INFRASTRUCTURE REQUIREMENTS FOR ENERGY FROM WASTE

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WASTE MANAGEMENT ASSOCIATION OF AUSTRALIA

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INFRASTRUCTURE REQUIREMENTS FOR ENERGY FROM WASTE

IEA BIOENERGY TASK 36: TOPIC 1

EXTENDED PRODUCER RESPONSIBILITY AND PRODUCT STEWARDSHIP SCHEME IMPACTS ON MUNICIPAL SOLID WASTE

STAGE 3 REPORT

PREPARED BY
WARNKEN ISE

FOR

WASTE MANAGEMENT ASSOCIATION OF AUSTRALIA
ENERGY FROM WASTE DIVISION

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Front cover photos (top to bottom):

Household materials like paint, oil and cleaning liquids can 'toxify' the residual waste stream and reduce resource recovery options.

Cement kilns need heat energy for the cement making process.

Power stations can use certain alternative fuels (where quality standards are met) to generate electricity.

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EXECUTIVE SUMMARY

There is a mounting body of evidence to highlight the fact that our systems of production and consumption are unsustainable. The over and inefficient use of resources worldwide is depleting resource stocks and are disrupting the operation of natural systems. The greatest manifestation of this disconnect between industry and ecology, and possibly the major environmental challenge for humanity in the 21st century, is climate change. The increasing concentration of carbon dioxide in the atmosphere is proof that industrial emissions have exceeded the planet's capacity to absorb greenhouse gas emissions.

All sectors of the economy are being forced to examine their carbon footprint within the context of required deep cuts in greenhouse gas emissions. The recovery of energy from waste is one sector where a valuable contribution to carbon abatement can be made, however this contribution needs to be viewed within a holistic definition of energy and resource conservation and implemented within a framework of sustainability that seeks to increase societal value and reduce environmental impact.

From this perspective, the infrastructure to support a reverse logistics network for Extended Producer Responsibility/Product Stewardship (EPR / PS) schemes is critical. Such infrastructure aims to ensure that products and their materials at the end of their useful life can be recovered either for their embodied energy value where appropriate, or for their calorific value. Because of the potential for EPR / PS schemes to significantly shape the composition of the residual waste stream, and facilitate increased resource recovery, EPR / PS schemes are of equal importance to the infrastructure required to actually convert the calorific value of residual urban waste into electrical or heat energy.

This study is the conclusion to a three part series undertaken by the Energy from Waste (EfW) Division, a national division of the Waste Management Association of Australia, as part of Task 36 - Energy Recovery from Municipal Solid Waste, organised through the International Energy Agency's (IEA) Bioenergy program. Stage 1 of the series provided a review of theoretical concepts surrounding Extended Producer Responsibility/ Product Stewardship (EPR / PS) and discussed the potential for product design to influence/deliver sustainable resource utilisation outcomes. Stage 2 examined the experience and outcomes of EPR / PS schemes in order to identify the existing level of integration between design intent and resource recovery, and provide a comparison of tangible results against the potential for integration of design and resource recovery infrastructure outlined in Stage 1. The purpose of this Stage 3 study is to synthesise outcomes from Stages 1 and 2 to scope the generic systems and infrastructure needs that should be available if energy recovery (embodied and inherent) from residual urban wastes is to be put on a sustainable footing.

Waste generation rates are expected to increase within OECD countries for the foreseeable future. For example, in 2003 total municipal waste generation for OECD was estimated to be 594 million tonnes, with per capita generation rates between 530 and 570 kilograms. It is estimated that 438 million tonnes of this waste is either being land-filled or is being incinerated. By 2020 this residual component of the urban waste stream is expected to increase to 484 million tonnes, or 385 kilograms per capita. These estimates assume that increased recycling of waste materials and increased waste avoidance act to offset increases in per capita residual waste generation rates.

The potential energy value of OECD residual waste is the energy that could displace primary fossil fuel use (gas, oil and coal), in addition to energy savings from recycling materials like metals and glass. It is estimated that in 2020 there will be 8,276 $x10^6$ gigajoules (GJ) of calorific value in residual waste that could be used as a fuel, and up to 2,409 $x10^6$ GJ of embodied energy that could be recovered trhough recycling. Together this represents an annual energy offset pool of 10,685 x 10^6 GJ, which could displace the use of 396 million tonnes of coal (assuming an average energy value of high quality coal of 27 GJ/tonne). This amount of coal represents 30 per cent of the forecast coal production from OECD North America in 2020.

The value proposition of recovering the energy potential of urban residual waste takes on new significance within the context of the climate change challenge and resource conservation. Climate change because of the direct link between energy usage and increasing concentration of greenhouse gases in the atmosphere, and resource conservation because of diminishing global resource availability driving toward the not too-distant future when 'peak-availability' is passed. (Peak availability refers to the point where more than 50 per cent of the available resource based has been extracted or depleted).

The recovery of energy from waste is one sector where a valuable contribution to carbon abatement can be made, however this contribution needs to be viewed within a holistic definition of energy and implemented within a framework of sustainability that seeks to increase societal value and reduce environmental impact. For example, a future waste management system should focus on recovering embodied energy through product reuse and recycling, and then on maximising the recovery of calorific value. In a decarbonising economy there is no room for landfilling of biogenic carbon or for lost opportunities to save energy through recycling.

The current waste management sector can contribute to a decarbonising global economy through the design, development and implementation of integrated systems and infrastructure to recover the highest resource value of 'wastes'. It is imperative that Energy from Waste be part of this solution. In order to ensure maximisation of the recovery of energy value from a waste stream, there is a need for infrastructure that includes the following:

- a mixture of reverse logistic centres to support EPR across brands and products – including reverse vending machines for containers, and drop off for household hazardous (to detoxify the waste stream and recover high embodied energy products and materials)
- materials recovery facilities for kerbside collection of dry recyclables
- organics processing facility for kerbside collection of 'garden and food materials
- broad pre-treatment facilities to stream residual materials into component materials streams
- additional value adding centres for materials recovery, carbonisation, composting, digestion
- direct energy recovery (alternate fuels for existing facilities)
- indirect energy recovery – maximising recycling at highest resource value to maximise energy savings – especially metals recovery
- residuals processing for construction applications.

The function of the EPR / PS component of this infrastructure is to ensure that the residual waste stream is 'detoxified' and also that maximum opportunity is created to recover resource value from the waste stream. Once these products and materials have been recovered, calorific energy conversion into heat and power can be effected using energy from waste technologies which include direct energy recovery, gasification, pyrolysis, fluidised bed systems and combined heat and power systems.

While the process of system optimisation will be unique for differing regions, it will generally follow a general preference for recovering the embodied energy of materials, particularly that of glass, plastic and metals. Combined heat and power (CHP) systems are generally preferred to electricity or heat generation systems as CHP systems achieve higher efficiencies. However, where CHP is not practicable, the utilisation of solid fuels for process heat, such as in cement kilns, is more thermally efficient than conversion into electrical energy. If electrical energy is the desired outcome, smaller purpose built facilities for electricity generation can be located closer to the source of the fuel, reducing transport needs, and also reduce power losses through reduced transmission and distribution requirements. Furthermore the use of pyrolysis can produce energy in addition to a carbon sequestering by-product – biochar.

Finally, in all circumstances the urban residual waste stream needs to be ‘detoxified’ and ‘mined for value’. In this respect the infrastructure for kerbside collection of wet and dry recyclables, and the provision of reverse logistic infrastructure for EPR / PS schemes are integral components of EfW infrastructure.

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1 BACKGROUND AND INTRODUCTION

The Energy from Waste (EfW) Division, a national division of the Waste Management Association of Australia, is a member of Bioenergy Australia. Bioenergy Australia, in turn, is the lead organisation for national participation in the International Energy Agency's (IEA) Bioenergy program.

IEA Bioenergy provides opportunities for interested countries to work collaboratively on topics of mutual interest and importance, one of which is Task 36 - Energy Recovery from Municipal Solid Waste. As part of this task, the EfW Division is taking responsibility for delivering Topic 1: Product Stewardship / Producer Responsibility.

1.1 Project Stages

The purpose of Topic 1 is to provide a platform to plan for an integrated system and infrastructure requirements for resource recovery in general, and energy recovery in particular, and as a conceptual model for developing initiatives in the future. The central thesis of Topic 1 is that product design and infrastructure planning need to be integrated in order to achieve desired sustainability outcomes.

In order to fully investigate this thesis, the Topic 1 Project is being undertaken in three stages:

Stage 1: Review theoretical concepts surrounding Extended Producer Responsibility/ Product Stewardship and discuss the potential for product design to influence/deliver sustainable resource utilisation outcomes.

Stage 2: Review actual experience and outcomes of Extended Producer Responsibility/ Product Stewardship schemes with case studies in order to identify the existing level of integration between design intent and resource recovery, and provide a comparison of tangible results against the potential for integration of design and resource recovery infrastructure outlined in Stage 1.

Stage 3: Synthesise outcomes from earlier Stages 1 and 2 to scope the generic systems and infrastructure needs that should be available if energy recovery (embodied and inherent) from residual urban wastes is to be put on a sustainable footing.

This discussion paper represents the outcomes from Stage 3 of the process. Further details on the structure of this paper are provided below, following a brief review of conclusions from Stage 1 and Stage 2 respectively.

1.2 Review of Stage 1

Stage 1 of the project identified that simulating systems of production and consumption using nature as (the ultimately sustainable) model suggests that the goal of the resource recovery industry is to establish a platform of cyclical material and energy flows that deliver sustainable outcomes. This requires a change from current 'take-make-waste' activities that rely on disposal in 'mass-dump' landfill or 'mass-burn' incineration to a cyclical system in which products at their end of life can be reused for their product, parts and materials (see Figure 1).

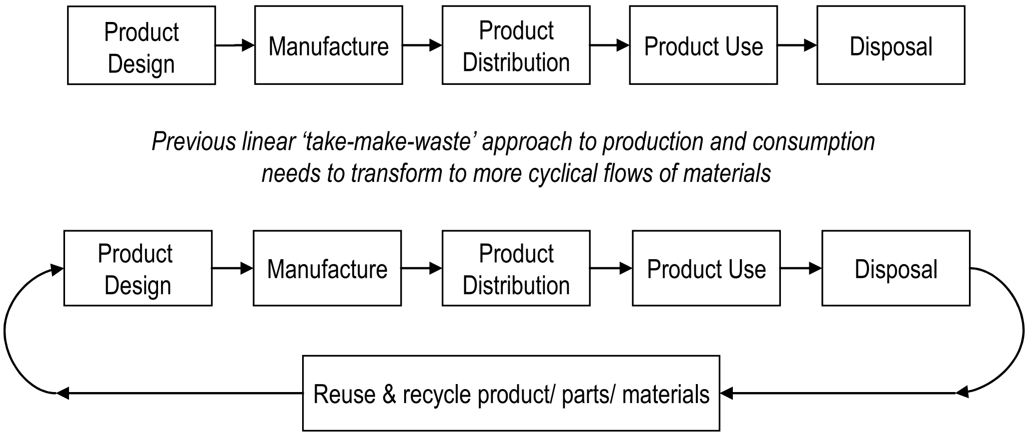

Figure 1 – Change is required from linear flows of waste to cyclical flows of resources

Both Extended Producer Responsibility (EPR) and Product Stewardship (PS) principles contribute to this cyclical system by making the original brand owner or manufacturer responsible for the total lifecycle of their product so that consideration is given to down stream impacts at the point of product design/initiation.

Next to the existence of EPR and PS schemes, the potential for positive end-of-life management outcomes is also influenced by the availability of post consumer services and capabilities to support recovery demonstrating the need to integrate design intent with resource recovery.

The concept of value chain analysis is a useful approach that can aid in development of a cyclical resource system. It includes the physical supply chain (resource flows from extraction through manufacturing, assembly service life and final disposal), and also flows of information, ideas, decisions and finance – everything that can add, retain or subtract value from a product or service, from its point of initiation to end-of-life management (see Appendix 1 for more information).

Mapping the value chain identifies the product designer as the key element in determining value balances of each stage during a product's life cycle -Value balance refers to value added, retained or subtracted along the value chain-. As value here refers to a combination of environmental, techno-economic and socio-political values, the role of product design becomes central to determining sustainability outcomes. For instance designing products without chemical substances will lead to less pollution, less danger to people involved in the manufacturing, recycling and general handling and will give the company a competitive advantage.

Value Chain Optimisation (VCO) refers to the intention of using design to maximise value added or retained throughout all stages of the value chain. VCO has the potential to engage designers into dialogue regarding: highest resource value pathways to deliver sustainable energy and material flows; overcoming market failures; development and sharing of reverse distribution infrastructure; development of resource recovery processing technologies; and education of consumers. Recognition of the need for VCO and the role that product designers and manufacturers can play is part of the rationale behind Extended Producer Responsibility (EPR) and Product Stewardship (PS) principles.

Other decision support tools and approaches that can also assist in delivering the change to 'resource circulation' are:[1]

- the Sustainability Guide for Energy from Waste developed by the Waste Management Association of Australia - to identify when energy recovery is the preferred resource recovery outcome
- assessment of Net Present Highest Resource Value - to qualitatively differentiate between resource recovery options
- Life Cycle Assessment - which can be used to quantitatively assess resource recovery options for a given region or city.

1.3 Review of Stage 2

In Stage 2 performance of EPR / PS schemes were reviewed and assessed, with reference to actual programs, experience and case studies from a range of OECD countries, within the context of the Stage 1. The components of several Extended Producer Responsibility and Product Stewardship (EPR / PS) schemes included:

- take-back requirements for specific products or waste streams to facilitate material recovery and recycling;
- economic instruments such as advance recovery/disposal fees, deposit/refund schemes, levies or taxes on particular materials, compliance measures and incentives and rewards;
- performance standards such as the setting of targets to improve environmental performance/ reduce waste - often established voluntarily by industry bodies as a means of avoiding regulation;
- other complementary measures including eco-labelling, education and awareness raising, extended product ownership, green procurement, developments in product design methods, cleaner production processes, and bans and restrictions on disposal and materials.

These various types of EPR / PS schemes and approaches can be used to cover a range product types, such as: general packaging, plastic bags, end-of-life vehicles, mobile phones, paint, electrical and electronic equipment, tyres, paper, rechargeable batteries, hazardous materials, oil, pesticides, etc.

Stage 2 explored the schemes in terms of the legislative frameworks, funding models, operational and social issues, technical challenges, and finally discussed in terms of participation, potential positive outcomes and demonstrated successes.

A variety of legislative frameworks were identified that are used to facilitate the implementation of EPR / PS schemes, ranging from voluntary industry led 'opt in' schemes to heavily regulated and mandatory schemes. Many of the European schemes are being driven by EU Directives.

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[1] *A detailed discussion on these tools and approaches can be found in GHD and Warnken ISE, 2006, '3 IEA Bioenergy Task 36: Topic 1 - PS/EPR Scheme Impact on MSW. Stage 2 Report: Review and Assessment of the Performance of PS/EPR Schemes',*

In terms of funding of EPR / PS schemes, it was noted that although all costs are ultimately passed on to consumers by industry, there are a number of different approaches to funding EPR / PS schemes (for example the creation of a secondary market in tradeable certificates for recovery services, and direct payments by industry or consumers), in addition to how these funds are used.

Operational issues for EPR / PS schemes are usually coordinated by an administrative organisation. These agencies undertake promotion and marketing; organise mechanisms for take back, collection and recycling; and support the development of in-house planning and continuous improvement. Other issues relate to the effectiveness of associated regulation as an impetus for industry change.

With respect to social issues related to the implementation of EPR / PS schemes, these relate primarily to achieving changes in market place. For example, the need to re-examine attitudes towards 'used' goods, price increases associated with internalising environmental costs into product prices, spheres of responsibility that extend to a product's end-of-life and the more general issue of societal impact caused by the actions of free riders.

The technical challenges created by the implementation of EPR / PS schemes relate to the:

- capacity of existing recovery infrastructure to handle increased volumes
- development of new resource recovery technologies to meet recovery requirements
- quality of recycled content and component reuse for incorporation into new product manufacture
- suitability of substitute materials to replace those being phased out.

For those EPR / PS schemes with flexibility in meeting recovery targets, the question of whether to recover materials for recycling or for energy generation is important. One factor in addressing this issue is the difference between a material's calorific value (inherent energy released during combustion) and embodied energy (amount of energy required to transform raw materials into final products).

In general most materials have a higher embodied energy than calorific value, meaning that a wholesale approach of calorific energy recovery will lose the embodied energy 'invested' within materials and products. At the same time it is of limited value to take no action to recover calorific energy while waiting for the perfect 'mousetrap', especially when disposal provides a zero value return. Also some material types cannot be infinitely recycled.

Next to that we see an increase of volumes of disposable products and lightweight composite convenience packaging in the urban waste stream, which is very suitable for energy recovery. Overall it seems likely that the recovery of calorific energy from waste will feature as part of an integrated and sustainable resource recovery system.

Schemes targeting domestic packaging have the end result of reducing the amount of dry recyclables that end up in the residual MSW stream, while other schemes that address domestic products, such as electrical and electronic equipment, mobile phones, rechargeable batteries and paint will reduce the occurrence of these items in the kerbside waste stream.

In order to deliver a system of resource recovery a new range of capabilities is required in planning, design and resource recovery services. For example:

- an understanding of materials currently in service within the economy, their stock life and recovery options at end-of-life
- the ability to design products to be readily assimilated into existing reverse logistic resource recovery pathways
- provision of infrastructure to keep pace with the changing composition of the urban waste stream.

Such capabilities are required to scope the generic systems and infrastructure needs that should be available if energy recovery (embodied and calorific) from residual urban wastes is to be put on a sustainable footing. This current stage (Stage 3) of the study addresses this need.

1.4 Conclusions Stage 1 & 2

The main conclusions from the first two stages of 'Task 36 - Energy Recovery from Municipal Solid Waste, Topic 1: Product Stewardship / Producer Responsibility' include the following:

- a closer relationship between product designers and providers of post consumer resource recovery services is needed to better plan for resource recovery technologies and infrastructure provision and thus achieve the aim of integration of design intent with resource recovery. Ultimately this will contribute to developing availability of post consumer services and capabilities to affect recovery
- market economics need to be changed in a way that they better reflect the true costs of production and consumption (internalisation of externalities). Ultimately this will create a commercial imperative to link product design with infrastructure planning. EPR (and in a lesser extent PS) will help to create this. By making the original brand owner or manufacturer responsible for the total lifecycle of their product, he will be inclined to improve this whole cycle and innovate his product to adapt to this
- participation in EPR / PS schemes show an increase of the resource recovery rates of targeted products and materials. Other beneficial outcomes include a reduction in associated litter and product innovation through improved design and process engineering in product manufacture. When confronted with constraints companies tend to adjust to changed situations by creating solutions, in other words innovate
- a direct link between EPR / PS schemes and design intent is identified. These include design to reduce hazardous materials, design for disassembly, design to dematerialise (light weighting), design for durability and design for recycling
- new and emerging EPR / PS schemes, which act to deal with additional product types and expand jurisdictional coverage, are addressing used tyres, paper and printing products, electrical and electronic equipment (EEE), disposable nappies and hazardous substances. Australia in particular is acting to establish a model of co-regulation when developing EPR / PS schemes.

Under this style of approach there are regulatory consequences for non-participation. This is done to remove 'free riders' and allow industry greatest flexibility in responding to the challenges that EPR / PS present

- recovery of material's embodied energy is preferred, but we can't ignore the possibilities of obtaining material's calorific value.

Challenges to the ongoing effectiveness of EPR / PS schemes include the continuous improvement of: covering reverse logistic infrastructure; support systems; innovative technologies for product and material dissimilation and assimilation; regulation and other policy measures, elimination of 'free-riders' through complementary regulations; development of markets for recovered resources; using tools such as Value Chain Optimisation and developing principles for it.
Short term results of resolving these challenges will be:

- a decrease in the amount of household hazardous materials disposed of in urban waste
- an increase in the variety and proportion of materials available to be recycled through the economy (with the associated economic value and reduced environmental impact of these commodities)
- a decrease in the amount of readily recyclable material in the urban waste stream (and thus a reduction of the amount of recyclable material going to disposal via kerbside collected Municipal Solid Waste (MSW))

In the long term results need to lead to a common network of integrated waste management systems and an infrastructure to optimise participation of every participant in the value chain and include as many product EPR schemes as possible.

EPR / PS should be an integral part of waste management generally and of Energy from Waste particularly because of the necessity of EPR / PS schemes to significantly shape the composition of the residual waste stream, and facilitate increased resource recovery.

In order to deliver a covering system of resource recovery a new range of capabilities is required in planning for infrastructure. For example, it is vital to know what materials are in the residual waste stream, and importantly whether new product designs are suitable for existing recovery pathways and resource recovery services.

1.5 Overview of the Stage 3 Report

This third stage of IEA Bioenergy Task 36 Topic 1: Product Stewardship / Producer Responsibility synthesises outcomes from earlier Stages 1 and 2 to scope the generic systems and infrastructure needs that should be available if energy recovery (embodied and inherent) from residual urban wastes is to be put on a sustainable footing. It is intended that this will provide useful and informative advice for future post consumer resource planning and capability building. The structure of the report is presented in Figure 2 overleaf.

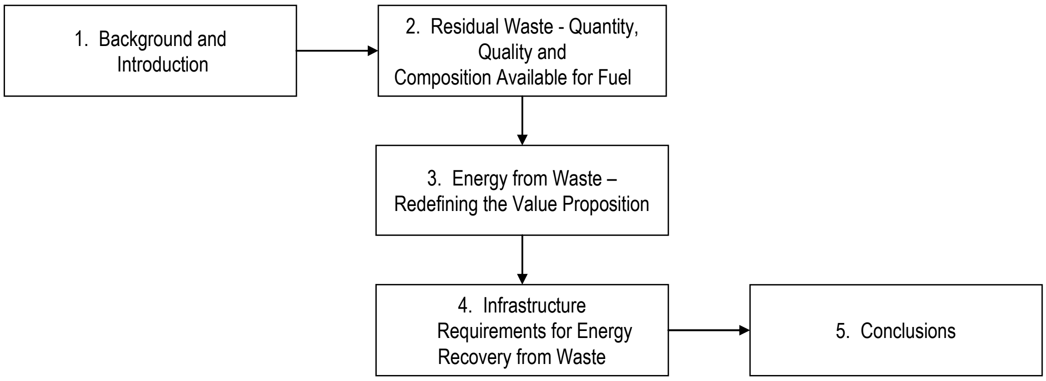

Figure 2 – Structure of report

Following this introduction, Section 2 of this report presents the composition and volume of the likely residual waste stream of the future, on the basis of information from the first two stages of the study. The value of this waste stream in terms of its energy value is explored. Section 3 explores the benefit of energy recovery from waste to society, and discusses some of the concerns and issues associated with this practice, and in so doing contextualises section 4, which discusses existing and emerging technologies which can be used for the recovery of energy from waste, and describes the infrastructure necessary for supporting and feeding these technologies. Finally, Section 5 presents the conclusions from the study.

2 RESIDUAL WASTE – QUANTITY, QUALITY AND COMPOSITION AVAILABLE FOR FUEL (EFW)

In order to set the context for energy from waste infrastructure needs, some indication of the composition and volumes of waste streams that will need to be processed in the future is presented. This section explores the likely waste streams which can be expected in the OECD, and analyses these in the context of representing opportunities for recovery for the embodied energy value of some of the components (such as metals and glass), and for recovery of the calorific value of the remaining components.

2.1 OECD Waste Generation Rates[2]

2.1.1 Total waste generation for the OECD

In 2004 it was estimated that the total waste generation for the OECD was greater than 2,700 million tonnes per year, or approximately 2,400 kg per capita. This figure is identified to be "greater than" because of missing data from certain countries and sectors, and the fact that data for some of the countries was for earlier years where the most recent data was not available. This data includes hazardous waste.

2.1.2 Municipal Waste Generation

Total municipal waste generation for OECD, based on 2003 or latest available figures, is estimated to be the order of 594 million tonnes [3], and per capita generation to be to the order of 549 kg/capita[4], with the estimates varying depending on the source of information. Generation intensity per capita has risen mostly in line with private final consumption expenditure and GDP, with a slight slowdown in recent years.

2.1.3 Fate of waste

An analysis of the current fate of municipal waste generated in the OECD is shown below.

Table 1 – Fate of Municipal Waste Stream

Final Destination	*Total for the OECD (million tonnes) (based on data from 1999 to 2002, depending on the country)*	*Average kg per capita*
Landfill	323	284
Recycling	105	92
Incineration	115	101
Other[5]	51	72
Total	**594**	**549**

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[2] *All data in this section comes from the following source unless otherwise indicated: OECD Environmental Directorate, 2004, 'OECD Environmental Data: Compendium 2004', accessed online at http://www.oecd.org/dataoecd/60/59/38106368.pdf, February 2007.*

[3] *OECD database query output, 2005, accessed online at http://ocde.p4.siteinternet.com/publications/doifiles/302006011P1-07-01-03-t01.xls, April 2007.*

[4] *OECD, 2004, 'OECD Key Environmental Indicators 2004' accessed online at http://www.oecd.org/dataoecd/32/20/31558547.pdf, February 2007.*

[5] *It is noted that landfill, recycling and incineration account for approximately 91% of the total municipal waste stream. This discrepancy is in part due to other smaller end uses, including composting and what is referred to as "other" applications in the reference sources, and in part due to differing information sources from different years for the different countries used to compile these estimates.*

2.1.4 Current and Future Populations in the OECD

In order to provide projections of likely waste generation in 2020, an estimate of current and projected populations in the OECD is required. In 2004 the population of the OECD was estimated to be 1,160,738,000 people.[6] Limited data is available in terms of future projections. The US Energy Information Agency[7] presents one estimate of a 2020 population of 1,257,000,000 and is used for this analysis.

2.1.5 Prediction of Future Waste Generation and Fate on the Basis of Current Trends

For the purpose of this study it is assumed that current per capita waste generation, landfilling and recycling rates remaining unchanged from those shown in Table 1. Although it is likely that per capita generation will in reality increase over time, at the same time the level of recycling is also likely to rise. In the absence of any other information, it is assumed that the increase in waste generation is offset by the increase in recycling rates. On this basis, and using the predicted population trends for the OECD from the previous paragraph, the predicted waste generation in the OECD is shown in Table 2.

Table 2 – Summary of current and predicted waste generation in the OECD

	Total Residual Waste potentially available for energy recovery	*Waste Disposed*	*Waste Incinerated*
Current OECD (million tonnes)	438	323	115
Forecast 2020 (million tonnes)	484	357	127
Forecast kg per capita (2020)	385	284	101

The following section explores the impact of EPR/PS on the future composition of residual waste.

2.2 Future Composition of Residual Waste

As identified in the first two stages of this study, EPR / PS schemes have the potential to reduce the amount of recyclable material going to disposal via kerbside collected Municipal Solid Waste (MSW). Those schemes targeted toward domestic packaging have the end result of reducing the amount of dry recyclables that end up in the residual MSW stream, thus resulting in a scenario different from that suggested in Table 2. Other schemes that address products which contribute to the hazardous component of the waste stream, such as electrical and electronic equipment, mobile phones, rechargeable batteries and paint will change the potential end applications for the municipal waste stream.

What is significant in both of these elements is that the EPR / PS schemes will allow for source separation of the waste streams. Many currently used alternative waste technologies use a mixed waste stream from which desirable elements are extracted. Source separation significantly improves the utilisation of the waste stream.

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[6] *OECD Factbook 2006, 'Economic, Environmental and Social Statistics', OECD, ISBN 92-64-03561-3.*

[7] *US Energy Information Agency, 2006, 'International Energy Outlook 2006', accessed online at http://www.eia.doe.gov/oiaf/ieo/pdf/ieoreftab_14.pdf, February 2007.*

The Stage 2 report gave consideration to the likely materials which would be left in the residual waste stream given increased EPR / PS scenarios. Typical product components unlikely to be covered by EPR / PS schemes and not collected in a separate collection service to households include:

- composite light weight convenience packaging
- disposable cleaning products including paper towels, sponges and cleaning cloths
- clothing and textiles – cheap to buy undermines 'opportunity shop' resale and makes it easy to discard
- food waste as not all municipalities will offer food collection services
- garden waste – similarly not all municipalities will offer garden waste collection services
- shoes – many with synthetic soles and leather uppers
- disposable personal hygiene such as tissues, brushes, combs etc
- nappies
- small DIY renovation materials
- self assemble furniture
- children's toys and
- sporting goods.

A likely outcome of the change in composition of the residual waste stream on the basis of EPR / PS and other recycling initiatives in the OECD was presented in the Stage 2 report, and is reproduced in Table 3 below. While results presented there suggested that these numbers were applicable to 2015, it is likely that they will not change significantly from 2015 to 2020. Also shown in the Table are the annual flows of various components, assuming the total residual waste stream presented in Table 2.

Table 3 – Composition and flow of residual waste in OECD in 2020[8]

Component	*Percentage (OECD 2005)*	*Percentage (OECD 2020)*	*2020 Mass per year (million tonnes)*
Paper and board	40%	17%	82
Glass	6%	5%	24
Ferrous Metals	6%	4%	19
Aluminum	1%	2%	10
Other Non-Ferrous	1%	0%	0
Plastic	10%	25%	121
Rubber and Leather	4%	7%	34
Textiles	5%	8%	39
Wood	9%	8%	39
Food Waste	13%	8%	39
Garden Waste	3%	12%	58
Other	3%	4%	19
Total	**100%**	**100%**	**484**

[8] *Derived from GHD and Warnken ISE, 2006, '3 IEA Bioenergy Task 36: Topic 1 - PS/EPR Scheme Impact on MSW. Stage 2 Report: Review and Assessment of the Performance of PS/EPR Schemes'. These estimates assume that increased recycling of waste materials and increased waste avoidance act to offset increases in per capita residual waste generation rates.*

2.3 Classification of Residual Waste as a Fuel Stream

When attempting to identify opportunities for- and planning recovery of- energy from the residual waste stream, it is more relevant to look at wastes according to the classification shown in Table 4. Here the waste stream is shown in terms of material classifications, likely flows (from Table 3), and energy value of the components of the stream.

Table 4 – Classification of OECD residual waste stream according to composition, calorific value and embodied energy

Classification	*Waste components*	*Total flow (million tonnes per annum)*	*Calorific value (GJ/tn)*	*Embodied Energy (GJ/tn)*	*Energy Value (10^6 GJ)*
		Potentially available for energy recovery			
Dry cellulosic materials	Paper and board, wood	121	15-19	6.5-36[9]	2,060
Dry hydrocarbon based materials	Plastic, synthetic rubber	138	28.5-40	90-110[10]	4,730
Other dry combustible materials	Leather, textiles	56	13.5[11]	143[12]	756
Wet cellulosic materials	Food waste, garden waste	97	6.6-8.5	0.5-2.3[13]	730
Total energy potential recoverable via EfW (10^6 GJ)		412			*8,276*
		Potentially available for embodied energy recovery (recycling)			
Metals	Ferrous, aluminium, other non ferrous	29	0	10-32 (steel) 170 (aluminium)	2,099
Glass	Container and sheet	24	0	13	310
Other (unknown)	Mixed materials	19	?	?	?
Total embodied energy (10^6 GJ)		72			*2,409*

The energy value of the components of the residual waste stream arises in one of two ways as shown in the table above. Those materials with calorific value can be burned or digested to recover the energy value of the materials, which in turn can replace the use fossil fuels such as coal. Metals and glass do not have calorific value, however their embodied energy can be recovered through recycling (avoided energy for primary processing of raw materials). Note that some materials with calorific value would be suitable for recycling, for example paper and cardboard, and wood. This inherent embodied energy is lost once

[9] This includes paper (36) and general wood (6.5), see Appendix 2
[10] This includes General Plastic (90) and synthetic rubber (110), see Appendix 2
[11] Taken as the value for cotton presented in the Stage 2 report.
[12] This includes other dry combustible materials as Cotton (143), see Appendix 2
[13] This includes Food General (2.3) and Garden Organics (0.5), see Appendix 2

the material is committed for use as a fuel, highlighting the importance of capturing the 'highest resource value' of the materials in question.[14]

To put these energy values into context, and assuming an average energy value of high quality coal of 27 giga-joules per tonne (GJ/tn),[15] the estimates provided in Table 4 suggest that the calorific value of the materials which could be used as fuel from OECD residual waste in 2020 would displace the use of 307 million tonnes of coal. Recovering the embodied energy of the remaining glass and metals could avoid the use of up to 89 million tonnes of coal required to manufacture these products from virgin materials. This combined pool of 396 million tonnes of coal replacement represents 30 per cent of the forecast production from OECD North America (United States, Canada and Mexico).[16]

Thus far this section has concentrated on material types, because the embodied energy of whole products is extremely diverse and complex making it hard to calculate and compare. For example, the manufacture of sheet metal roofing requires additional energy to transform 'steel-billets' into a saleable product. However, the embodied energy of more complex steel products, such as in electronic and electrical items, would be higher again than metal roofing. The combination of extracting and processing of resources, dozens of steps in fabrication, assemblage and transport. result in a product with high embodied energy and corresponding high resource value (an electrical appliance delivers greater value than bulk steel). Figure 3 below shows this relationship between increasing levels of resource value and energy inputs to transform raw materials into complex products (embodied energy).

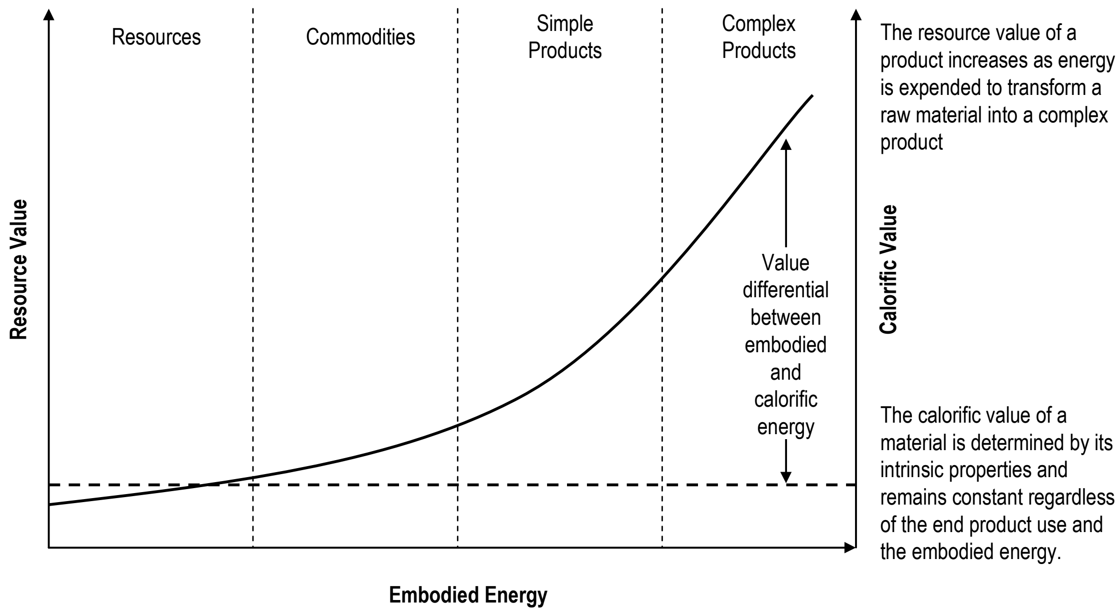

Figure 3 – Resource Value vs. Embodied Energy and Calorific Value

Complex products, like electrical items, have a high resource value and contain a high amount of embodied energy. On the other hand, simpler materials, like wood, have lower amounts of embodied

[14] *See EfW Division, 2005, 'Sustainability Guide for Energy from Waste (EfW) Projects and Proposals', Waste Management Association of Australia, Sydney, accessed at http://www.wmaa.asn.au/director/divisions/energy_from_waste/EFWGuideline.cfm, April 2007, for an applied approach to determining highest resource value in the context of Energy from Waste.*

[15] *For example, washed black coal - AGO, 2006, ' AGO Factors and Methods Workbook - For use in Australian greenhouse emissions reporting', Australian Greenhouse Office, Canberra, found at http://www.greenhouse.gov.au/workbook/pubs/workbook2006.pdf, March 2007.*

[16] *IEA, 2003, 'Coal Industry Advisory Board Meeting with IEA Governing Board, Wednesday 10 December 2003 - Background Paper', International Energy Agency, Paris, accessed at http://www.iea.org/textbase/papers/2003/ciab_demand.pdf, July 2007.*

energy and arguably a lower resource value on a per unit comparison. Regardless of the amount of embodied energy, the direct reuse of a product retains all of the resource value.

The calorific value of a product, on the other hand, is dependent on material composition and is constant regardless of product complexity and energy inputs. In many cases the choice to convert a product into energy, as opposed to reuse or recycling, will deliver a net loss of resource value. Any decision to recover calorific value is thus not a trivial decision. Energy from waste, however, is preferable to losing resources to disposal options such as landfill.

A future waste management system should focus on recovering embodied energy through product reuse and recycling, and then on maximising the recovery of calorific value.

The following section explores the value proposition to society associated with recovery of energy from waste in greater detail, especially given the challenge of addressing climate change.

3 ENERGY FROM WASTE: REDEFINING THE VALUE PROPOSITION

Prior to considering the infrastructure requirements for realising the energy from waste proposition (covered in Section 4), this section examines the value to society from recovering energy from waste in the broader context of saving resources and prevention of severe climate change.

3.1 Societal Value of Waste Management

Historically the role of waste management in society was to address health related issues associated primarily with putrescible waste, by reducing exposure of humans to rotting material, and diseases associated with vermin breeding in inappropriately disposed materials. In more recent times, as society has become more consumption oriented, the removal of waste from the economy has played a role in removing unwanted goods and those at the end of their service lives, thus creating 'space' for new goods and allowing further consumption.

Landfill has traditionally been the preferred waste management option used in society, with incineration being less widely accepted, primarily due to concerns surrounding air pollution and contaminated ash management. Both of these 'technologies' have been very effective in providing disposal solutions. However, the provision of disposal services has been the limit of their value offering, other than in some instances, the recovery of power from incineration and capturing some landfill gas for electricity generation. Both mass-burn incineration and mass-dump landfill completely fail to value the intrinsic properties of materials and prevent any further contribution of value to society.

Resource recovery operations, on the other hand, provides disposal services as a by-product to their core value proposition – returning value to society through the recycling of products, materials, nutrients, soils, and energy. General disposal means losing resources and energy through 'mass-dump' landfill or 'mass-burn' incineration. Currently, because of resource availability, the necessity of resource recovery is low. However with diminishing global resource availability this might change in the not too-distant future when 'peak-availability' is passed. (Peak availability refers to the point where more than 50 per cent of the available resource based has been extracted or depleted).

For some materials, like platinum and indium, this peak has already passed making resource recovery an absolute necessity.[17] A sustainable waste management system and infrastructure should focus on conserving all resources within a product, not just the major components. For instance metal recovery shouldn't just be concentrated on the steel within an automobile, but also on the platinum in the catalytic converter, amongst other things.

Generally the community has been very supportive of recycling initiatives, as evidenced by participation rates in kerbside recycling collections.[18] However, there have been many community concerns regarding the recovery of energy from waste materials. One of the main negative perceptions of energy from waste

[17] Cohen, D, 2007, 'Earth's natural wealth: an audit', New Scientist Environment, 23 May 2007, p.1

[18] In Australia it is reported that 98% of households participate in recycling. ABS 2006, 'Environmental Issues: People's Views and Practices', Australian Bureau of Statistics, Canberra, accessed at http://www.abs.gov.au/Ausstats/abs@.nsf/7d12b0f6763c78caca257061001cc588/989527f462991f5eca2568a90013933e!OpenDocument, April 2007.

is that technologies give rise to significant pollution concerns. As identified in previous stages of the report, one of the outcomes from EPR / PS schemes is the detoxification of the residual municipal waste stream, removing potentially hazardous wastes and reducing the potential risk associated from energy from waste recovery. In well-managed and controlled technologies many of the (negative) public perceptions of EfW are unfounded.

Part of the challenge in changing these perceptions is thus good communication and information dissemination. That's why the Energy from Waste Division of the Waste Management Association of Australia developed a sustainability guide for EfW projects in order to assist project proponents develop more sustainable projects and in doing so, overcome opposition and gain a 'community operating licence'.[19] It is suggested that the current attention being paid to climate change issues provides an added incentive to not only develop EfW projects, but also to maximise the recovery of energy from waste. For example, previous opposition to energy from waste projects may need to be reconsidered given the opportunity to recover energy from biogenic (as opposed to fossilised) carbon.

3.2 The Climate Change Challenge

The Intergovernmental Panel on Climate Change's 'Fourth Assessment Report', Sir Nicholas Stern's 'The Economics of Climate Change', and Al Gore's documentary 'An Inconvenient Truth' have effectively created the scientific, economic and social imperative to take action on reducing greenhouse gas concentrations in the atmosphere. The current (2005) concentration of greenhouse gases is approximately 430 parts per million carbon dioxide equivalent (ppm CO_2e), an increase from the pre-industrial level of 280 ppm CO_2. [20]

One of the main contributors to increases in greenhouse gas concentrations is the combustion of fossilised carbon – fossil fuels such as oil, gas and coal. These fuels represent one part of the sequestration component of the natural carbon cycle. Carbon is turned into biomass through photosynthesis and sunlight. Biomass in turn, is converted into oil, gas and coal over millennia. Accessing these fossilised carbon sinks and combusting the carbon increases the rate of carbon dioxide emissions over and above the absorbing capacity of the natural carbon cycle – hence the increase in concentration.

Fossilised carbon needs to be contrasted against 'biogenic' carbon, or the carbon in current stocks of biomass, like food, garden organics, paper, wood and some textiles. When this carbon is harvested and combusted there is no net difference in carbon concentrations, assuming that the harvested stock of biomass is regrown, otherwise the natural carbon equilibrium as part of the carbon cycle can be disturbed.

Current emissions are approximately 45 giga-tonnes of carbon dioxide equivalent ($GtCO_2e$). If no action is taken then emissions are forecast to increase to 84 $GtCO_2e$ by 2050, with a corresponding increase in concentration to 630 ppm CO_2e. With greenhouse gases at this concentration it is virtually certain that there will be a 2ºC increase in global mean temperature (82 – 100 per cent probability). There is even a

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[19] *EfW Division, 2005, 'Sustainability Guide for Energy from Waste (EfW) Projects and Proposals', Waste Management Association of Australia, Sydney, accessed at http://www.wmaa.asn.au/director/divisions/energy_from_waste/EFWGuideline.cfm, April 2007.*

[20] *IPCC 2007, 'Climate Change 2007: The Physical Science Basis: Summary for Policymakers. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change', Intergovernmental Panel on Climate Change, Geneva, accessed at http://www.ipcc.ch/SPM2feb07.pdf, March 2007.*

5 – 53 per cent chance of a 5ºC increase in global mean temperature. Some of the impacts associated with increased global meant temperatures include:[21]

- melting glaciers with increased flood risk and reduced dry-season water supply to one-sixth of the world's population
- declining crop yields, especially in Africa
- ocean acidification, a direct result of rising carbon dioxide levels, will have major effects on marine ecosystems
- increased worldwide deaths from malnutrition and heat stress
- increased vector-borne diseases such as malaria and dengue fever (if effective control measures are not in place)
- population displacement due to rising sea levels, heavier floods, and more intense droughts
- increased vulnerability of ecosystems with an estimated 15 – 40 per cent of species facing extinction.

The Stern Review estimates that global greenhouse gas emissions would need to reduce to 14 $GtCO_2e$ by 2050 in order to stabilise concentrations at 450 ppm CO_2e and significantly reduce the risks of damage from climate change.[22] To put this emissions reduction target into context, the global population at 2050 is forecast to be 8.9 billion,[23] which means there is a per-capita 'carbon allowance' of 1.6 tonnes of CO_2e (making no allowances for equity issues). Based on the OECD average emissions of 11.41 tonnes of CO2e per capita[24], a reduction of 86 per cent is required.

Energy related emissions make up 65 per cent of total global greenhouse emissions.[25] Naturally addressing energy issues be a major factor in combating climate change. Recovering energy from waste, both through saving embodied energy within products and materials through recycling and also as heat energy (calorific value) will be necessary components in an integrated suite of abatement initiatives.

3.3 Climate Change and Energy from Waste

Previous stages of this study have identified that the residual urban waste stream contains resources, which, when recovered, return value to society. For example through the recovery of embodied energy within products and materials. Recovering embodied energy in metals, glass, plastics and paper results in energy savings to society as a reduced amount of energy per unit of recycled commodity is required, in comparison to manufacture from virgin resources. The energy savings directly translated to reduced greenhouse gas emissions from material manufacture.

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[21] *Stern Review, 2006, 'The Economics of Climate Change', HM Treasury, London, accessed at http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm, April 2007.*

[22] *Ibid.*

[23] *UN, 2002, 'World Population Totals for 1980 - 2050, According to the 18 United Nations Revisions of World Population Estimates and Projections', United Nations Department of Economic and Social Affairs, New York, accessed at http://www.un.org/esa/population/publications/longrange2/worldpoptotals.doc, April 2007.*

[24] *Boyd, R,' Canada vs The OECD: An Environmental Comparison', accessed at http://www.environmentalindicators.com/htdocs/indicators/5gree.htm, April 2007.*

[25] *Stern Review, 2006, 'The Economics of Climate Change', HM Treasury, London, accessed at http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm, April 2007.*

Other fractions within the residual waste stream have an inherent energy value which can be used to displace primary fossil based energy resources fuels that are greenhouse intensive. Energy from Waste can thus make the following contributions to greenhouse gas mitigation:

- maximising recovery of embodied energy – as EfW is a process that operates best with prepared feedstocks, the opportunity is created for additional materials recycling, especially for metals, that otherwise would be lost to landfill
- energy from biogenic carbon – all biomass components (food, garden organics, paper, wood and some textiles) of the residual waste stream are considered renewable and greenhouse gas neutral on combustion. This is because carbon from the atmosphere is converted into biomass by photosynthesis. When the carbon is released again during combustion it results in no 'net' change in greenhouse gas concentrations (short time frame between conversion of atmospheric carbon into biomass and then release back into the atmosphere on combustion)
- carbonising biogenic carbon – some Energy from Waste (EfW) processes, such as pyrolysis, produce biochar as a by-product of converting biomass into an energy rich 'pyrolyitic oil'. The transforming of biomass into char converts the biogenic carbon into a very stable form, with potential land application use. This process effectively captures carbon from the atmosphere and sequesters it in land, while at the same time delivering additional upside through reduced fertiliser use
- refined hydrocarbons (plastics and synthetic rubber) – the hydrocarbon based elements in residual waste are high calorific potential fuels that have already performed a useful function in the economy. There is an argument for preferring these 'second-hand' hydrocarbons as an energy source over primary fossil fuels that need to be mined and refined, especially within the context of maximum direct recycling and dematerialisation of packaging and material requirements in consumables
- source for heat and power – in many cases EfW plants can be sited within an industrial setting, providing a localised source for heat and power, that overcomes transmission losses. These distributed sources of heat and power can then form the basis of sustainable business clusters in line with the concepts of industrial ecology. Furthermore, recovering energy from waste through the use of industrial technology is a controlled process with minimal risks of fugitive emissions, fire or post-closure site remediation.

3.4 The Energy from Waste Imperative

There is a mounting body of evidence to highlight the fact that our systems of production and consumption are unsustainable. The over use and inefficient use of resources worldwide are causing shortages and disruption of natural systems. Climate change is the greatest manifestation of this disconnect between industry and ecology, and possibly the major environmental challenge for humanity in the 21st century.

The global economy will need to find innovative pathways to decarbonise in order to successfully reduce greenhouse gas emissions and avoid the worst impacts of climate change. At present a significant amount of biogenic carbon is lost to landfill, and much of energy supply is provided by fossilised carbon which is released from inert storage in the ground or under the oceans. In a decarbonising economy there is no room for landfilling of biogenic carbon or for lost opportunities to save energy through recycling.

This means using energy and resources as efficiently as possible. Reducing energy usage through reusing products and products, and through recycling (recovery of embodied energy) or using biogenic carbon as an energy source will contribute to carbon abatement measures. Mass-dump landfill has no place in a resource efficient society, rather a system of infrastructure that recovers the highest resource value of waste materials is needed, including energy recovery from residual wastes in the most efficient manner possible. Within this context, the reverse logistics infrastructure needed to support EPR / PS schemes is as essential to energy recovery as is the actual energy conversion plant.

The current waste management sector can contribute to a decarbonising global economy through the design, development and implementation of integrated systems and infrastructure to recover the highest resource value of 'wastes'. It is imperative that Energy from Waste be part of this solution.

The following section explores the selection of technology and infrastructure to facilitate energy recovery.

4 INFRASTRUCTURE REQUIREMENTS FOR ENERGY RECOVERY FROM WASTE

The previous section of this report demonstrated that energy recovery from waste returns value to society, instead of losing it through 'mass-dump' landfill or 'mass-burn' incineration. Importantly energy from waste also contributes to mitigating greenhouse gases as part of efforts to avoid dramatic climate changes. This is met through maximising the recovery of energy from wastes with biogenic carbon, and also from wastes with refined hydrocarbons that are already present in the economy, as well as recovering the embodied energy inherent in materials and products in the residual waste stream to avoid the need for manufacture from virgin resources.

In order to select an appropriate energy recovery technology that ensures recovery of highest resource value from various waste streams, due consideration needs to be given to development of the necessary infrastructure to ensure that products and materials reach the appropriate end application. Figure 3 below shows the infrastructure requirements for energy recovery according to functional aspects that need to be delivered and the design considerations for supporting infrastructure. These design considerations involve the ability to collect, receive, separate and prepare fuel products. Several technologies can then use these fuel products and the benefits they delivery need to be reviewed on an ongoing basis in order to continuously improve the performance of the whole system.

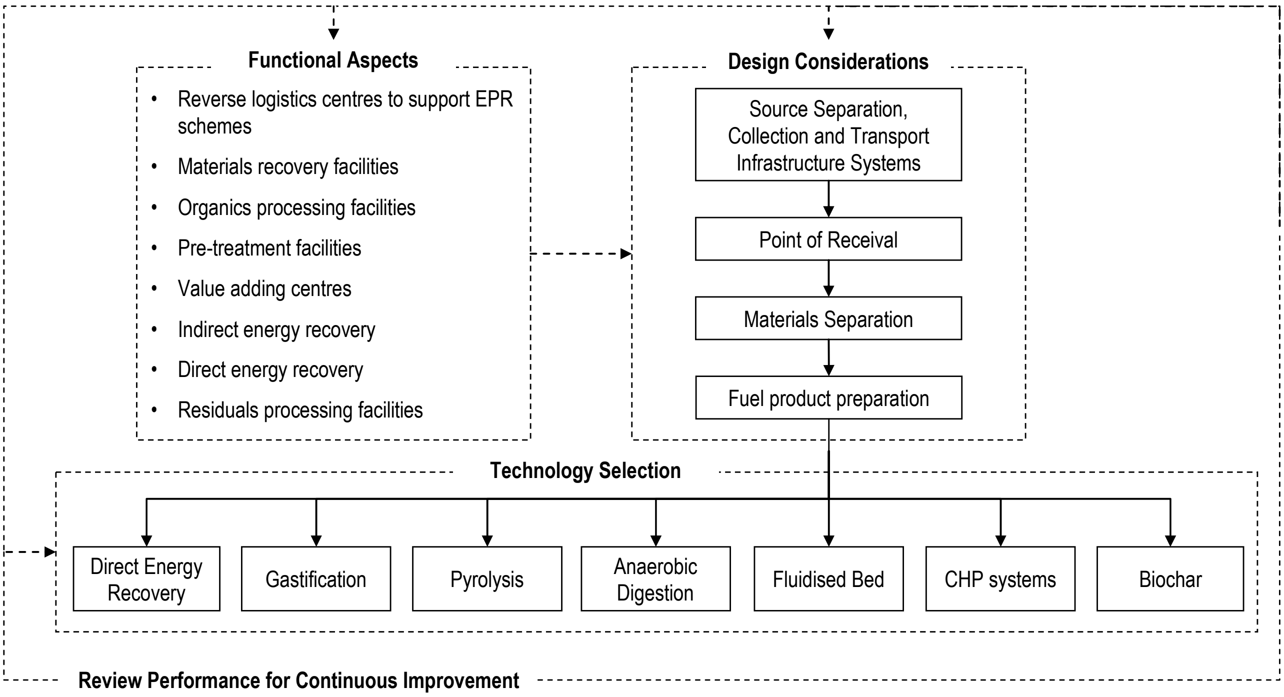

Figure 4 – Determining infrastructure requirements for Energy from Waste

4.1 Functional Requirements of EfW Infrastructure

The purpose of EfW infrastructure is to maximise the recovery of products, materials and energy from residual urban waste within the context of highest resource value and saving energy through the recovery of embodied energy. In order to meet this purpose, a broad suite of infrastructure is required, and potentially includes:

- a mixture of reverse logistic centres to support EPR across brands and products – including reverse vending machines for containers, and drop off for household hazardous (to detoxify the waste stream)
- materials recovery facilities for kerbside collection of dry recyclables such as packaging, newspapers and some containers
- organics processing facility for kerbside collection of 'wet recyclables' such as garden and food materials
- broad pre-treatment facilities to stream residual materials into component materials streams
- additional value adding centres for materials recovery, carbonisation, composting, digestion
- direct energy recovery (alternate fuels for existing facilities)
- residuals processing for construction applications
- indirect energy recovery – maximising recycling at highest resource value to maximise energy savings – especially metals recovery.

The function of this infrastructure is to create maximum opportunity to recover value from the waste stream and to ensure that the residual waste stream is 'detoxified'. A schematic showing the interrelationship between these components is presented in Figure 5 overleaf.

There are four main avenues for recovering value from municipal waste. These include drop-off facilities for products covered by EPR / PS schemes, the kerbside collection of 'dry' recyclables, the kerbside collection of 'wet' recyclables and the kerbside collection of residual materials from households.

EPR reverse logistics infrastructure provides convenient drop-off points for the full range of products covered under EPR / PS schemes. This alleviates the need for all product types and brands to develop and maintain their own infrastructure. Ideally these facilities would be as accessible as a petrol service station. An additional value adding process step would sort different products with potential for refurbishment, or for spare parts.

Kerbside collection removes high value and high embodied energy recyclables (wet and dry) and delivers them to a materials recovery facility. Here packaging, newspapers and containers (dry recyclables) are sorted according to material type and prepared for further value adding and recycling. A residual stream is created through process of sorting, which would form an in feed either into a fuels preparation plant, or into a facility for further homogenisation and perhaps use as a construction base material. Glass and metals go through a Materials Recovery Facility as well to be recycled and eventually used again as a commodity product.

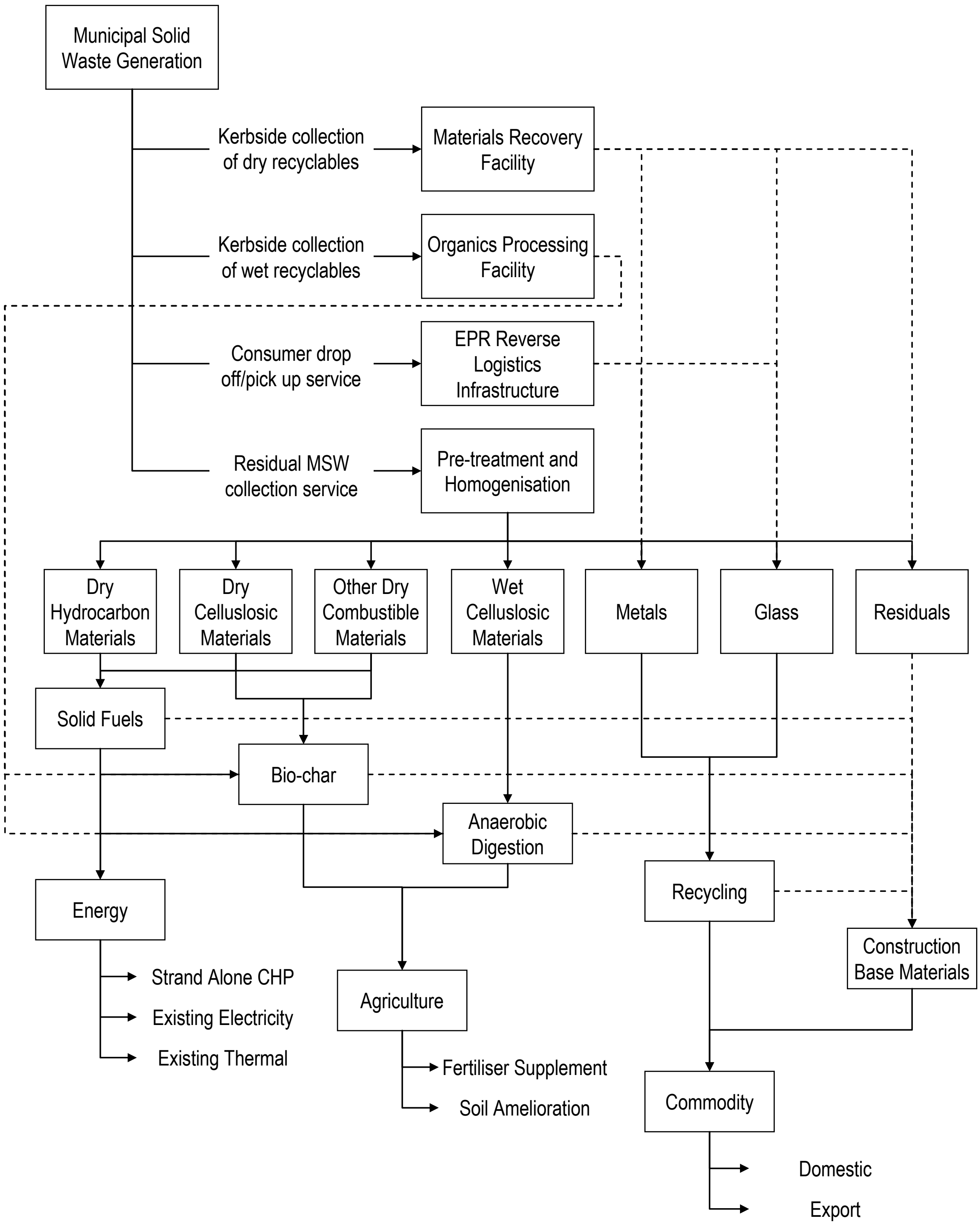

Figure 5 – Components of the Infrastructure Required to Support EfW Applications

The wet recyclables (food and garden materials) go through an Organics Processing Facility for use as biochar (with an energy rich 'pyrolytic oil' and combustible gas as by-products) or to be used in anaerobic digestion (breakdown of organic matter under conditions of low oxygen supply to produce biogas and a nutrient rich digestate product). Both biochar and digestate can be used in agriculture as a fertiliser supplement or soil improver.

The remainder of municipal waste is collected through household waste kerbside services and delivered into pre-treatment and homogenisation facilities. The purpose of these facilities is to convert a heterogeneous residual waste into seven broad categories:

- dry hydrocarbon materials
- dry cellulosic materials
- other dry combustible materials
- wet cellulosic materials
- metals
- glass
- residuals.

Solid fuel preparation can use inputs of dry hydrocarbon materials, dry cellulosic materials, and other dry combustible materials to manufacture a fuel that is suitable for use in a cement kiln, power station or purpose built facility (such as a combined heat and power facility). Some of the same inputs can also be used for biochar manufacture, which can be used in agriculture products. Although hydrocarbons can be used in the process, there may be a preference to concentrate on using biogenic carbon in order to maximise the carbon sequestration benefits.

Anaerobic digestion requires primarily wet organic materials such as food and garden materials and, as already mentioned above, can also be used in agriculture. Metals and glass will be used for recycling and residuals can undergo further processing for use as construction base materials (aggregate, road base or drainage), or for site remediation.

Considerations in developing each of these components of the infrastructure are presented in Section 4.2. Section 4.3 presents a description of proven and emerging technologies for recovery of the energy value of the waste stream.

4.2 Considerations in the Design of Energy from Waste Support Infrastructure

The functions of support infrastructure for energy recovery relate to source separation, collection and transport infrastructure systems, in addition to providing an accessible receiving point and materials separation process.

4.2.1 Source Separation, Collection and Transport Infrastructure Systems

Decisions made at the point of discard ultimately determines the value return on embedded investments of energy, water and materials from a given material or product. Ideally at the 'point of discard', whether it be in an office, construction site, factory or household, there would be a range of bins available to keep materials source separated. If mixed bins had to be used for space, volume or economic considerations, care should be taken to ensure that at the minimum 'contaminating' materials be kept separate from the mixed material bin. This will ensure that the opportunity to recover value is not destroyed through the addition of, for example, hazardous materials.

A general change in social ecology is required to maximise the effectiveness of source separated collection systems. For instance, if people could employ just 10 per cent of the effort spent in making the original purchase decision on selecting a discard option for their 'waste', then a significant improvement in resource recovery would result. The discard options should also be 'conditionally convenient'. 'Convenient' enough to reinforce and optimise participation. 'Conditional' in that some effort is required to select the correct bin, giving rise to a 'pause-to-reflect' emotion to support educational messages regarding source separation.

A flexible system of collection and transport is needed to support source separation systems and to deliver potential resources to beneficiation operations. The functions of collection and transport are important, however should not result in the degradation or devaluing of transported materials. Methods of collection and transport should be selected to benefit opportunities to recover resources, and not to benefit the transport company. Currently, the nature and quality and potential of the recovered resources in the truck are not valued, only the collection rate and distance to emptying.

There are also opportunities for the collection process to form an integral link in resource recovery and processing by acting as the first point of quality control in checking for contamination and in collecting information on material amounts. This primary data is useful for designing education and consultancy (for example waste minimisation) packages to further reinforce key messages of resource efficiency and source separation.

4.2.2 Point of Receival

Once the four separated streams of products and materials are collected they need to be unloaded at a receiving point for further processing. This first point of receival is where the various types of mixed or source separated materials are received direct from the collection vehicles, or where wastes are dropped off directly by the public. A network of these facilities is required in order to allow ready access from short haul vehicles, drawing down from a potential 'catchment' anywhere between 20,000 and 200,000 population. Some receival centres should also be able to accept materials directly from members of the public, allowing the centre to play a part in national extended producer schemes.

Incoming materials can be bulked up, de-contaminated and preliminarily processed prior to transport to a specialist processor. In some cases this processor may share the same site, limiting the need for additional transport. If transport is required, longer haul vehicles with larger payloads can be used to minimise vehicle movements. At the very least the first point of receival would act as a transfer station with efforts made not to commingle source separated collections.

4.2.3 Materials Separation

Energy recovery from a mixed waste stream is inefficient for a number of reasons including that the stream is likely to be heterogeneous, may have a high moisture content which is unsuitable for applications such as combustion, may be supplied in a range of particle sizes and may contain materials which would better be recovered for their embodied energy value. The water content will lower the recoverable energy content per unit mass of waste. The heterogeneous nature, variability in stream composition and potential hazardous content of the stream can result in inconsistent emissions, thereby adding to the difficulty of cleanup, and impeding design for maximum efficiency.

It is at this point in an optimised EfW system that collected materials that were not separated at source, or require further separation, are thus separated and processed into products for sale back into the economy or into resource streams that require additional beneficiation. These facilities could be co-located on the same site as the ‘first point of receival’, or located in a manufacturing zone. Engineering materials for specific applications includes processes such as screening for removal of glass, grit and sand, shredding, air classification and magnetic separation for metals removal. The extent to which noncombustible materials are removed varies from application to application. Some systems also utilise air classifiers, trommel screens, or rotary drums to further refine the waste. Separation of the combustible and non-combustible material can increase in the energy value of the stream. The resultant refuse derived fuel (RDF) is often co-fired with coal for energy recovery or organic matter sent to digesters (see below).

The primary function of special purpose processing facilities is thus to provide an adequate level of processing to match the input materials, such that a quality assured product or material input can be created. The commercial focus of these facilities is consequently predicated on product sale, as opposed to ‘waste management’ style gate fees.

In some instances there may be a need for even further beneficiation of materials before they are suitable inputs back into the economy. For example, potential fuel products need thermal oxidation before energy, the marketable commodity, can be sold. Similarly organic materials may require anaerobic digestion to create a concentrated fertiliser product and energy as a by-product.

Again it may be the case that the facilities for first point of receival, special purpose processing and additional beneficiation are co-located on the same site. However, a much larger catchment area, in the order of some 400,000-1,000,000 population, may be required in order to be viable. It is thus anticipated that there would be a limited number of these beneficiation plants within a metropolitan setting. Ideally they would not be classified as waste facilities, as any materials received would have already passed through two processing phases.

4.3 Technologies used for Direct Recovery of Energy from Waste

Various technologies are available for the recovery of energy from waste. A summary of the main types of technologies, various configurations of which have been used successfully around the world, are presented here. Common to all of these approaches is the potential advantage of preceding the processes with a separation step for removal of recyclable waste stream components for material recovery. This contributes towards optimal resource recovery, reduces the extent of contamination and may also increase the calorific value of the fuel stream.

4.3.1 Direct Energy Recovery

Direct Energy Recovery refers to the complete or partial substitution of fuels in industrial applications which require energy for their production processes, such as cement kilns and boilers, with components of the waste stream. Cement kilns have been used with varying degrees of success as a combination waste disposal mechanism and energy recovery for waste streams such as tyres. Issues associated with both gaseous streams and components of the waste which are incorporated into the clinker must be considered in such operations.

4.3.2 Gasification

Gasification is the thermal decomposition of organic material at elevated temperatures in an oxygen restricted environment. The process produces a mixture of combustible gases (primarily methane, complex hydrocarbons, hydrogen and carbon monoxide). This gas can burned directly in a boiler or stripped of CO_2 and used in combustion turbines or generators. The gasification process generally requires an energy supply for initiation and is thereafter either self sustaining once the operating temperature is reached or may need to be maintained by recycling a small proportion of the energy produced from the combustion of the fuel gases.

Large scale gasification technologies have not yet been proven to be economically viable. Such technologies may, however, be suited to smaller applications rather than managing waste streams from large cities. Furthermore, there is less need to keep the gasifier running 100 per cent of the time as start-up periods are relatively short. Finally these systems are able to operate at less than 100 per cent of capacity so there is flexibility when there is a decline in waste availability.

A further benefit of gasification is pollutants (sulphur, heavy metals etc.) are retained in the ash instead of being released in the gaseous phase as potentially occurs during burning of wastes. The solid waste (ash) streams are generally easier to manage than off gases.

The key disadvantage of gasification is the requirement of a homogeneous feed stock. The fuel material requires shredding prior to gasification. However, the savings made by not requiring significant gaseous emission controls may offset fuel preparation costs, resulting in a potentially economically viable process.

4.3.3 Pyrolysis

Thermal pyrolysis differs from gasification in that the thermal decomposition takes place in the absence of oxygen. This process modification results in the creation of an energy rich 'pyrolytic oil' and solid residue (known as biochar) together with a fuel gas.

The majority of the advantages and disadvantages of gasification hold true for pyrolysis, including small scale application, flexibility in feed volumes, retention of pollutants in the solid phase, and the need for preparation of a homogeneous feed stock. The process can also be optimised towards biochar production (see below).

4.3.4 Biological Mechanisms – Anaerobic Digestion

Anaerobic digestion relates to the organic breakdown of wastes via biological degradation to produce a relatively stable solid residue similar to compost, and biogas, a mixture of methane and carbon dioxide which may be burnt for the recovery of its energy value. Anaerobic digestion is particularly suited to wet, organic material and as such has been used for the treatment of sewerage sludge for over a century, and is applicable for components of the waste stream such as food waste.

Compared to other EfW processes, anaerobic digestion recovery of energy for the purpose of electricity generation is only a third as efficient as recovery via mass burn, and a fifth as efficient as gasification.

Potential negative impacts will be similar to other solid waste management options and with proper planning can be minimised to acceptable levels. Advantages include that the input of waste can be reduced to a saleable soil conditioner and that methane generated during digestion of the waste stream is burnt for energy recovery rather than letting some of it escape to the atmosphere as would occur in landfill.

4.3.5 Fluidised bed combustion of biomass

In a fluidised bed, the solid fuel is suspended on upward-blowing jets of air during combustion. The result is a turbulent mixing of gas and solids. The tumbling action, much like a bubbling fluid, provides more effective chemical reactions and heat transfer. Advantages of fluidised bed systems over other conventional combustion systems include improvement in efficiency in combustion of high moisture content fuels, and the ability to be adaptable to a variety of fuels, including various waste fuel streams.

Combined heat and power systems on waste or biomass

In typical energy provision systems electricity is generated at central power plants, while heating and cooling requirements for buildings are met using equipment such as boilers or air conditioners. This is inefficient in that electricity plants lose a large amount of energy as low grade steam, and at the same time onsite equipment for heating and cooling is generally inefficient in the conversion of electricity to heat.

Combined heat and power (CHP) systems or cogeneration systems generate electricity and heat or thermal energy in a single, integrated system. The thermal energy recovered in a CHP system can be used for heating or cooling in industry or buildings. Because CHP captures the heat that would otherwise be rejected in traditional generation of electric power, the overall efficiency of these integrated systems is much greater than from separate systems. In addition to the efficiency benefits, CHP systems can be run on a variety of waste streams, thus making them significant in the EfW context.

CHP have been successfully demonstrated in cold climates, and a number of examples of such systems can be found in Europe. Less application has been found in recovery for air conditioning in warmer climates.

4.3.6 Biochar

The manufacture of biochar through pyrolysis creates a form of carbon that is stable over long term horizons. The longevity of biochar has been established by studies into the so called 'Terra Preta' soils (black earth) of Amazonian Indians formed by the 'slash and char' agricultural practices. The resulting soils are still identifiable some two thousand years later, with much a higher carbon content than surrounding plots of land.[26] Biochar can be manufactured such that 50 per cent of the bio-based carbon in the input material is converted into a stable form, net of the energy used to operate the charring process.[27]

4.4 Maximising Recovery of Energy from Waste

The previous sections have identified the functionality requirements for each node within the system for product and materials recovery in general. This needs to be further extended and a decision hierarchy is required to help guide the appropriate allocation of various components of the stream to the appropriate technology to ensure maximum energy recovery. This avoids a one-size-fits-all approach that can deliver sub-optimal results and creates a system of infrastructure focussed on maximising the value of material flows throughout the economy.

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[26] *Lehmann, J. (undated),' Terra Preta: Soil Improvement and Carbon Sequestration', Cornell University Soil Biochemistry Programme, Ithaca, found at http://www.css.cornell.edu/faculty/lehmann/terra_preta/Flyer%20terra%20preta%20landuse%20strategy.pd, April 2007.*

[27] *See for example, UK Forestry Research, (undated), 'Carbon Accounting', found at http://www.forestresearch.gov.uk/website/forestresearch.nsf/ByUnique/INFD-633DJ4, April 2007.*

In particular the residual waste stream needs to be 'detoxified' and 'mined for value'. From this perspective the infrastructure for kerbside collection of wet and dry recyclables, and the provision of reverse logistic infrastructure for EPR / PS schemes are integral components of EfW infrastructure. Furthermore, the performance of all embodied and calorific energy recovery technologies needs to be reviewed in order to continuously improve on the performance of the whole system in recovering value from waste. While the choice of what is best is dependant on the stream, location, facilities available, stakeholder preferences and other factors, some generic principles include:

- focus on the development of EPR/ PS schemes and setting up the infrastructure including a mixture of reverse logistic centres to support EPR across brands and products in order to recover products with a high resource value
- recover the embodied energy, particularly that of plastic, glass and metals where possible. As has been demonstrated here, the embodied energy of these materials is significant, and any opportunity to save the energy requirement for manufacturing these from new materials should be explored
- combined heat and power systems are generally preferred to electricity or heat generation systems as CHP systems achieve higher efficiencies. The appropriate energy usage infrastructure is, however, required, and in particular in hot climates, applications for the heat generated need to be investigated (for example combined 'coolth' and power)
- utilisation of solid fuels for process heat, such as in cement kilns, are more thermally efficient than conversion into electrical energy
- smaller purpose built facilities for electricity generation can be located closer to the source of the fuel, reducing transport needs, and also reduce power losses through reduced transmission and distribution requirements
- use of pyrolysis can produce energy in addition to a carbon sequestering by-product – biochar.

A diverse range of elements need to be incorporated into the design of an industrial ecology that promotes a resource efficient society as its primary objective through the provision of innovative energy recovery (embodied and calorific) from waste infrastructure.

5 CONCLUSIONS

Throughout the OECD, the total amount of waste generation is growing due to increases in consumption per capita and population growth. The issue of recovering resource value from this waste generation is fundamental to the sustainability of OECD member countries in the context of the climate change challenge and resource conservation.

It is very likely that a range of components, such as food waste, single use thin film packaging and disposable products, would not be included in EPR/ PS schemes, and will end up in the general waste stream. Energy can be recovered from this residual waste stream through recycling of materials for their embodied energy. Energy can also be recovered from materials with calorific value. Here primary fossil fuel energy sources of oil, gas and coal are replaced with secondary energy sources that are largely biogenic in nature, creating a greenhouse neutral source of fuel

Recovering energy returns value to society, instead of losing resources and energy through 'mass-dump' landfill or 'mass-burn' incineration and it also contributes to greenhouse gas abatement through lower energy use in materials manufacture and the direct substitution of fuel use. A complete waste management system and infrastructure would thus optimise opportunities for reuse, recycling and energy conversion. In such a system the point of discard ultimately determines the value return on embedded investments, which means that opportunities for source separation need to be maximised.

There are four main streams for recovering value from municipal waste: drop-off facilities for products covered by EPR / PS schemes, kerbside collection of dry recyclables, kerbside collection of wet recyclables (organics), and the kerbside collection of residual materials from households. A broad range of infrastructure is required to support energy recovery from waste, starting with reverse logistic centres to support EPR across brands and products, facilities are also required to convert heterogeneous residual waste into seven broad categories of materials including dry hydrocarbon materials, dry cellulosic materials, other dry combustible material, wet cellulosic materials, metals, glass and residuals.

Infrastructure with the above components can then prepare 'fuel' products for the following technologies that recover energy from waste: direct energy recovery, gasification, pyrolysis, biological mechanisms – anaerobic digestion, fluidised bed combustion of biomass, combined heat and power systems on waste or biomass and biochar.

Generic guidelines for waste from energy are:

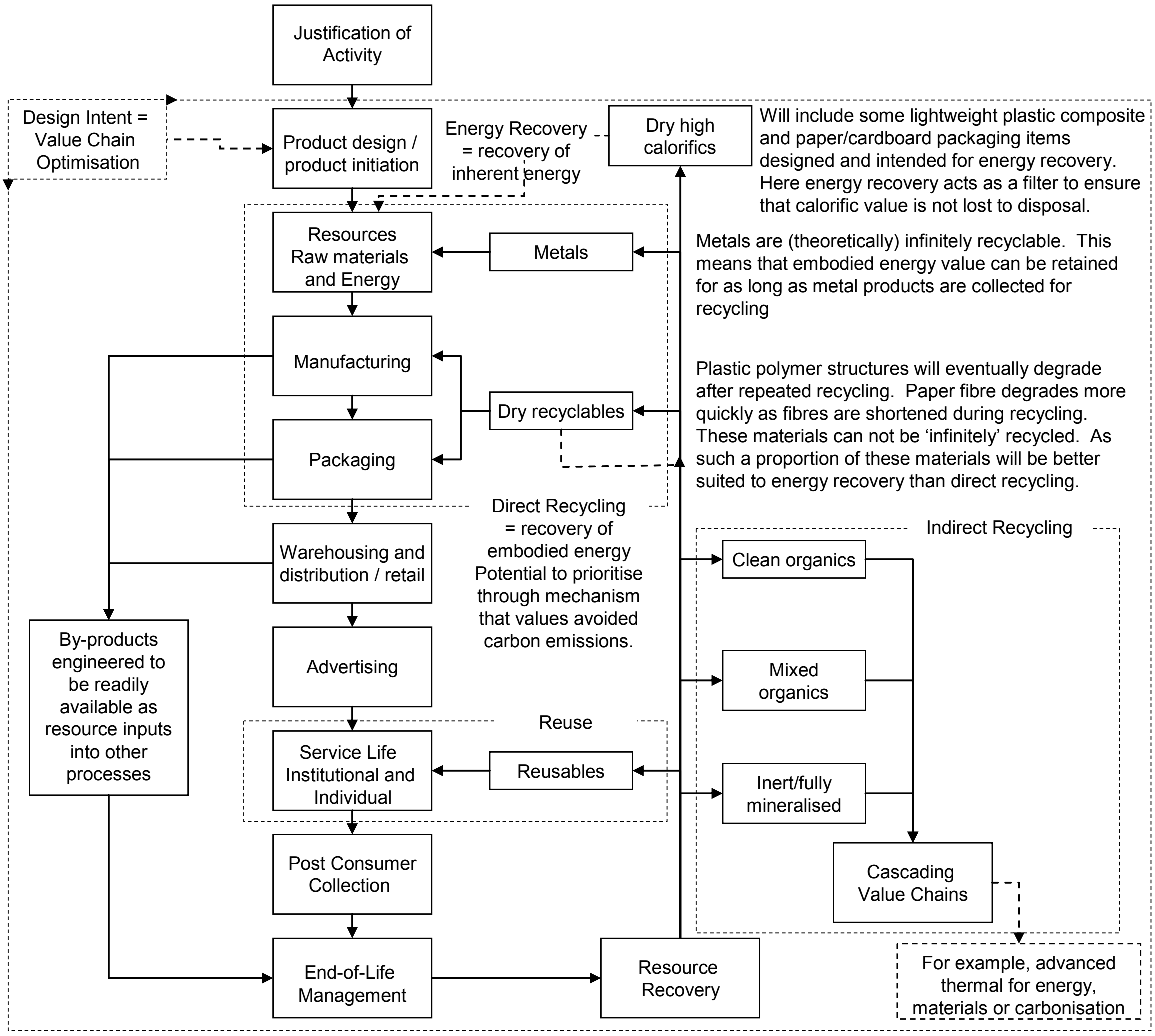
- make recovery of embodied energy a priority
- combine heat and power systems
- solid fuels for process heat are more efficient
- small purpose built electricity generation facilities can be located closer to the source of the fuel
- use pyrolysis to produce energy and biochar.

In all circumstances the urban residual waste stream needs to be 'detoxified' and 'mined for value'. In this respect the infrastructure for kerbside collection of wet and dry recyclables, and the provision of reverse logistic infrastructure for EPR / PS schemes are integral components of EfW infrastructure.

6 APPENDICES

6.1 Appendix 1

The figure below outlines the conceptual elements within value chain optimisation.



6.2 Appendix 2 - Embodied Energy and Inherent Energy References

Material Type	Embodied Energy (MJ/kg)	Calorific Value (Inherent energy) MJ/kg
Paper	36[2]	15-19[9]
Glass	13[1]	0
Steel General	32[2]	0[13]
Aluminium	170[1]	0[13]
Other non-ferrous metal (eg. copper)	100[1]	0[13]
General Plastic	90[1]	29-40[11]
Synthetic Rubber	110[1]	28.5 - 35[9]
Cotton	143[2]	13.5[12]
General Wood	6.5[6,7]	16[11]
Food – General	2.3[3,4]	6.6[10]
Garden Organics	0.5[5]	8.5[9]
Other		
Coal (for comparison)[14]	1	27.5

[1]Technical Manual Design for Lifestyle and the Future (2004) - http://www.greenhouse.gov.au/yourhome/technical/fs31.htm

[2]Centre for Building Performance Research, Victoria University of Wellington, New Zealand http://www.vuw.ac.nz/cbpr/documents/pdfs/ee-coefficients.pdf

[3]Stepping Forward (2005) 'Deriving the ecological footprint results: Component by component' - http://www.steppingforward.org.uk/tech/compbycomp.htm - conservative average of Pulses 5, Cereals 4, Starchy root 2, Vegetables 1, Fruits 1, Eggs 1 = 2.3

[4]Stepping Forward (2005) 'Deriving the ecological footprint results: Component by component' - http://www.steppingforward.org.uk/tech/compbycomp.htm - average of Confectionary 43, Vegetable Oils 21, and Miscellaneous 17 = 27

[5]Garden Organics use air dried sawn hardwood = 0.5 from [1] as proxy to account for transportation and energy in cutting

[6]Hardwood/softwood = average of Kiln dried sawn softwood 3.4, Kiln dried sawn hardwood 2.0, Air dried sawn hardwood 0.5 = 2.0 from [1]

[7]Engineered Timber = average of Hardboard 24.2, Particleboard 8, MDF 11.3, Plywood 10.4, Glue-laminated timber 11, and Laminated veneer lumber 11 = 12.5 from [1]

[8]Based on a study where recycled polyethylene carrier bags reduced energy consumption by two thirds. Waste Online (2004), 'Plastic Recycling Information Sheet', http://www.wasteonline.org.uk/resources/InformationSheets/Plastics.htm

[9]C-tech Innovation (2003), 'Thermal methods of municipal waste treatment', http://www.hm-treasury.gov.uk/media/C43/44/Thermal_Methods_mass_balance.pdf

[10]Andersson, C., Gough, C., Hedlund, J. and Paz A. (2001), 'Municipal Waste for Energy Production at Uppsala Energi', http://www-sml.slu.se/sve/kurser/aktsopu.pdf

[11]WRc, IFEU, ECOTEC and Eunomia (2003). 'Refuse Derived Fuel, Current Practice and Perspectives (B4-3040/2000/306517/Mar/E3) - Final Report', http://europa.eu.int/comm/environment/waste/studies/pdf/rdf.pdf – assumes moisture content of 10 – 15 per cent

[12]Andersson, *et al* (2001) – figure for textiles

[13]However it is noted that thin foils and filings, when in composite materials or subjected to high enough temperatures, have the ability to oxidise and release energy.

[14]Fording Coal Limited 1999 Report to the Voluntary Challenge and Registry Inc. http://www.ghgregistries.ca/registry/out/C0657-FORDINGCOAL-PDF.PDF - note that embodied energy was rounded up to 1 MJ/kg.