Cities as Mine Sites of the Future

M Glover[1] and M Warnken[2]

ABSTRACT

Major cities are not only the focal point for Australian's work, leisure and homes, they also are the focal point for the flow of resources into the built environment, motor cars and transportation and urban consumables. The steady increases in 'stock' and waste generation, in line with GDP growth, means that cities will become the mine sites of the future if the inherent value is recovered from these materials at end of life.

The urban waste stream can be characterised as containing approximately nine per cent hydrocarbon-based materials; 57 per cent biomass-based material; 28 per cent fully mineralised materials that are inert, five per cent metals and less than one per cent of problematic materials that are potentially hazardous and toxic.

In order to convert these wastes into value added inputs into the economy, a number of technological interventions are required. These 'urban waste mining techniques' revolve around source separation and material streaming. One issue that needs to be overcome when determining which mining technique to implement, is identifying the option that will deliver optimal value, both from a financial and a sustainability perspective. The difference between embodied energy and calorific value is a case in point.

Highest net resource value (HNRV) is a concept that can assist in choosing between different resource recovery options. The assessment can be done at a strategic level, or can be used to work out material specific issues. For example, used tyres can be recovered for their energy content at an approximate cost of $120 per tonne, whereas mechanical processing of used tyres can deliver a net benefit of $192.

INTRODUCTION – CITIES AS SINKS

It can be argued that the majority of the economy (as measured by gross domestic product) exists to service the community's social needs, requirements and wants. Part of the economy meets 'essential' services or base line needs and requirements. However, it is also true that many 'essentials' have been distorted, and are in fact determined by an out of control marketing and advertising sector (see for example Hamilton, 2003).

To service this consumer/societal demand primary resources are mined, extracted or harvested for conversion into manufacturing inputs. These inputs are then transformed into the material content of the goods and services recognisable in our everyday lives.

Since more than 80 per cent of Australians live, work and recreate in capital cities (ABS, 2004), the material content of the consumed goods and services (stock) also resides within these cities. When these products reach the end of their service life, they usually present as a waste/disposal problem. However, this 'problem' can be turned into a significant opportunity given the appropriate 'urban mining techniques'.

The 'waste' materials in question are often complex or significantly transformed items that are lost to disposal as mixed residual wastes if intervention does not occur. With innovative intervention, recovered materials can be made available for reuse and recycling and supplement (or replace) virgin material inputs in traditional manufacturing supply chains.

After some 150 years of 'stock' accumulating in major metropolitan areas, the availability of resources for recovery can now be accurately determined and included in future supply side/demand planning – giving rise to the concept of the 'City as the Mine of the Future'.

The stock of resources in cities can be split into three categories: the built environment; transport and end-of-life vehicles (ELVs); and urban consumables. The built environment includes the buildings, infrastructure and engineered structures that represent considerable bulk and mass. Such materials are predominantly lower valued quarried materials, converted with considerable pure energy input. Examples include cement, masonry, glass and metal. Finished structures in the built environment tend to have long service lives (in excess of twenty years) and contain relatively small quantities of complex or significantly transformed products (for example elevators, heating/cooling systems, fit out fixtures and other finishing materials).

The demolition sector has become proficient in recovering the lower value components of buildings, with some 70 per cent by mass being recycled in metropolitan areas. However, the higher value items tend to present as nuisance contaminants in such recovered aggregates rather than as a prime source of resources for presentation back into the economy.

The second major category of 'stock' within cities is transport and end-of-life vehicles (ELVs). The existing scrap sector is well established in the recovery of ferrous metal content (60 to 70 per cent by weight) from ELVs (aided by commonly adopted market and trading structures such as the London Metal Exchange (LME) and Chicago Board of Trade (CBOT)). However, the non-ferrous and non-metal content of ELVs is lost and still presents as a difficult mixed residual waste (shredder flock).

While there are opportunities to mine value from the first two categories, it is perhaps the third sector that presents the greatest opportunity for wholesale 'secondary' resource recovery: urban consumables. Urban consumables include those products that invariably make their way to landfill as part of the complex urban waste stream comprising:

- commercial and industrial (C&I) wastes (as generated by the manufacturers of urban consumables), and
- municipal solid waste (MSW) streams (as generated by the consumers' post consumption of the same goods and services).

These materials have presented as a significant disposal problem for state and local government jurisdictions for long enough to gain considerable knowledge of their content and characteristics, and the opportunity that they could present for secondary resource recovery – or urban city mining.

URBAN WASTE GENERATION RATES

In OECD countries the generation rate of urban waste is closely linked to GDP (EEA, 2001). Recently, greater efforts are being made by way of public policy initiatives to break this direct relationship between economic growth and waste production; but such outcomes are still nascent.

Figure 1 shows the potential for increases in the rate of waste disposed of to landfill to outstrip resource recovery efforts if there is no decoupling between waste generation and resource recovery. For example, the below scenario outlines the case where waste generation increases by an additional 64 per cent

1. Director, Eco Waste Pty Ltd, 36A St Marks Road, Randwick NSW 2031. Email: mark@ecowaste.com.au

2. Projects Director, Warnken ISE, PO Box 705, Glebe NSW 2037. Email: matthew@warnkenise.com.au

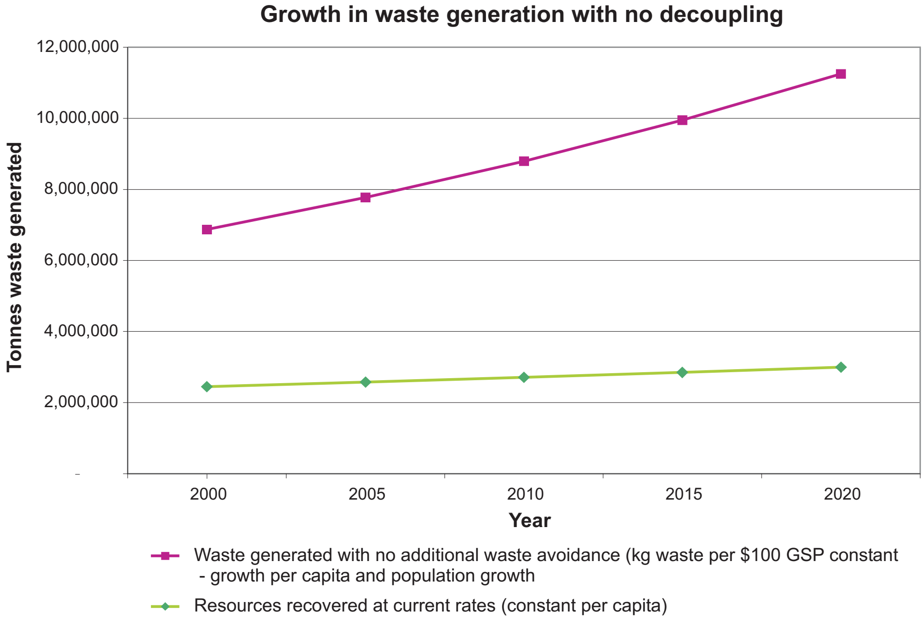

FIG 1 - Potential for waste disposal to outstrip gains in resource recovery if no decoupling between economic growth and waste generation is achieved (adapted from Warnken and Stewart, 2003).

over the year 2000 rates in New South Wales, accounting for growth in the population and growth in the economy (Gross State Product). However, resource recovery rates stay at year 2000 growth rates. Under this case the amount of waste disposed of to landfill would nearly double from 4.5 million tonnes (Mt) in 2000, to 8.25 Mt in 2020.

In Australia, after all existing reuse and recycling activity, we are currently producing these residual urban wastes at the rate of 18 Mt per year. To put this into context, this amount of waste is approximately equivalent to:

- 50 000 tonnes per day,
- one tonne per head of population per year, and
- the Sydney Cricket Ground filled to the top of the grandstands each day.

The composition of the materials disposed of to landfill is presented in Tables 1 and 2. Table 1 presents a breakdown according to generic material characteristics, while Table 2 presents the waste composition on a material type basis.

Table 2 presents a breakdown of waste disposed of to landfill in Australia for the year 2002/2003. This breakdown has been based on Hyder Consulting (2006), for all states other than Tasmania and Northern Territory, which were estimated on the basis of data supplied by the Department of Primary Industries, Water and Environment and Darwin City Council respectively. There was no national breakdown of material composition identified, and so New South Wales and Victoria have been used as proxies to estimate national totals. For the purposes of this analysis, 'other' waste has been broken down into generic material characteristics on the basis of a proportional basis.

MINING TECHNIQUES

The urban wastes presented above are 'wastes' purely as a result of mixture or heterogeneity. The entire 18 Mt per year could be sorted and processed into at least the categories shown in Figure 2. Because these potential resources present as spent, surplus or otherwise unwanted materials in the hands of the current owner, the primary urban mining techniques are source separation and material streaming. If separation and streaming occurred, there would be no waste, but homogeneous resource streams that would present as reliable inputs back into the economy.

TABLE 1

Breakdown of waste disposed of to landfill according to material characteristics.

Material type	Material characteristic	Potentially recoverable as
Plastics including: • Polyethylene terepthalate (PET) • High density polyethylene (HDPE), • Polyvinyl chloride (PVC) Polypropylene • Polystyrene	Hydrocarbon based 9% ∴ 1.67 Mtpa	• Products • Polymers • Energy
• Paper and cardboard • Garden organics • Food and other organics • Wood/timber	Biomass based (lignocellulosic) 57% ∴ 10.26 Mtpa	• Products • Fibre • Soil amendment Energy
• Glass • Soil/rubble • Concrete • Bricks • Asphalt • Other clean excavated • Materia	Inert fully mineralised 28% ∴ 4.99 Mtpa	• Products • Glass • Aggregates • Fill
• Steel • Iron • Aluminum • Other non-ferrous metals	Metals Fe 4% ∴ 0.76 Mtpa Non-Fe 1% ∴ 0.13 Mtpa	• Direct reuse/ supplementing existing markets for metals
• Paint • Batteries • Household chemicals • Asbestos • Hospital waste • Acids and solvents	Misc chemical contaminants <1% ∴ 0.18 Mtpa	• Crucial contaminants in the above categories

For the mining of cities to be optimised in the future, a mix of technological reprocessing capabilities will be necessary. These include (where the notation 1 - 7 refers back to Figure 2):

1. Complex product deconstruction/disassembly to recover the individually small quantities of expensively converted resource (especially metals) – specialist capabilities required.

TABLE 2

Breakdown of waste disposed of to landfill according to material types.

Commodity	Tonnes sent to disposal	Percentage of total
Paper and cardboard	278 000	15%
Glass	515 000	3%
Aluminium	126 000	1%
Ferrous	749 000	4%
Plastic	1 641 000	9%
Garden organics	2 358 000	13%
Food and other organics	3 158 000	18%
Wood/timber	1 754 000	10%
Soil/rubble and other clean excavated material	2 585 000	14%
Concrete, bricks and asphalt	1 796 000	10%
Misc chemical contaminants	180 000	1%
Other hydrocarbon based	33 068	0%
Other biomass based	202 640	1%
Other inert based	98 660	1%
Other metals based	17 632	0%
Total	18 000 000	100%

2. Non-ferrous, precious and semi-precious metal recovery from mixed inputs – specialist capabilities required.
3. Systematic polymer recovery from mixed 'high calorific' inputs – specialist capabilities required.
4. 'Inherent' energy recovery techniques from all urban waste streams – specialist capabilities required including existing facilities such as kilns, power stations and metallurgical processes.
5. Biomass optimisation technologies before making the final binary decision to recover the inherent calorific value. Basic composting facilities exist and some anaerobic digestion facilities are emerging – but much more is needed, including carbonisation (pyrolysis) capabilities.
6. Non-bottle and jar glass processing capabilities (plate, motor vehicle, cathode ray tube, etc).
7. Reverse logistic handling capacity for materials managed under extended producer responsibility (EPR) and product stewardship (PS) schemes. These materials are then presented back into the productive economy. This process would be optimised and made genuinely sustainable if the full 'external' costs of virgin/primary extraction were evident in the market place.

Having passed through a sophisticated mix of processing technologies, the 'secondary resources' are able to be traded as quality assured resource streams. Such existing commodity streams include:

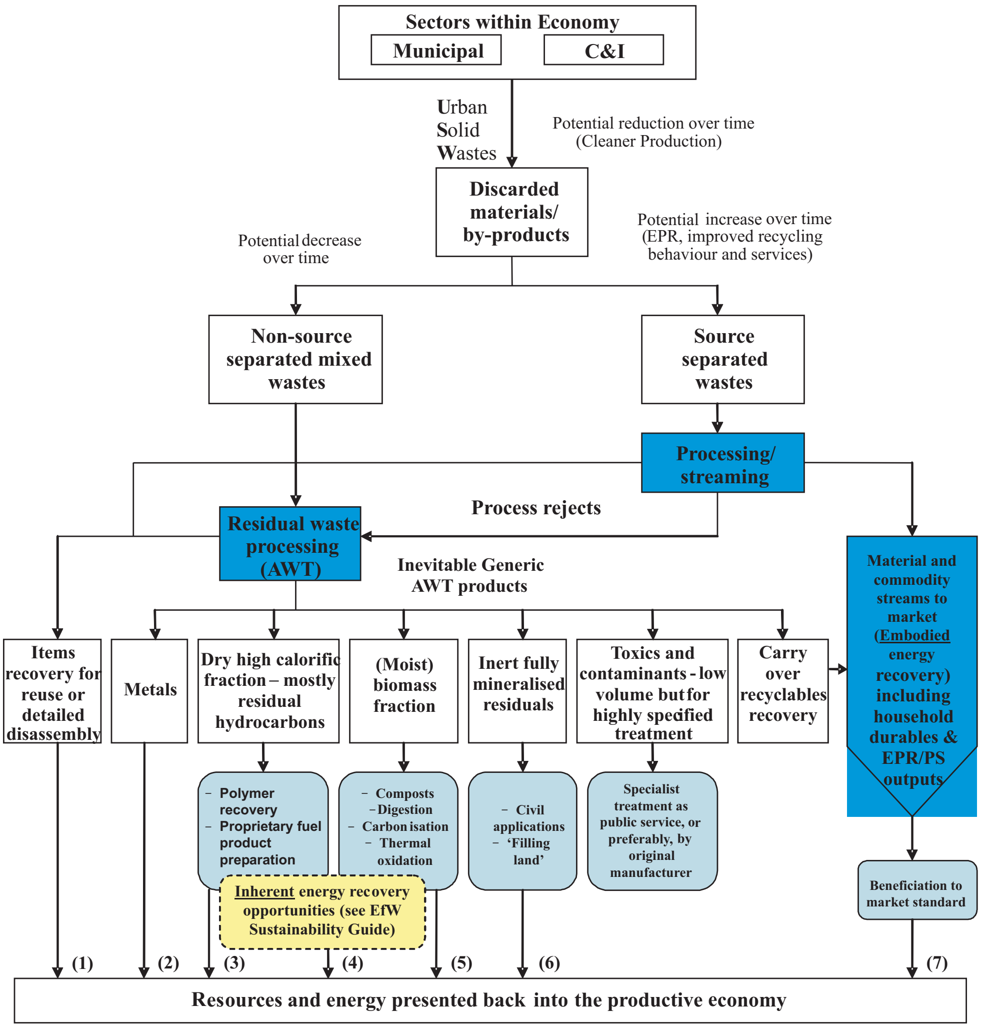

FIG 2 - Generic schematic showing the function of source separation and materials processing to present the 'waste stream' as value added commodities ready for use by the economy.

- paper/cardboard/newsprint,
- ferrous and non-ferrous metals,
- mineral oils,
- containers/cullet, and
- certain plastic streams (for example PET, PE and PP).

While some of these secondary resources are currently recovered and traded, this level of processing is not common across other fractions of urban waste. In order to fully mine the city of the future a wide range of additional resource value recovery facilities and capabilities will be needed.

When determining the viability of such capabilities and the capital justification for each opportunity, the concept of highest net resource value (HNRV) is an important factor. HNRV is a concept that attempts to express the effective resource value of the various materials, net of the cost or effort to realise that value in the market place. It is noted that in sustainability terms the existing market place is not an accurate benchmark, unless all the externalities and impacts of primary/virgin extraction are internalised, or reflected in such a market place, but it can serve as a useful starting position.

For example, urban wastes are often considered too difficult to segregate and value-add, leading to the suggestion of mass burn incineration with energy recovery to gain some heat value from material disposal. However, when considering this value judgement as whether calorific energy recovery from mixed urban wastes presents as the HNRV option, it is useful to consider the embodied energy of the materials in question.

The embodied energy refers to the amount of energy required to transform raw materials into final products during the preconsumer stages of a product's life cycle, whereas inherent energy (or calorific value) refers to energy released during combustion. In general most materials have a higher embodied energy than calorific value, meaning that a wholesale approach of energy recovery will not recover the maximum value possible as the embodied energy 'invested' within materials and products is lost.

Table 3 attempts to quantify embodied energy for some common urban waste materials.

The embodied energy values can be an important factor when establishing HNRV as part of the viability / capital justification / risk analysis / justification-of-the-demand assessment for the establishment of any of the capabilities 1 - 7 in Figure 2. Some of the overarching principles that can be used to qualitatively assess the HRV of a given material or project is presented in Table 4.

TABLE 3

Embodied and inherent energy value of common waste material types (GHD and Warnken ISE, 2006).

Material type	Embodied energy (MJ/kg)	Calorific value (inherent energy) MJ/kg
Paper	36	15 - 19
Food – unprocessed plant	2.3	6.6
Garden organics	0.5	8.5
Wood/timber	3	15 - 17
Cotton	143	13.5
Synthetic rubber	110	28.5 - 35
Glass	13	0
General plastic	90	29 - 40
Steel general	32	0
Steel recycled	10	0
Aluminium	170	0
Recycled aluminium	8	0
Concrete	2	0
Coal (for comparison)	1	27.5

Note: Metals, especially thin foils and filings, when in composite materials or subjected to high enough temperatures, have the ability to oxidise and release energy. However, this release of energy is not normally associated with combustion, and so no attempt has been made to estimate the potential heat value.

This approach is somewhat limited by its qualitative approach, and while very useful in the strategic and prefeasibility stage of projects, does not necessarily deliver 'bankable' results. A more practical example is presented in Table 5 to illustrate this point, that is the case of used tyres.

TABLE 4

Assessment matrix to determine first order net present highest resource value (Warnken ISE, 2004).

Assessment criteria	Comments
What are the recovery options for the material in question?	This should include a listing of all of the 'possible' options to ensure that as wide a net as possible has been cast to investigate opportunities.
How many of these are commercial at the present time?	Moving from the possible to the probable, what options currently exist as commercial operations?
What kind of recovery opportunity is it?	Reuse – another trip through the economy for the product as is Direct recycle – another trip through the economy for the material Indirect recycle – possibly the last use before dispersion back to the environment, for example compost Energy recovery – irrecoverable loss of material structure to capture energy content.
What is the planned and accessible end-of-life use for the recovered material?	Reuse, direct recycle, indirect recycle or energy recovery.
What is the economic case for the commercial recovery options?	An assessment of the business case for each recovery option as a traditional cost and benefit analysis, including a comment on market maturity and stability.
What is the environmental case for the commercial recovery options?	An overview of the environmental impacts (both positive and negative) including potential emissions to land. Also including offset benefits such as reduced need for virgin materials, increased quality of soil and decreased fossil fuel use.
What is the social case for the commercial recovery options?	An overview of the social impacts (both positive and negative) including local amenity, jobs, preferences (as identified through stakeholder involvement) and issues in gaining a community operating licence.
What are the prevailing local conditions?	An overview of pertinent factors that could influence the resource recovery choice, for example, drought, brown outs, available land, level of industrial activity and/or urban encroachment and distance to markets.

TABLE 5

HNRV estimate for rubber/used tyres.

Key input data		$A/t
1.	Original cost of labour, materials and energy to manufacture a passenger tyre	>2000
2.	Value of externalities and impacts not reflected in the 'market' pricing of (1)	To be valued on a case by case basis
3.	Potential (CV) (benchmarked against coal, etc)	Approx $30
3.1.	Cost to collect and present tyres for energy recovery	Say $150
4.	Potential value as re-refined (pyrolysis) materials (oils, metals, chars, etc) benchmarked for quality against virgin equivalents – because of poor product definition	Say $50
4.1.	Cost to re-refine (pyrolysis) used tyres	Say $250
5.	Potential value of mechanically (size reduction) generated tyre derived products (TDPs)	$412

Tyre derived product market segmentation				
Total tonnes for processing			**Say 10 000**	
Breakdown of processed volume				
Item	**Description**	**Estimated yield**	**Average sale price ($/t)**	**Average income**
TDP1	**Whole tyres** (typically for TD fuel)	3%	$50	$15 000
TDP2	**Cut tyres including Ecoflex** Segmented or sidewall removed	5%	$150	$75 000
TDP3	**Shred** 150 × 300 mm	2%	$150	$30 000
TDP4	**Chip** 50 to 75 mm square	5%	$150	$75 000
TDP5	**Buffings** Steel and fibre free	5%	$250	$125 000
TDP6	**Granulate/Crumb** Magnetically cleaned	50%	$500	$2 500 000
TDP7	**Powder** Derived from crumb	5%	$750	$375 000
TDP8	**Clean powder** Derived from buffings	9%	$900	$810 000
TDS1	**Steel bead whole** Derived from de-beading	3%	$120	$36 000
TDS2	**Steel from magnet separation** Derived from crumbing process	7%	$50	$35 000
Fibre	**Fibre from air separation** Derived from crumbing process	6%	$80	$48 000
	Totals	**100%**		**$4 124 000**
Therefore: Average value recovered per tonne processed = $412.00				

5.1.	Cost of mechanical processing	Say $220
6.	Last resort disposal (landfill) option	Say $160

Using the above information, four options for tyre recovery can be assessed. For example:

- Simple disposal – this option has direct (and net) costs of $160 per tonne and an indirect impact of no resource value recovery.
- Simple combustion – for example, calorific value recovery through a cement kiln. This option has direct costs of $150 per tonne, less the value of the heat recovery at $30 per tonne, leading to net direct costs of $120 per tonne. This option also has the indirect impact of no recovery of embedded energy (110 MJ/kg for synthetic rubber in tyres), in addition to no recovery of inherent properties of the complex polymers and resources in tyres.
- Re-refining (pyrolysis) – this option has direct costs of $250 per tonne and a product(s) value of $50 per tonne, leading to a net direct cost of $200.
- Mechanical processing – this option has direct costs of $220 per tonne and a market value of $412 per tonne, leading to a net commercial benefit of $192 per tonne in addition to the retention of embodied and embedded values.

CONCLUSIONS

The general principles of capturing value from waste streams arising in the city have been presented. The strategy is to drive towards the highest net resource value. This has been illustrated with a practical example, namely used tyres. In this specific case, simple energy recovery (net cost of $120 per tonne) shows some improvement over simple disposal to landfill (net cost $160 per tonne). However, the most sustainable and commercially sound outcome is achieved by investing in capital to select and operate systems and technologies focused to recover the available material value (net benefit $192 per tonne).

REFERENCES

ABS, 2004. 2032.0 – Census of population and housing: Australia in Profile — A regional analysis, 2001. Australian Bureau of Statistics, Canberra [online]. Available from: <http://144.53.252.30/AUSSTATS/abs@.nsf/Lookup/2032.0Main+Features12001?OpenDocument>. [Accessed April 2006].

EEA, 2001. Indicator fact sheet signals 2001 – Chapter waste, European Environment Agency, Copenhagen [online]. Available from: <http://themes.eea.eu.int/Environmental_issues/waste/indicators/generation/w1_total_waste.pdf> [Accessed April 2006].

GHD and Warnken ISE, 2006. IEA bioenergy task 36: Topic 1 – PS/EPR scheme impact on MSW extended producer responsibility and product stewardship scheme, impacts on energy recovery from municipal solid waste – Stage 2 Report: Review and assessment of the performance of PS/EPR schemes, Waste Management Association of Australia, Sydney [online]. Available from: <http://www.wmaa.asn.au/efw/Task36_S2.pdf> [Accessed: April 2006].

Hamilton, C, 2003. *Growth Fetish (*Allen and Unwin: Sydney).

Hyder Consulting, 2006. Waste and recycling in Australia, Department of Environment and Heritage, Canberra [online]. Available from: <http://www.pc.gov.au/inquiry/waste/subs/sub103attachmenta.pdf> [Accessed: April 2006].