loose wet cardboard	5,320.0	0.31%
Waxed cardboard	2,181.0	0.13%
Compacted dry cardboard production spoils	1,254.0	0.07%
Loose dry cardboard production spoils	270.0	0.02%
Textile – carpet / underlay	39,745.0	2.29%
Textile – cloth	30,512.0	1.76%
Textile – furniture	11,968.0	0.69%
Textile – leather/other	3,305.0	0.19%
Textile – mattress	2,017.0	0.12%
Metal – ferrous	32,314.0	1.86%
Metal – non ferrous	5,317.0	0.31%
Glass – containers/other	15,542.0	0.89%
Glass – plate	9,091.0	0.52%
Vegetation – branches/grass clips	53,003.0	3.05%
Vegetation – tree stumps /logs	3,479.0	0.20%
Rubber – shredded tyres	1,538.0	0.09%
Rubber – other	10,254.0	0.59%
Rubber – tyres/tubes	7,734.0	0.45%
Concrete/cement	28,066.0	1.62%
Clay	19,587.0	1.13%
Plasterboard	17,894.0	1.03%
Rubble > 150mm	33,584.0	1.93%
Rock	11,530.0	0.66%
Tiles	10,580.0	0.61%
Bricks	8,055.0	0.46%
Soil/cleanfill	38,122.0	2.19%
Insulation	1,357.0	0.08%
Fibreglass	652.0	0.04%
Asphalt	513.0	0.03%
Sand	392.0	0.02%
Ceramic	200.0	0.01%
Dirt	71.0	0.00%

… continues

SOURCE : (DECCW 2010), Table A2-3, p.76-77

Table 38. Commercial and Industrial waste composition, 2008 audit – Sydney Metropolitan Area (continued)

Material	SMA - 2008 Audit	
	Amount, t	Percent, %
continued …		
Hazardous/special – chemical/clinical	29,665.0	1.71%
Hazardous/special – light globes	357.0	0.02%
Batteries	346.0	0.02%
Electronics/electrical television etc.	11,003.0	0.63%
Computer/office equipment	716.0	0.04%
Toner cartridges	191.0	0.01%
Whitegoods – washing machine/ fridges	743.0	0.04%
Sludge	6,206.0	0.36%
Foundry sand	5,763.0	0.33%
Storm water	13,522.0	0.78%
Christmas decorations	950.0	0.05%
Animals	376.0	0.02%
Other	82,818.0	4.77%
Total	1,737,595.0	100.00%

SOURCE : (DECCW 2010), Table A2-3, p.76-77

Waste breakdown structure

In this section we present the allocation method used to aggregate the waste composition figures obtained presented above into the following process fractions:

- **Combustible fraction,** including waste materials from the Oils, Paper, Plastics, Rubber, Textile and Wood categories;
- **Putrescible fraction,** including waste materials from the Food and Green waste categories;
- **Inert fraction**, including waste materials from Construction and Demolition (C&D), Glass and Metal categories;
- **Hazardous fraction**, including waste materials from the Hazardous category;
- **Other fractions,** including waste materials from the Whitegoods, e-Waste and Other categories.

Combustible fractions

Table 39. Combustible fractions, Domestic Commercial and Industrial waste

Category	Waste materials: Domestic wastes[a]	Commercial and Industrial wastes[b]
Oils		
	C05-Oils	n/a
Paper		
	A01-Newspapers	Paper – all other
	A02-Magazines, Brochures	Paper – office
	A03-Miscellaneous Packaging	Compacted dry cardboard
	A04-Corrugated Cardboard	Loose dry cardboard
	A05-Package Board	Compacted wet cardboard
	A06-Liquid Paperboard Containers	Loose wet cardboard
	A07-Disposable Paper Products	Waxed cardboard
	A08-Print/Writing Office Paper	Compacted dry cardboard production spoils
	A09-Composite (mostly paper)	Loose dry cardboard production spoils
	A092-Contaminated Soiled Paper	
	A90-Nappies	
Plastics		
	E01-PET #1	Plastic – bags & film
	E02-HDPE #2	Plastic – hard
	E03-PVC #3	Plastic – other
	E04-LDPE #4	Plastic – recyclable containers
	E05-Polypropylene #5	Polystyrene/foam
	E06-Polystyrene #6	
	E07-Other Plastic	
	E071-Foams	
	E072-Plastic Bags	
	E073-Film	
	E08-Composite (mostly plastic)	
Rubber		
		Rubber – shredded tyres
		Rubber – other
		Rubber – tyres/tubes
Textile		
	C02-Textile/Rags/Carpet (Organic)	Textile – cloth
	C03-Leather	Textile – furniture
		Textile – leather/other
		Textile – mattress
Wood		
	C01-Wood/Timber	Wood – pallets/ other
		Wood – mdf/chipboard
		Wood – furniture
		Wood – fencing/board/pole (untreated)
		Wood – fencing/board /pole (treated)
		Sawdust

[a] Domestic waste: adapted from (APC 2011a,b)
[b] C&I waste: adapted from (DECCW 2010)

Putrescible fractions

Table 40. Putrescible fractions, Domestic Commercial and Industrial waste

Category	Waste materials Domestic wastes[a]	Commercial and Industrial wastes[b]
Food		
	B01-Food/Kitchen	Food/kitchen Food – dense
Green waste		
	B02-Garden/Vegetation B03-Other Putrescible	Vegetation – branches/grass clips Vegetation – tree stumps /logs

[a] Domestic waste: adapted from (APC 2011a,b)
[b] C&I waste: adapted from (DECCW 2010)

Inert fractions

Table 41. Inert fractions, Domestic Commercial and Industrial waste

Category	Waste materials Domestic wastes[a]	Commercial and Industrial wastes[b]
Construction and Demolition (C&D)		
	I01-Ceramics I02-Dust/Dirt/Rock/Inert I03-Ash/Earth-based	Concrete/cement Clay Plasterboard Rubble > 150mm Rock Tiles Bricks Soil/cleanfill Insulation Fibreglass Asphalt Sand Ceramic Dirt
Glass		
	D0121-Glass Clear Packaging/Containers D0122-Glass Green Packaging/Containers D0123-Glass Brown/Blue Packaging/Containers D050-Mixed Glass/Fines D02-Miscellaneous/Other Glass	Glass – containers/other Glass – plate
Metal		
	F01-steelCans Food & Pet F011-steel Aerosols F012-steelPaint Cans F03-Composite (mostly ferrous) F02-Other ferrous G01-Aluminium G03-Composite (mostly non-ferrous} G02-Other Non-Ferrous	Metal – ferrous Metal – non ferrous

[a] Domestic waste: adapted from (APC 2011a,b)
[b] C&I waste: adapted from (DECCW 2010)

Hazardous fractions

Table 42. Hazardous fractions, Domestic Commercial and Industrial waste

Category	Waste materials	
	Domestic wastes[a]	Commercial and Industrial wastes[b]
Hazardous		
	H01-Paint H02-Fluorescent tubes H03-Dry cell batteries H04-Car batteries H05-Household chemicals H06-Building Materials H07-Clinical (Medical) -Gas Bottles -Hazardous other	Hazardous/special – chemical/clinical Hazardous/special – light globes Batteries

[a] Domestic waste: adapted from (APC 2011a,b)
[b] C&I waste: adapted from (DECCW 2010)

Other fractions

Table 43. Other fractions, Domestic Commercial and Industrial waste

Category	Waste materials	
	Domestic wastes[a]	Commercial and Industrial wastes[b]
Whitegoods		
	n/a	Whitegoods – washing machine/ fridges
e-Waste		
	Y57-Toner Cartridges -Computer Equipment -Electrical Items -Mobile Phones	Electronics/electrical television etc. Computer/office equipment Toner cartridges
Other		
	XX00 -Other	Sludge Foundry sand Storm water Christmas decorations Animals Other

[a] Domestic waste: adapted from (APC 2011a,b)
[b] C&I waste: adapted from (DECCW 2010)

Composition analysis

The resulting composition analysis of the different process fraction and categories is summarized in the Table below.

Table 44. Composition analysis - domestic, commercial and industrial waste, by waste fraction and category

Fraction/category	MSW - CoS, 2011 Audit		MSW - SSROC, 2011 Audit		C&I - SMA, 2008 Survey	
	kg/wk	wt%	kg/hh-wk	wt%	t/y	wt%
Combustible fractions						
Oils	0.2	0.01%	0.006	0.06%		
Paper	383.4	24.23%	2.083	20.66%	303,246.0	17.45%
Plastics	227.7	14.38%	1.282	12.71%	293,741.0	16.91%
Rubber	3.5	0.22%	0.035	0.35%	19,526.0	1.12%
Leather	1.0	0.06%	0.027	0.27%	3,305.0	0.19%
Textile	53.0	3.35%	0.330	3.27%	84,242.0	4.85%
Wood	28.6	1.81%	0.121	1.20%	288,366.0	16.60%
Total combustible	*697.5*	*44.07%*	*3.884*	*38.52%*	*992,426.0*	*57.11%*
Inert fractions						
C&D	89.6	5.66%	0.422	4.18%	170,603.0	9.82%
Glass	105.2	6.64%	0.330	3.27%	24,633.0	1.42%
Metal	41.2	2.60%	0.247	2.45%	37,631.0	2.17%
Total inert	*235.9*	*14.91%*	*0.999*	*9.91%*	*232,867.0*	*13.40%*
Putrescible fractions						
Food	522.1	32.99%	3.820	37.88%	303,164.0	17.45%
Green waste	81.5	5.15%	0.783	7.76%	56,482.0	3.25%
Total Putrescible	*603.6*	*38.14%*	*4.603*	*45.65%*	*359,646.0*	*20.70%*
Hazardous fractions						
Hazardous	7.3	0.46%	0.068	0.67%	30,368.0	1.75%
Total hazardous	*7.3*	*0.46%*	*0.068*	*0.67%*	*30,368.0*	*1.75%*
Other fractions						
Whitegoods					743.0	0.04%
e-Waste	12.5	0.79%	0.114	1.13%	11,910.0	0.69%
Other	25.9	1.64%	0.416	4.13%	109,635.0	6.31%
Total other	*38.4*	*2.43%*	*0.530*	*5.26%*	*122,288.0*	*7.04%*
Total	1,582.8	100.00%	10.084	100.00%	1,737,595.0	100.00%

MSW - City of Sydney LGA: adapted from (APC 2011a), Table 13, p..37-38.
MSW - SSROC region: adapted from (APC 2011b) Table 18, pp.55-56.
C&I: SMA data adapted from (DECCW 2010), Table A2-3, p.76-77.

Elemental analysis

In this section we present the elemental analysis of process fractions, obtained by combining moisture content and ultimate analysis data from (Niessen 2010) with the composition figures presented earlier for the domestic waste streams collected within the City of Sydney LGA and SSROC region, and commercial and industrial waste streams collected within the Sydney Metropolitan Area.

Domestic waste fractions

City of Sydney LGA

Table 45. City of Sydney LGA, Domestic waste – ultimate analysis (est.), by waste categories and fractions

	Composition	Ultimate analysis (dry basis), weight %					
	wt%	C	H	O	N	S	Ash
Combustible							
Oils	0.01%	66.85	9.63	5.2	2	0.02	16.3
Paper	24.23%	45.4	6.1	42.1	0.3	0.12	5.98
Plastics	14.38%	59.8	8.3	19	1	0.3	11.6
Rubber	0.22%	77.65	10.35	0	0	2	10
Leather	0.06%	60	8	11.5	10	0.4	10.1
Textile	3.35%	46.2	6.4	41.8	2.2	0.2	3.2
Wood	1.81%	48.3	6	42.4	0.3	0.11	2.89
Inert							
C&D	5.66%	13	2	12	3	0	70
Glass	6.64%	0.52	0.07	0.36	0.03	0	99.02
Metal	2.60%	4.5	0.6	4.3	0.05	0.01	90.54
Putrescible							
Food	32.99%	41.7	5.8	27.6	2.8	0.25	21.85
Green waste	5.15%	49.2	6.5	36.1	2.9	0.35	4.95
Hazardous							
Hazardous	0.46%	13	2	12	3	0	70
Other fractions							
Whitegoods	0.00%	13	2	12	3	0	70
e-Waste	0.79%	13	2	12	3	0	70
Other	1.64%	13	2	12	3	0	70
CoS LGA - total	100.00%	39.79	5.46	27.23	1.64	0.19	25.69
Combustible	44.07%	50.47	6.86	34.28	0.69	0.19	7.51
Inert	14.91%	5.95	0.90	5.47	1.16	0.00	86.52
Putrescible	38.14%	42.71	5.89	28.75	2.81	0.26	19.57
Hazardous	0.46%	13.00	2.00	12.00	3.00	0.00	70.00
Other	2.43%	13.00	2.00	12.00	3.00	0.00	70.00
CoS LGA - feedstock resource							
LTC/HTC (comb.+putrescible)		46.87	6.41	31.71	1.67	0.23	13.10
HTCM (comb.+putrescible+inert)		40.59	5.57	27.69	1.59	0.19	24.37

SSROC region

Table 46. SSROC region, Domestic waste – ultimate analysis (est.), by waste categories and fractions

	Composition	Ultimate analysis (dry basis), weight %					
	wt%, dry basis	C	H	O	N	S	Ash
Combustible							
Oils	0.06%	66.85	9.63	5.2	2	0.02	16.3
Paper	20.66%	45.4	6.1	42.1	0.3	0.12	5.98
Plastics	12.71%	59.8	8.3	19	1	0.3	11.6
Rubber	0.35%	77.65	10.35	0	0	2	10
Leather	0.27%	60	8	11.5	10	0.4	10.1
Textile	3.27%	46.2	6.4	41.8	2.2	0.2	3.2
Wood	1.20%	48.3	6	42.4	0.3	0.11	2.89
Inert							
C&D	4.18%	13	2	12	3	0	70
Glass	3.27%	0.52	0.07	0.36	0.03	0	99.02
Metal	2.45%	4.5	0.6	4.3	0.05	0.01	90.54
Putrescible							
Food	37.88%	41.7	5.8	27.6	2.8	0.25	21.85
Green waste	7.76%	59.59	9.47	24.65	1.02	0.19	5.08
Hazardous							
Hazardous	0.67%	13	2	12	3	0	70
Other fractions							
Whitegoods	0.00%	13	2	12	3	0	70
e-Waste	1.13%	13	2	12	3	0	70
Other	4.13%	13	2	12	3	0	70
SSROC - total	100.00%	41.41	5.81	26.72	1.74	0.19	24.13
Combustible	38.52%	50.74	6.91	33.81	0.76	0.20	7.58
Inert	9.91%	6.78	1.02	6.25	1.29	0.00	84.67
Putrescible	45.65%	44.74	6.42	27.10	2.50	0.24	19.00
Hazardous	0.67%	13.00	2.00	12.00	3.00	0.00	70.00
Other	5.26%	13.00	2.00	12.00	3.00	0.00	70.00
SSROC - feedstock resource							
LTC/HTC (comb.+putrescible)		47.49	6.64	30.17	1.70	0.22	13.77
HTCM (comb.+putrescible+inert)		43.20	6.05	27.65	1.66	0.20	21.24

Commercial and Industrial waste fractions

Sydney Metropolitan Area

Table 47. SMA, Commercial and Industrial waste – ultimate analysis (est.), by waste categories and fractions

	Composition	Ultimate analysis (dry basis), weight %					
	wt%	C	H	O	N	S	Ash
Combustible							
Oils	0.00%	66.85	9.63	5.2	2	0.02	16.3
Paper	17.45%	45.4	6.1	42.1	0.3	0.12	5.98
Plastics	16.91%	59.8	8.3	19	1	0.3	11.6
Rubber	1.12%	77.65	10.35	0	0	2	10
Leather	0.19%	60	8	11.5	10	0.4	10.1
Textile	4.85%	46.2	6.4	41.8	2.2	0.2	3.2
Wood	16.60%	48.3	6	42.4	0.3	0.11	2.89
Inert							
C&D	9.82%	13	2	12	3	0	70
Glass	1.42%	0.52	0.07	0.36	0.03	0	99.02
Metal	2.17%	4.5	0.6	4.3	0.05	0.01	90.54
Putrescible							
Food	17.45%	49.06	6.62	37.55	1.68	0.2	4.89
Green waste	3.25%	48.51	6.54	40.44	1.71	0.19	2.61
Hazardous							
Hazardous	1.75%	13	2	12	3	0	70
Other fractions							
Whitegoods	0.04%	13	2	12	3	0	70
e-Waste	0.69%	13	2	12	3	0	70
Other	6.31%	13	2	12	3	0	70
SMA - total	100.00%	41.93	5.66	29.84	1.31	0.16	21.10
Combustible	57.11%	51.26	6.84	34.39	0.69	0.22	6.60
Inert	13.40%	10.31	1.57	9.52	2.21	0.00	76.39
Putrescible	20.70%	48.97	6.61	38.00	1.68	0.20	4.53
Hazardous	1.75%	13.00	2.00	12.00	3.00	0.00	70.00
Other	7.04%	13.00	2.00	12.00	3.00	0.00	70.00
SMA - feedstock resource							
LTC/HTC (comb.+putrescible)		50.65	6.78	35.35	0.96	0.21	6.05
HTCM (comb.+putrescible+inert)		44.72	6.01	31.56	1.14	0.18	16.39

Energy content

The energy content, or *heating value* of a fuel is defined on the basis of either of the following two conventions, as follows (Basu 2010):

- the **higher heating value (HHV),** the amount of heat released by the unit mass or volume of fuel (initially at the standard temperature condition of 25 °C) once it is combusted and the products have returned to the standard temperature, thus including the latent heat of vaporization of water in the combustion product; and

- the **lower heating value (LHV),** is defined as the amount of heat released by fully combusting a specified quantity of fuel, minus the latent heat of vaporization of the water in the combustion product.

Throughout this study we report energy quantities and energy performances on a HHV basis for consistency with other related studies developed for the City of Sydney within the scope of its *Renewable Energy* (City of Sydney 2013a) and *Trigeneration* (City of Sydney 2013b) Master Plans.

The relationship between the LHV and HHV of a fuel is expressed as follows:

$$\boldsymbol{LHV} = \boldsymbol{HHV} - \boldsymbol{h_g}\left(\frac{9\boldsymbol{H}}{100} + \frac{\boldsymbol{M}}{100}\right) \tag{4}$$

where:

- $\boldsymbol{LHV}$ and $\boldsymbol{HHV}$ are the lower and higher heating values of the fuel, respectivelys the latent heat of vaporization for water, 2260 kJ/kg;
- the latent heat of vaporization for water, 2260 kJ/kg;
- $\boldsymbol{h_g}$ is the latent heat of vaporization for water, 2260 kJ/kg;
- $\boldsymbol{H}$ is the hydrogen content, by weight on an as received basis; and
- $\boldsymbol{M}$ is the moisture content, by weight on an as received basis.

The most reliable means of determining the heating value of a fuel is through experimental methods, such as the D5468 standard test method issued by the American Society for Testing of Materials (ASTM D34 2007).

Alternatively, a number of empirical relationships are available to estimate the heating value of fuels on the basis of its ultimate analysis and moisture content data.

Consistent with the approach for the evaluation of pyrolysis and gasification processes presented in (Basu 2010) we compute HHV (dry basis, db) based on the unified correlation published in (Channiwala & Parikh 2002):

$$\boldsymbol{HHV_{db}} = 349.1 \cdot \boldsymbol{C} + 1178.3 \cdot \boldsymbol{H} + 100.5 \cdot \boldsymbol{S} - 103.4 \cdot \boldsymbol{O} - 15.1 \cdot \boldsymbol{N} - 21.1 \cdot \boldsymbol{Ash} \tag{5}$$

where $\boldsymbol{C}$, $\boldsymbol{H}$, $\boldsymbol{S}$, $\boldsymbol{O}$, $\boldsymbol{N}$, and $\boldsymbol{Ash}$ are the percentages, by weight, of carbon, hydrogen, sulphur, oxygen, nitrogen and ash, as determined by ultimate analysis on a dry basis.

The LHV or HHV on an as received basis (ar) can be calculated from the corresponding dry basis figures as follows:

$$HHV_{ar} = HHV_{db} \cdot \frac{M}{100} \tag{6}$$

Domestic waste fractions

City of Sydney LGA

Table 48. City of Sydney LGA, Domestic waste – estimated energy contents, by waste categories and fractions

	Composition	Moisture	Higher Heating Value (MJ/kg)		Lower Heating Value (MJ/kg)	
Category	wt%	wt%	as received	dry basis	as received	dry basis
Combustible						
Oils	0.01%	0	33.77	33.77	31.82	31.82
Paper	24.23%	24.3	14.05	18.57	12.70	16.78
Plastics	14.38%	13.8	24.53	28.46	22.81	26.46
Rubber	0.22%	13.8	33.87	39.29	31.79	36.88
Leather	0.06%	13.8	24.88	28.86	23.21	26.92
Textile	3.35%	23.8	14.68	19.27	13.28	17.43
Wood	1.81%	15.4	16.49	19.49	15.16	17.92
Inert						
C&D	5.66%	3	4.01	4.13	3.55	3.66
Glass	6.64%	3	-1.81	-1.86	-1.89	-1.95
Metal	2.60%	6.6	-0.07	-0.08	-0.33	-0.35
Putrescible						
Food	32.99%	63.6	6.57	18.06	5.62	15.44
Green waste	5.15%	37.9	13.03	20.99	11.68	18.81
Hazardous						
Hazardous	0.46%	3	4.01	4.13	3.55	3.66
Other fractions						
Whitegoods	0.00%	3	4.01	4.13	3.55	3.66
e-Waste	0.79%	3	4.01	4.13	3.55	3.66
Other	1.64%	3	4.01	4.13	3.55	3.66
MSW TOTAL	100.00%	32.55	11.44	16.97	10.20	15.12
Combustible	44.07%	20.39	17.52	22.01	16.04	20.15
Inert	14.91%	3.63	0.70	0.72	0.44	0.46
Putrescible	38.14%	60.13	7.36	18.46	6.34	15.90
Hazardous	0.46%	3.00	4.01	4.13	3.55	3.66
Other	2.43%	3.00	4.01	4.13	3.55	3.66

SSROC region

Table 49. SSROC region, Domestic waste – energy contents (est.), by waste categories and fractions

Category	Composition wt%, dry basis	Moisture wt%	Higher Heating Value (MJ/kg) as received	Higher Heating Value (MJ/kg) dry basis	Lower Heating Value (MJ/kg) as received	Lower Heating Value (MJ/kg) dry basis
Combustible						
Oils	0.06%	0	33.77	33.77	31.82	31.82
Paper	20.66%	24.3	14.05	18.57	12.70	16.78
Plastics	12.71%	13.8	24.53	28.46	22.81	26.46
Rubber	0.35%	13.8	33.87	39.29	31.79	36.88
Leather	0.27%	13.8	24.88	28.86	23.21	26.92
Textile	3.27%	23.8	14.68	19.27	13.28	17.43
Wood	1.20%	15.4	16.49	19.49	15.16	17.92
Inert						
C&D	4.18%	3	4.01	4.13	3.55	3.66
Glass	3.27%	3	-1.81	-1.86	-1.89	-1.95
Metal	2.45%	6.6	-0.07	-0.08	-0.33	-0.35
Putrescible						
Food	37.88%	63.6	6.57	18.06	5.62	15.44
Green waste	7.76%	37.9	18.20	29.31	16.47	26.53
Hazardous						
Hazardous	0.67%	3	4.01	4.13	3.55	3.66
Other fractions						
Whitegoods	0.00%	3	4.01	4.13	3.55	3.66
e-Waste	1.13%	3	4.01	4.13	3.55	3.66
Other	4.13%	3	4.01	4.13	3.55	3.66
MSW TOTAL	100.00%	35.42	11.64	18.02	9.76	16.04
Combustible	38.52%	20.31	17.69	22.20	16.21	20.34
Inert	9.91%	3.89	1.07	1.11	0.78	0.82
Putrescible	45.65%	59.23	8.14	19.97	7.06	17.33
Hazardous	0.67%	3.00	4.01	4.13	3.55	3.66
Other	5.26%	3.00	4.01	4.13	3.55	3.66

Commercial and Industrial waste fractions

Sydney Metropolitan Area

Table 50. SMA, Commercial and Industrial waste – energy contents (est.), by waste categories and fractions

Category	Composition wt%, dry basis	Moisture wt%	Higher Heating Value (MJ/kg) as received	Higher Heating Value (MJ/kg) dry basis	Lower Heating Value (MJ/kg) as received	Lower Heating Value (MJ/kg) dry basis
Combustible						
Oils	0.06%	0	33.77	33.77	31.82	31.82
Paper	20.66%	24.3	14.05	18.57	12.70	16.78
Plastics	12.71%	13.8	24.53	28.46	22.81	26.46
Rubber	0.35%	13.8	33.87	39.29	31.79	36.88
Leather	0.27%	13.8	24.88	28.86	23.21	26.92
Textile	3.27%	23.8	14.68	19.27	13.28	17.43
Wood	1.20%	15.4	16.49	19.49	15.16	17.92
Inert						
C&D	4.18%	3	4.01	4.13	3.55	3.66
Glass	3.27%	3	-1.81	-1.86	-1.89	-1.95
Metal	2.45%	6.6	-0.07	-0.08	-0.33	-0.35
Putrescible						
Food	37.88%	63.6	6.57	18.06	5.62	15.44
Green waste	7.76%	37.9	18.20	29.31	16.47	26.53
Hazardous						
Hazardous	0.67%	3	4.01	4.13	3.55	3.66
Other fractions						
Whitegoods	0.00%	3	4.01	4.13	3.55	3.66
e-Waste	1.13%	3	4.01	4.13	3.55	3.66
Other	4.13%	3	4.01	4.13	3.55	3.66
MSW TOTAL	100.00%	35.42	11.64	18.02	9.76	16.04
Combustible	38.52%	20.31	17.69	22.20	16.21	20.34
Inert	9.91%	3.89	1.07	1.11	0.78	0.82
Putrescible	45.65%	59.23	8.14	19.97	7.06	17.33
Hazardous	0.67%	3.00	4.01	4.13	3.55	3.66
Other	5.26%	3.00	4.01	4.13	3.55	3.66

Feedstock resource analysis

Processable fractions

The analysis presented in Section 4. Advanced Waste Treatment Scenarios, considers a range of thermal conversion technologies, grouped into three conversion strategies:

- **Low-Temperature Conversion (LTC) –** including, pyro-combustion, slow pyrolysis and fixed-bed gasification technologies;
- **High-Temperature Conversion (HTC) –** including pyro-gasification and fluid-bed gasification technologies;
- **High-Temperature Conversion + Melting (HTCM) –** including pyro-gasification + melting, fluid-bed gasification + melting, and plasma gasification.

The processable waste fractions for the three families of conversion technologies considered are summarized in the matrix below.

Table 51. Syngas from Waste conversion technologies – waste fractions processed, by conversion strategy

STRATEGY/TECHNOLOGY	Mixed Waste Fractions					
	Combustible	Inert	Putrescible	Hazardous	Other	SR [a]
Low-Temperature Conversion (LTC)						
Pyro-Combustion	✓	✕	✓	✕	✕	✕
Slow Pyrolysis	✓	✕	✓	✕	✕	✕
Fixed-Bed Gasification	✓	✕	✓	✕	✕	✕
High-Temperature Conversion (HTC)						
Fluid Bed Gasification	✓	✕	✓	✕	✕	✕
Pyro-Gasification	✓	✕	✓	✕	✕	✕
High-Temperature Conversion + Melting (HTCM)						
Pyro-Gasification + Melting	✓	✓	✓	(✓)	✕	(✓)
Fluid Bed Gasification + Melting	✓	✓	✓	(✓)	✕	(✓)
Plasma Gasification	✓	✓	✓	(✓)	✕	(✓)

[a] Shredder Residues from Whitegoods processing at resource recovery facility

Within the scope of this study, Low-and High-Temperature Conversion technologies are considered to process the combustible and the putrescible fractions of the incoming residual waste stream. High-Temperature Conversion + Melting technologies, by virtue of the high-temperatures reached inside the reactor (for plasma gasification) or in a separate high-temperature *melting* zone located immediately downstream (for pyro-gasification + melting and fluid-bed gasification + melting), have furthermore the ability to process the inert fraction of the incoming residual waste stream[22].

[22] The hazardous and shredder residues fractions can be also processed by HTCM technologies, but have been excluded from this assessment as, based on experience with the City of Sydney domestic waste streams, they are delivered to specialized alternative waste treatment facilities.

Elemental analysis

The matrix of processable fractions has been applied to the elemental analysis presented earlier for each of the waste resource streams considered to determine the ultimate analysis, dry basis, for the resulting feedstock resources for the three families of conversion technologies.

Domestic waste fractions

City of Sydney LGA

Table 52. City of Sydney LGA, Domestic waste – feedstock resource ultimate analysis (est.)

	Composition	Ultimate analysis (dry basis), weight %					
	wt%	C	H	O	N	S	Ash
SMA - total	100.00%	41.93	5.66	29.84	1.31	0.16	21.10
Combustible	57.11%	51.26	6.84	34.39	0.69	0.22	6.60
Inert	13.40%	10.31	1.57	9.52	2.21	0.00	76.39
Putrescible	20.70%	48.97	6.61	38.00	1.68	0.20	4.53
Hazardous	1.75%	13.00	2.00	12.00	3.00	0.00	70.00
Other	7.04%	13.00	2.00	12.00	3.00	0.00	70.00
SMA - feedstock resource							
LTC/HTC (comb.+putrescible)		50.65	6.78	35.35	0.96	0.21	6.05
HTCM (comb.+putrescible+inert)		44.72	6.01	31.56	1.14	0.18	16.39

SSROC region

Table 53. SSROC region, Domestic waste – feedstock resource ultimate analysis (est.)

	Composition	Ultimate analysis (dry basis), weight %					
	wt%, dry basis	C	H	O	N	S	Ash
SSROC - total	100.00%	41.41	5.81	26.72	1.74	0.19	24.13
Combustible	38.52%	50.74	6.91	33.81	0.76	0.20	7.58
Inert	9.91%	6.78	1.02	6.25	1.29	0.00	84.67
Putrescible	45.65%	44.74	6.42	27.10	2.50	0.24	19.00
Hazardous	0.67%	13.00	2.00	12.00	3.00	0.00	70.00
Other	5.26%	13.00	2.00	12.00	3.00	0.00	70.00
SSROC - feedstock resource							
LTC/HTC (comb.+putrescible)		47.49	6.64	30.17	1.70	0.22	13.77
HTCM (comb.+putrescible+inert)		43.20	6.05	27.65	1.66	0.20	21.24

Commercial and Industrial waste fractions

Sydney Metropolitan Area

Table 54. SMA, Commercial and Industrial waste – feedstock resource ultimate analysis (est.)

	Composition	Ultimate analysis (dry basis), weight %					
	wt%	C	H	O	N	S	Ash
SMA - total	100.00%	41.93	5.66	29.84	1.31	0.16	21.10
Combustible	57.11%	51.26	6.84	34.39	0.69	0.22	6.60
Inert	13.40%	10.31	1.57	9.52	2.21	0.00	76.39
Putrescible	20.70%	48.97	6.61	38.00	1.68	0.20	4.53
Hazardous	1.75%	13.00	2.00	12.00	3.00	0.00	70.00
Other	7.04%	13.00	2.00	12.00	3.00	0.00	70.00
SMA - feedstock resource							
LTC/HTC (comb.+putrescible)		50.65	6.78	35.35	0.96	0.21	6.05
HTCM (comb.+putrescible+inert)		44.72	6.01	31.56	1.14	0.18	16.39

Energy content

The empirical correlation in (Channiwala & Parikh 2002) has been used to determine the heating value figures presented in the Table below.

Table 55. Feedstock energy content - domestic, commercial and industrial waste, by conversion strategy

STRATEGY/FEEDSTOCK	Moisture	Higher Heating Value (MJ/kg)		Lower Heating Value (MJ/kg)	
	wt%	as received	dry basis	as received	dry basis
Low-Temperature Conversion (LTC)					
MSW - CoS LGA	38.83	12.46	20.36	11.12	18.18
MSW - SSROC	41.42	12.30	20.99	10.96	18.71
C&I - SMA	29.29	15.48	21.89	14.03	19.85
High-Temperature Conversion (HTC)					
MSW - CoS LGA	38.83	12.46	20.36	11.12	18.18
MSW - SSROC	41.42	12.30	20.99	10.96	18.71
C&I - SMA	29.29	15.48	21.89	14.03	19.85
High-Temperature Conversion + Melting (HTCM)					
MSW - CoS LGA	33.43	11.55	17.35	10.29	15.46
MSW - SSROC	37.47	11.82	18.90	10.52	16.82
C&I - SMA	25.51	14.22	19.09	12.88	17.29

Biomass, renewable energy and biogenic carbon content

Three coefficients – biomass fraction, renewable energy fraction and biogenic carbon content (BCC) – are calculated on an as received basis for each resource stream and conversion strategy on the basis of the feedstock composition analysis data presented earlier. The results for the three coefficients are presented in the Table below.

Table 56. Biomass, renewable energy and biogenic carbon content – all feedstocks, by conversion strategy

Category	Mass, wt% as received		Energy, HHV as received		Carbon, wt% dry basis	
	biomass	other	renewable	non renewable	biogenic	non-biogenic
Low-Temperature Conversion (LTC)						
MSW - CoS LGA	82.49%	17.51%	69.14%	30.86%	77.65%	22.35%
MSW - SSROC	84.82%	15.18%	72.70%	27.30%	80.88%	19.12%
C&I - SMA	78.27%	21.73%	67.30%	32.70%	74.35%	25.65%
High-Temperature Conversion (HTC)						
MSW - CoS LGA	82.49%	17.51%	69.14%	30.86%	77.65%	22.35%
MSW - SSROC	84.82%	15.18%	72.70%	27.30%	80.88%	19.12%
C&I - SMA	78.27%	21.73%	67.30%	32.70%	74.35%	25.65%
High-Temperature Conversion + Melting (HTCM)						
MSW - CoS LGA	69.83%	30.17%	67.10%	32.90%	75.91%	24.09%
MSW - SSROC	75.89%	24.11%	70.48%	29.52%	79.54%	20.46%
C&I - SMA	66.77%	33.23%	65.22%	34.78%	71.83%	28.17%

Biomass content

The fractions considered for the estimation of the total biomass have been selected according to methods prescribed in the National Greenhouse and Energy Reporting (NGER) guidelines[23] and a general methodology document published under by the UNFCCC Clean Development Mechanism (CDM)[24], these are:

- **Biomass fractions:** Food, paper, green waste, wood, textile, leather and rubber;
- **Non-biomass fractions:** oils, plastic, construction and demolition waste, glass and metal, hazardous fractions and other (e-waste, whitegoods, shredder residues, etc.)

Renewable energy content

The renewable energy content is calculated for each resource stream and conversion strategy as the ratio between the energy content (HHV, as received basis) for the biomass fractions and for the total feedstock resource stream.

Biogenic carbon content

The biogenic carbon content (BCC) for waste feedstocks is calculated for each resource stream, conversion strategy and catchment region, as the ratio between the carbon content for the biomass fractions and the total feedstock resource stream (both on an as received basis).

[23] DCCEE 2012a. National Greenhouse and Energy Reporting System Measurement. Technical Guidelines for the estimation of greenhouse gas emissions by facilities in Australia. Department of Climate Change and Energy Efficiency, Australian Government, July 2012. http://www.climatechange.gov.au/.../national-greenhouse-factors.aspx

[24] CDM 2012. AM0025: Alternative waste treatment processes --- Version 14.0.0. Clean Development Mechanism, United Framework Convention on Climate Change. Valid from 20 July 2012. http://cdm.unfccc.int/methodologies/

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Appendix B. Performances, Costs and Emissions Survey

Performance survey

Energy and Mass Balances

Low-Temperature Conversion

Table 57. Low-Temperature Conversion, representative mass balance for fixed bed gasification

INPUTS	Consumption		OUTPUTS	Yield	
Stream/component	kg/h	kg/t_{feed}	Stream/component	kg/h	kg/t_{feed}
TOTAL INPUTS	3767.00	3767.00	TOTAL OUTPUTS	3767.00	3767.00
Feedstocks			Products		
MSW, as received	1000.00	1000.00	Syngas	3727.00	3727.00
Oxidant			Residues	40.00	40.00
Air (@ 0.4 eq. ratio)	2,467.00	2467.00			
Steam (150 °C, 0.35 MPa)	300.00	300.00			
			CONVERSION and RECOVERY PERFORMANCES		
			Total Residues	40.00	40.00
			MASS REDUCTION (solids)		96.00%

SOURCE: (Hyder 2013)

Table 58. Low-Temperature Conversion, representative energy balance for fixed bed gasification

INPUTS			OUTPUTS		
Stream/component	GJ/t_{feed}	MW	Stream	GJ/t_{feed}	MW
TOTAL INPUTS	24.57	6.83	TOTAL OUTPUTS	24.57	6.83
Feedstocks			Products		
MSW, as received	18.15	5.04	Syngas	13.93	3.87
			Heat	4.67	1.30
Auxiliary thermal inputs			Losses		
Steam (150 °C, 0.35 MPa)	0.83	0.23	Conversion losses	5.97	1.66
Fuel (unspecified)	5.60	1.55			
			ENERGY RECOVERY PERFORMANCES		
			Syngas energy @ ambient temperature	13.93	3.87
			HOT GAS EFFICIENCY, HHV basis		75.70%
			COLD GAS EFFICIENCY, HHV basis		56.69%

SOURCE: (Hyder 2013)

High-Temperature Conversion

Table 59. High-Temperature Conversion, representative mass balance for fluidized-bed gasification

INPUTS	Consumption		OUTPUTS	Yield	
Stream/component	kg/h	kg/t_{feed}	Stream/component	kg/h	kg/t_{feed}
TOTAL INPUTS	4366.40	1047.94	TOTAL OUTPUTS	3681.25	883.50
Feedstocks			Products		
RDF	4166.67	1000.00	Syngas	3681.25	883.50
Oxidant			Residues		
Air	199.73	47.94	Char	951.25	228.3
Oxygen	--	--	Ash	63.25	15.18
Steam	--	--			
			CONVERSION and RECOVERY PERFORMANCES		
			Total By-products	0.00	0.00
			Total Residues	1014.50	243.48
			MASS REDUCTION (solids)		75.65%

SOURCE: (Granatstein 2003)

Table 60. High-Temperature Conversion, representative energy balance for fluidized-bed gasification

INPUTS			OUTPUTS		
Stream/component	GJ/t_{feed}	MW	Stream	GJ/t_{feed}	MW
TOTAL INPUTS	19.36	22.41	TOTAL OUTPUTS	19.36	22.41
Feedstock - RDF			Syngas	11.67	13.51
RDF	17.20	19.91			
			Heat losses	7.69	8.90
Fuels					
Natural gas	2.16	2.50			
Electricity					
BoP, kWh/t_{feed}	195.79	0.82			
			ENERGY RECOVERY PERFORMANCES		
			Syngas energy, @ ambient temperature		10.27
			THERMAL EFFICIENCY, HHV basis		94.13%
			COLD GAS EFFICIENCY, HHV basis		60.30%

SOURCE: (Granatstein 2003)

High-Temperature Conversion + Melting

Table 61. High-Temperature Conversion + Melting, representative mass balance for plasma gasification

INPUTS	Consumption		OUTPUTS	Yield	
Stream/component	kg/h	kg/t_{feed}	Stream/component	kg/h	kg/t_{feed}
TOTAL INPUTS	48223.00	1543.14	TOTAL OUTPUTS	48223.00	1543.14
Feedstocks			Products		
MSW	29583.00	946.66	Syngas	37629.00	1204.13
Tyres	1667.00	53.34			
			Recoverable by-products		
Additives			Aggregate (slag and metal)	9550.00	305.60
Coke	1250.00	40.00			
Limestone	3209.00	102.69	Residues		
			Char solids	142.60	4.56
Oxidant			Other residues	901.40	28.84
Air	2345.00	75.04			
Oxygen	10169.00	325.41			
Steam	--	--			
			CONVERSION and RECOVERY PERFORMANCES		
			Total By-products	9550.00	305.60
			Total Residues	1044.00	33.41
			MASS REDUCTION (solids)	96.66%	0.03

SOURCE: (Willis *et al*. 2010)

Table 62. High-Temperature Conversion + melting, representative energy balance for plasma gasification

INPUTS			OUTPUTS		
Stream/component	GJ/t_{feed}	MW	Stream	GJ/t_{feed}	MW
TOTAL INPUTS	15.15	119.24	TOTAL OUTPUTS	15.15	119.24
Feedstocks			Syngas		
MSW	12.31	101.13	Energy content	9.83	80.30
Tyres	1.67	0.77	Sensible heat	1.79	15.54
			Latent heat	0.49	4.22
Additives					
Coke	1.18	10.20	By-products		
Limestone	--	--	Slag	0.60	5.17
Electricity			Residues		
Plasma torch, kWh/t_{feed}	102.94	3.22	Char solids	0.15	1.30
Oxygen facility, kWh/t_{feed}	125.52	3.92	Other residues		
			Losses		
			Heat losses	1.35	4.50
			Plasma torch losses	0.06	0.48
			Limestone calcination	0.13	1.10
			Other losses	0.76	6.63
			ENERGY RECOVERY PERFORMANCES		
			Syngas energy, @ ambient temperature		80.30
			THERMAL EFFICIENCY, HHV basis		94.90%
			COLD GAS EFFICIENCY,HHV basis		67.34%

SOURCE: (Willis *et al*. 2010)

Cost survey

Low-Temperature Conversion

Pyrolysis and Pyro-combustion

Table 63. Pyrolysis/pyro-combustion, capital and O&M cost survey

facility size	capital cost	O&M cost	monetary unit (m.u.)			
tpd	m.u YEAR		currency	year	estimate description	source
23	6,500,000	n/a	USD	1993	Conrad Industries proposal	(URS 2005b)
50	8,000,000	n/a	USD	2005	IES test facility, Romoland, CA	(URS 2005b)
161	50,000,000	5,000,000	AUD	2010	50000 tpy pyrolysis plant	(URS 2010a)
163	23,225,500	2,328,650	USD	2005	IES proposal	(URS 2005b)
167	9,936,167	2,526,681	USD	2005	PAR proposal	(URS 2005b)
228	25,000,000	5,000,000	USD	1992	SITA facility, Bochum, Germany	(URS 2005b)
304	60,000,000	3,427,000	USD	2005	WasteGen proposal	(URS 2005b)
335	31,250,000	2,500,000	USD	2001	RWE facility, Hamm-Uentrop, Gerr	(URS 2005b)
1000	60,000,000	n/a	USD	2004	PAR estimate	(ARI 2004)

Fixed bed gasification

Table 64. Fixed bed gasification, capital and O&M cost survey

facility size	capital cost	O&M cost	monetary unit (m.u.)			
tpd	m.u YEAR		currency	year	estimate description	source
26	6,500,000	600,000	USD	2005	PRM Philadelphia facility	(URS 2005b)
46	14,000,000	4,800,000	USD	2005	PRM Stanton facility	(URS 2005b)
55	12,000,000	n/a	USD	2010	Middlebury College/Chiptec	(Pytlar 2010)
55	22,000,000	1,500,000	USD	2005	PRM Stuttgart facility	(URS 2005b)
100	19,356,500	1,783,960	USD	2005	Ntech proposal	(URS 2005b)
107	15,500,000	1,557,000	USD	2005	Primenergy proposal	(URS 2005b)
128.5	22,145,328	n/a	EUR	2004	Entech case study, 45 ktpa facility	(Stein and Tobias
155	20,000,000	n/a	USD	2010	University of South Carolina/Next	(Pytlar 2010)
161	40,000,000	6,650,000	AUD	2010	50000 tpy gasification plant	(URS 2010a)

High- Temperature Conversion

Fluidised bed gasification

Table 65. Fluid bed gasification, capital and O&M cost survey

facility size	capital cost	O&M cost	monetary unit (m.u.)			
tpd	m.u YEAR		currency	year	estimate description	source
63	7,000,000	750,000	USD	2005	Omnifuel technologies proposal	(URS 2005b)
93.6	27,900,000	3,590,000	EUR	2003	Greve in Chianti TPS/Ansaldo plan	(Granatstein 200
200	52,000,000	n/a	USD	2010	Burlington facility, FERCO	(Pytlar 2010)
300	14,000,000	n/a	USD	2005	Burlington facility	(URS 2005b)
300	23,100,000	2,000,000	USD	2004	Taylor estimate	(ARI 2004)

Pyro-gasification

Table 66. Pyro-gasification, capital and O&M cost survey

facility size	capital cost	O&M cost	monetary unit (m.u.)		estimate description	source
tpd	m.u YEAR		currency	year		
70.5	47,490,000	3,590,000	USD	2005	GES proposal	(URS 2005b)
161	70,000,000	8,100,000	AUD	2010	50000 tpy pyro-gasification plant	(URS 2010a)

High-Temperature Conversion + Melting

Fluidised bed gasification + Ash Melting

Table 67. Fluid bed gasification, capital and O&M cost survey

facility size	capital cost	O&M cost	monetary unit (m.u.)		estimate description	source
tpd	m.u YEAR		currency	year		
40	14,000,000	n/a	USD	2004	Ebara low end estimate	(ARI 2004)
40	21,000,000	n/a	USD	2004	Ebara high estimate	(ARI 2004)
70.5	47,490,000	3,590,000	USD	2005	Ebara proposal	(URS 2005b)

Plasma gasification

Table 68. Plasma gasification, capital and O&M cost survey

facility size	capital cost	O&M cost	monetary unit (m.u.)		estimate description	source
tpd	m.u YEAR		currency	year		
20	18,000,000	700,000	USD	2002	Mihama-Mikata plant	(URS 2005b)
70.5	47,490,000	3,590,000	USD	2005	GeoPlasma proposal	(URS 2005b)
161	90,000,000	8,500,000	AUD	2010	50000 tpy plasma gasification plant	(URS 2010a)
200	65,000,000	5,500,000	USD	2002	Utashinai plant	(URS 2005b)
300	89,500,000	8,967,345	USD	2010	Proposed plasma arc facility, Mario	(Clark and Rogof
600	161,000,000	n/a	USD	2010	Scaled-up plasma arc facility	(Clark and Rogof
3000	800,000,000	n/a	USD	2005	Rigel estimate	(ARI 2004)
3000	800,000,000	73,050,000	USD	2005	Rigel proposal	(URS 2005b)

Pyro-gasification + ash melting

Table 69. Pyro-gasification + ash melting, capital and O&M cost survey

facility size	capital cost	O&M cost	monetary unit (m.u.)		estimate description	source
tpd	m.u YEAR		currency	year		
161	50,000,000	5,000,000	AUD	2010	50000 tpy pyr-gasification plant	(URS 2010a)
300	80,000,000	13,000,000	USD	2005	Chiba facility	(URS 2005b)
304	75,511,000	10,787,432	USD	2005	IWT proposal	(URS 2005b)
720	120,000,000	19,500,000	USD	1999	Karlsruhe facility	(URS 2005b)
720	110,000,000	8,500,000	USD	2002	Karlsruhe facility	(Hesseling 2002)
3051	457,000,000	n/a	USD	2005	IWT/Thermoselect estimate	(ARI 2004)

Emissions survey

Air pollutant emissions

Table 70. Emission performance survey

	PM	HCl	NO_x	SO_x	Hg	PCDD/PCDF
	mg/Nm^3 @11% O_2					ng_{TEQ}/Nm^3
European Standard	10	10	200	50	0.05	0.1
Japanese Standard	10.1-50.6	15.2-50.6	30.3-126.4	10.1-30.3	0.03-0.051	0.51
US Standard	24.3	25.3	151.7	30.3	0.03-0.051	0.14-0.21
Plant						
Ebara TwinRec - Kawaguchi, JAPAN	1.0	2.0	29.2	2.8	4.99E-03	5.13E-05
Entech - Kuznica - Poland	0.7	5.6	174.5	37.0	5.70E-03	1.99E-02
InEnTec - Richland, WA USA	2.4	1.9	115.4	-	4.77E-04	4.77E-03
INEOS Bio - Fayetteville, AK, USA	1.4	-	7.1	-	7.12E-05	2.14E-03
IES - Romoland, CA, USA	4.1	-	91.9	0.3	-	4.14E-04
JFE/Thermoselect - Nagasaki, Japan	3.3	8.3	-	-	-	1.78E-02
Mitsui R21 - Toyohashi, Japan	0.7	39.7	59.0	18.4	-	3.21E-03
Nippon Steel DMS - Kazusa, Japan	10.0	8.9	22.2	15.6	-	3.21E-02
Plasco, Ottawa, CANADA	9.1	2.2	106.8	18.5	1.42E-04	6.58E-03
OE Gasification Heanam, S. Korea	6.1	19.5	74.8	26.7	4.99E-03	4.00E-02

SOURCE: (CERT 2009), all values normalized to 11% O_2

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