Routledge
Taylor & Francis Group

Construction Management & Economics

ISSN: 0144-6193 (Print) 1466-433X (Online) Journal homepage: https://www.tandfonline.com/loi/rcme20

# Strategies for successful construction and demolition waste recycling operations

Chun-Li Peng , Domenic E. Scorpio & Charles J. Kibert

**To cite this article:** Chun-Li Peng , Domenic E. Scorpio & Charles J. Kibert (1997) Strategies for successful construction and demolition waste recycling operations, Construction Management & Economics, 15:1, 49-58, DOI: 10.1080/014461997373105

**To link to this article:** https://doi.org/10.1080/014461997373105

*Construction Management and Economics* (1997) **15**, 49–58

# Strategies for successful construction and demolition waste recycling operations

CHUN-LI PENG, DOMENIC E. SCORPIO and CHARLES J. KIBERT*

*Center for Construction and Environment, University of Florida, Gainesville, Florida 32611–5703, USA*

Received 26 June 1995; accepted 29 August 1995

Establishing a successful construction/demolition (C&D) waste recyling operation in the USA is a challenge today, especially because secondary materials markets have not yet matured. Increasingly, municipal solid waste (MSW) landfill operations refuse to accept C&D waste. Skyrocketing tipping fees due to the scarcity of landfill sites, and growing concerns from regulatory agencies and the public, have placed C&D waste recycling operations under intense scrutiny. The experiences of regional C&D recyclers indicate that successful recycling operations require a minimum of 0.8 ha of clear space for processing equipment, incoming waste stockpiles, recycled materials, and manoeuvring room for mobile equipment and operations. Reasonable quality, reliable equipment suitable for these operations generally costs between $300 000 and $750 000 for a 400–500 tonne/day operation. At present, operators of these facilities make a profit almost solely on tipping fees, with the recycling operation functioning mainly to maintain materials throughput. Different categories of C&D recycling machinery and waste processing strategies are presented. Strategies for converting C&D landfills into successful C&D recycling operations are also examined. C&D waste recycling economics are presented to demonstrate the essential ingredients for successful operations.

*Keywords*: Recycling, landfill, machinery, demolition, waste, sustainability, environmental impact

## Introduction

Recycling is recognized today as a solid waste management strategy that is preferable to landfilling or incineration, and environmentally more desirable (Ruiz, 1993). The construction industry is facing a challenging problem of looking for landfill sites for construction and demolition (C&D) waste. Waste from construction activities ranges from 20 to 30 kg/m$^2$ for most types of building in the USA. On a per capita basis this amounts to about 500 kg/person/year for the total of all C&D waste. C&D landfill tipping fees range from $8/tonne in New Mexico to $75/tonne in New Jersey, and the cost to dispose of C&D waste is rising rapidly across the USA (Steuteville, 1995). Many landfills no longer accept C&D waste materials. Although once thought to be inert, C&D waste is now recognized to produce harmful leachate and other contaminants (Federle, 1993). In some cases C&D waste is considered part of the municipal solid waste (MSW) stream and is disposed of in municipal landfills. Because of trends encouraging recycling and reuse, and the more stringent constraints of MSW landfills, communities and contractors are increasingly targeting C&D waste for disposal other than landfilling. A growing number of public and private organizations are formulating programmes to separate C&D for recycling or other reuse projects. Because segregated materials are available from a wide variety of C&D recovery activities, many companies are establishing facilities to commercially recycle the materials generated. C&D waste is a target because it is both heavy and bulky, and therefore undesirable for disposal in engineered, lined landfills (Class I) because of the space it consumes. On the other hand, many C&D materials have high potential for recovery and reuse. Recovering C&D waste can help communities reach their recycling goals and preserve valuable space in their local landfills (Schlauder and Brickner, 1993).

*Author to whom correspondence should be addressed.

C&D waste recycling also makes sense environmentally, and it is also beginning to make economic sense in many parts of the USA. It is a fairly complex proposition to determine the real essence of a successful C&D recycling business, the key element in directing waste from the landfill into new products.

Each year builders in the USA produce approximately 31.5 million tonnes of construction waste, accounting for nearly one-quarter of the municipal solid waste stream. Demolition waste at least doubles the content of construction-related waste. The foremost argument for reducing and recycling C&D waste is purely economic: waste costs money. Builders are only now beginning to evaluate the potential for recycling construction waste generated by each project to determine if recycling is economical. The key steps in determining if recycling makes economic sense and in recycling C&D waste are (NAHB, 1993):

1. Identify recyclable materials.
2 Determine the costs/savings of recycling.
3. Develop a site-specific waste management plan and include it in the contract documents.
4. Implement the waste management plan and train all contractors/employees.
5. Monitor and encourage the participation of contractors and employees.

The scale of the project will determine the overall potential for materials recovery and recycling possibilities from an economic standpoint. There are several issues to be considered when developing a site-specific waste management plan. The techniques utilized must be clearly established, and the proper equipment and machinery to perform the required tasks must be available. The success of the operation will ultimately be determined by how efficiently the machinery and crews perform the tasks required of them. Not all C&D equipment can be utilized for recycling processes. The machinery must be selected as a function of the materials identified for recycling.

## Hierarchy of C&D materials disposal

There are many possibilities for disposing of waste from construction and demolition activities, from recycling to incineration and landfilling. Prior to considering the various options that could be utilized, a hierarchy of disposal options needs to be established (Figure 1).

The hierarchy is based on minimization of both resource consumption and environmental damage, the two pillars of sustainability in construction. Reduction is the best and most efficient method for minimizing the generation of waste and eliminating many of the

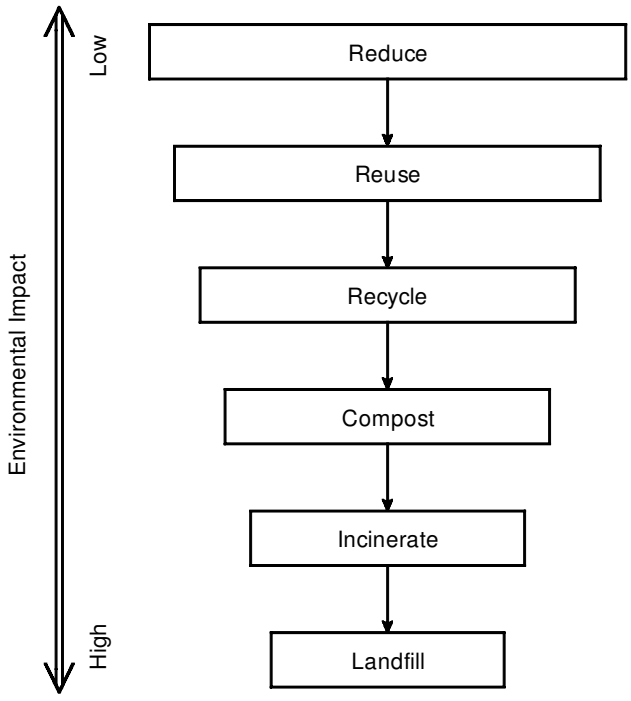


**Figure 1** Hierarchy of C&D waste materials disposals

waste disposal problems. Traditionally, hazardous/toxic materials in most industries are the prime target for reduction. Rising costs of hazardous/toxic waste disposal have stimulated efforts to reduce them. It is an emerging phenomenon that the increasing costs of hazardous/toxic waste disposal will start acting as a strong incentive to reduce non-hazardous wastes as well. Reuse, simply moving materials from one application to another, is the most desirable option after reduction because a minimum of processing and energy use is achieved. Recycling, in which reprocessing of the materials into new products is the objective, is also a high priority. Making new materials out of wastes not only fulfils the purpose of recycling but also generates economic benefits. Composting has also begun to emerge as a new application of an ancient technology, where organic land-clearing debris is processed to produce tonnes of humus for soil treatment.

Incinerators can extract the energy from the materials without generating toxic substances if carefully operated. With landfill space rapidly disappearing, many communities are considering burning their waste, but there are still unanswered questions about the environmental impacts of municipal waste incinerators. Incinerators can emit acid gases such as hydrogen chloride and sulfur dioxide, heavy metals such as lead and cadmium, dioxins, and particulates, all threats to human health as well as to environment. Landfilling is

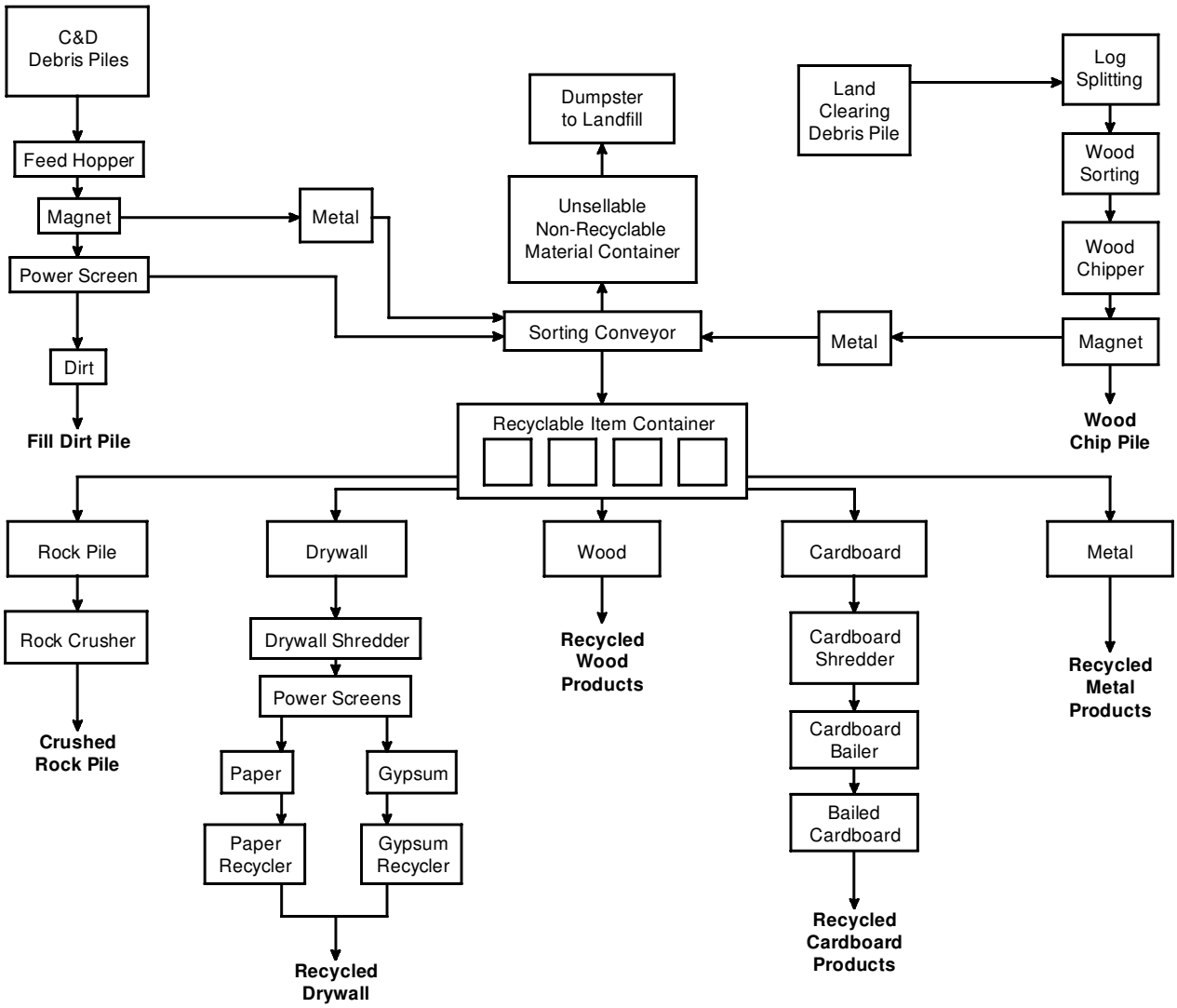


**Figure 2** C&D waste process flow diagram

the lowest in the hierarchy and should be considered only when all other options are exhausted. Leachate, off-gassing, and potential groundwater contamination are typical problems of landfills.

In light of the complexity of the problems of every option in the hierarchy of C&D waste disposal, it is ultimately more cost-effective to process C&D waste for recycling and composting than for incineration and landfilling when full cost accounting is considered.

## Techniques for recycling C&D waste

Several types of facilities and equipment can be utilized to process C&D waste materials into reusable, secondary materials. Figure 2 depicts a typical C&D waste processing system. There are three major categories of C&D processing facilities with corresponding equipment requirements (Schlauder and Brickner, 1993).

### Concrete/asphalt crushing plants

Concrete/asphalt crushing and screening processing systems utilize three principal types of size-reduction units. These units include jaw crushers, impactors, and cone crushers. Several complementary pieces of equipment (e.g. the primary crusher feeder, magnetic separator, vibrating screens for product sizing, and several belt conveyors) form the typical processing system. All of the crushed C&D waste is recycled for use as subbase or aggregate materials.

### Mixed C&D waste

Some facilities are designed to process mixed C&D material that arrives in the same load. Mixed C&D waste processing facilities usually consist of a wide variety of mechanical processing and sorting methods for the mixed materials, and use various mechanical separation devices in conjunction with dry or wet processing separators. Dry processing systems that utilize air separators require the use of a cyclone baghouse or bio-filter control system to properly treat and dispose of dust. In the wet process, the heavy fraction, rich in inorganic materials, sinks to the bottom of the wet quench tank. The organic materials tend to float, so they can be removed in the wash water.

### Wood waste facilities

Equipment typically used for processing waste wood products includes shredders or grinders, magnetic separators, and various screen systems. Clean wood waste can be processed into mulch for use in landscaping activities. It can also be used as a fuel source in boilers, as an agent for composting operations, or for use in manufactured building products. Contaminated wood entering the processing system needs to be closely monitored. Painted wood from the demolition of old houses with lead-laden paint and pressure-treated wood from railroad ties (sleepers) may not be utilized as secondary materials in most cases.

As markets for secondary materials expand, the economic feasibility of recycling a larger range of waste products also increases. Today's market has already established the potential to recycle drywall, cardboard, wood, metals, subgrade materials and fill dirt.

## Classification of C&D waste recycling machinery

In C&D waste processing, equipment can essentially be grouped into three main types: conveying, crushing/reducing, and screening/separating. Table 1 lists various types of equipment for different purposes.

### Conveying equipment

The most common type of conveying equipment used to process C&D is rubber belt conveyors. In certain sections of the system, such as the main infeed point, heavy-duty steel-apron conveyors are used because of their impact-absorbing capability. They are also more durable than the rubber belt conveyors in resisting punctures.

### Crushing/reducing equipment

In assembling C&D processing equipment, the selection of crushing and reduction equipment is the key to a successful operation. For C&D waste processing, the actual size reduction equipment depends on the constituents of the waste stream to be reduced.

### Screening/separating equipment

Screening and separating equipment are used at the final C&D processing station to separate similar material into various size fractions and to segregate the different materials.

## Requirements for a successful C&D recycling operation

It is not enough to simply determine the potential recyclables and the machinery required to create the product. The true success of a C&D recycling operation must be determined by establishing the scale of the operation to be implemented and its resulting economics. All possible alternatives should be identified before establishing a waste recycling operation, and existing or previous operations should be carefully researched.

In the eastern USA, C&D recycling is driven by high landfill tipping fees, while in the West, landfill fees and a huge wood fuel market are the primary factors. Traditional secondary materials markets for C&D recycling include wood fuel, mulch, bulking agents for composting, clean fill, and scrap metal (Steuteville, 1994). Figures 3 and 4 show a typical C&D recycling facility in the USA.

Table 2 lists the requirements for setting up and operating a profitable C&D recycling business.

### Site and site location

The site must have adequate space for the C&D processing equipment, an area for the incoming waste materials, and space for the processed materials. The total space must be sufficient to account for mismatches in the rate of incoming versus outgoing materials. For a nominal operation, an allocation of 0.4 ha for equipment and at least 0.4 ha for processed materials would be a minimum requirement for materials handling and throughput. The location must also be satisfactory in terms of where it is situated in the jurisdiction it serves. It must be able to be permitted and must be in reasonable proximity to the construction operations it serves to be competitive with other C&D landfills or recyclers.

**Table 1** Classification of C&D recycling machinery

| Category | Machinery | Purpose/usage |
|---|---|---|
| Conveying equipment | Troughed conveyor | Most common type, made of rubber belt |
| | Heavy-duty steel apron | At the main infeed point of the system because of the impact-absorbing capability |
| | Pan-type conveyor | Less common, series of linked containers |
| Crushing/reducing equipment | Hydraulic breaker or jackhammer | Pneumatic impact tools to break oversized material into small pieces for the primary reduction unit |
| | Impactor | As primary and secondary crushing units. Handle friable, non-friable, and compressible materials |
| | Jaw crusher | Specifically designed to accept, crush, and discharge Portland cement concrete or similar materials |
| | Hammermill | For wood wastes mostly. It can produce a consistently sized product |
| | Stump grinder | Often trailer-mounted and top-loaded by on-board knuckleboom loader. It can handle large bulky material up to 60 in (1.5 m) in diameter |
| | Rotary shear shredder | Ideal for primary reduction of bulky wood material such as pallets, crates, and stumps, up to 3 or 4 in (75 or 100 mm) in diameter |
| | Screw shredder | This equipment can process bulky wood material such as tree stumps up to 3 ft (1 m) in diameter |
| Screening/separating equipment | Grizzly screen | Scalping or crude screening. Consists of a feed hopper with a vibrating bottom deck made up of evenly spaced steel bars |
| | Disk screen | Used to size wood chips |
| | Trommel | A large, rotating cylindrical screen on its side and slightly elevated on the material feed end |
| | Vibrator screen | Long used in the sand and gravel industry with high/low speed and inclined/horizontal configuration |
| | Magnetic separator | Designed to remove ferrous metals from a moving bed of material with permanent/electromagnetic format |
| | Float tank | A gravity separator using water as a medium to separate wood from rubble-base material |
| | Air classifier | A density separator using air as a medium. A vertical or horizontal air flow is used to separate different density materials |
| | Manual picking station | An elevated platform with a conveyor and a catwalk along both sides of the belt |

## Proper equipment

Experienced C&D operators have learned that it pays to have the proper equipment for the job, preferably equipment made specifically for C&D recycling operations or for a similar business such as quarrying operations. The result of using makeshift equipment or other equipment not specifically designed for handling and separating mixed C&D waste is breakdowns, downtime, and loss of revenue. The equipment must also be able to be maintained by the operators. This includes good knowledge of the equipment, technical information about the equipment, and access to spare parts. The older the equipment, the greater is the chance that parts will be unavailable or that the manufacturer will be out of business. Functional equipment is absolutely essential because the tight operating mar-

**Table 2** Seven determining factors for success of a C&D recycling business

1. Good site and site location
2. Proper equipment
3. Experience in C&D recycling operations
4. Trained supervisors and employees
5. Knowledge of secondary materials markets
6. Business/financial capacity
7. Knowledge of environmental and safety regulations

**Figure 3** Major equipment at a typical US C&D recycling facility

gins of C&D recycling force a high throughput and reliable, rugged equipment. The equipment must be able to produce secondary materials of sufficient quality to meet market demands. The equipment needed to operate a 400–500 tonne/day recycling operation will range from $750 000 in cost for a complete set of new machinery including mobile equipment down to $300 000 if the operator has mobile equipment or can obtain used equipment in good condition.

### Experience in C&D operations

Unlike other salvage operations, C&D is a waste stream that has only a few components of real value mixed in with many materials with little or no value. Understanding the equipment, separation techniques, quality control issues, and other essential features of C&D operations is key to the success of the recycling business. The recovery rate of secondary materials or percentage of the incoming waste stream converted to secondary materials is the quantity that can determine the success of a C&D operation. A high recovery rate indicates a successful operation able to technically handle the problems of separating mixed materials. The disposal costs of the non-recovered or residue materials can be very high, as the only disposal option for these truly waste materials is a Class I or large engineered, lined landfill. Some materials, such as concrete, masonry and rock, may have to be cleaned prior to processing to meet the quality requirements of the secondary materials markets. This requires good knowledge of the equipment and process needed to accomplish cleaning, as well as other quality control procedures. Cross-contamination of materials is another quality control problem that an experienced C&D operator will recognize and have the technical capability to solve. The operator must have knowledge of how to set both tipping fees and secondary materials prices.

### Trained employees

As with any other business, the employees of a C&D recycling operation must be well trained to operate equipment, understand the general business, recognize

**Figure 4** Conveyor system at a typical US C&D recycling operation.

the value of the various materials, and be able to function safely in a hazardous environment. The variety of equipment, such as front end loaders, conveyors, trommel screens, wood chippers, crushers, hoppers, hammermills, and others, requires a number of relatively skilled workers who can operate, maintain and repair a variety of equipment. In addition to knowing the operations and equipment, the employees need to be trained as a team to maximize their productivity, maintain availability of equipment, and produce a high quality output.

### Knowledge of secondary materials markets

The primary goal of present-day C&D recycling operations is to maximize the throughput of materials to earn tipping fees and sell the recovered materials to the secondary materials markets. This requires an aggressive marketing effort to locate markets and sell materials at the highest possible prices. The present rather low level of market development means that significant time and money must be invested in establishing relationships, keeping track of pricing changes, and becoming a reliable supplier of materials. In order to ensure a continuous intake of C&D materials, the operator also has to locate, and develop relationships with, demolition and general contractors with projects in the area to sell their C&D recycling business as the disposal option of choice for the contractors. This latter effort includes keeping tipping fees low and service high.

### Business/financial capacity

A C&D recycling operation requires a relatively expensive system of equipment and conveyors for proper, reliable operation. The operator must have the finances to acquire the appropriate equipment and start-up the operation. Startup costs are always significant, because the entire system must undergo a shakedown period during which productivity will be low. Additionally, markets for products will be only partially developed, and sales of the operation's output will be initially slow. During slower economic times the operation may see both a decrease in C&D intake and a decrease in the

**Table 3** Cost considerations for C&D recycling business start-up and operation

| Capital costs | Operations and maintenance costs |
|---|---|
| Site preparation | Labour |
| Buildings | Supervision |
| Equipment | Operators |
| Mechanical/electrical installation | Labourers |
| Rolling stock | Utilities |
| Engineering | Electricity |
| Start-up | Water |
| Contingencies | Fuel |
| | Parts and supplies |
| | Outside maintenance |
| | Services |
| | Legal |
| | Accounting |
| | Insurance |
| | Marketing |
| | Residue disposal |
| | Permits |

**Table 4** Composition of mixed C&D debris entering a typical Florida operation

| Material | Volume (%) | Recycled (%) | Landfilled (%) |
|---|---|---|---|
| Construction wood | 25.0 | 70.0 | 5.0 |
| Trees/stumps | 5.0 | 100.0 | 0.0 |
| Cardboard | 17.0 | 75.0 | 25.0 |
| Miscellaneous paper | 0.8 | 0.0 | 100.0 |
| Concrete/masonry | 2.5 | 20.0 | 80.0 |
| Plastics | 2.0 | 0.0 | 100.0 |
| Metals | 7.0 | 95.0 | 5.0 |
| Roofing materials | 13.0 | 0.0 | 100.0 |
| Dirt | 2.0 | 30.0 | 70.0 |
| Drywall | 15.0 | 0.0 | 100.0 |
| Glass | 0.1 | 0.0 | 100.0 |
| Building insulation | 4.0 | 0.0 | 100.0 |
| Miscellaneous[a] | 5.8 | 0.0 | 0.0 |
| Unacceptable[b] | 0.8 | 0.0 | 0.0 |
| **Overall** | **100.0** | **55.0** | **45.0** |

[a] Miscellaneous materials
[b] Batteries, paint cans, and similar

sales of secondary materials. Liability considerations are such that a C&D operation should be well insured to protect itself from product or other liability problems. All these matters related to finances require the operator to have an assured source of funds to survive the wide variety of problems that face this and any other business operation. As with any other business, the operator must have good business skills to deal with employees, customers, regulatory agencies, banks, neighbours, and many other forces impacting on the operation. The operator must know how to survive and make a profit in a competitive marketplace in a business with thin profit margins.

### Knowledge of environmental and safety regulations

C&D operations must follow strict safety and environmental guidelines to operate in a manner that protects the public from air and water contamination as well as excessive noise and other nuisances. US safety regulations are such that heavy penalties can be levied on operators whose workers are functioning in a risky environment and who are untrained in safety issues specific to the C&D operation. Environmental regulations produce another group of concerns for the C&D recycling operator, resulting in another set of costs in terms of penalties for violating environmental standards.

## Cost considerations for establishing a C&D recycling operation

The major difficulty that C&D recycling operations encounter when setting up is failure to perform a detailed cost analysis of the proposed operation. A reasonably complete analysis would include the cost categories shown in Table 3.

The recycling business operator has to carefully consider the stream of materials that will be flowing into the site to prepare the operation for processing the waste into secondary materials with reasonably high value. Table 4 shows a breakdown of C&D experience at a typical Florida recycling operation receiving mixed C&D waste. The composition of C&D waste will vary from site to site and from time to time depending on the ratio of commercial to residential construction as well as the proportion of demolition activities taking place in a given jurisdiction. Some C&D operators restrict their intake to items such as concrete and asphalt from road construction operations, providing a more specialized and profitable operation. However, for the typical operation, the quantities in Table 4 are realistic. The noteworthy quantity is the percentage of materials rejected because of a lack of value or markets for the secondary materials. In this particular case, only 55% of C&D waste by volume was recoverable, while the remainder had to be disposed of in suitable landfills.

## Economics of C&D recycling operations

C&D landfills produce income by charging a fee for allowing construction operations to deposit the debris from site clearing, demolition, and construction on land owned by the C&D landfill operator. This 'tipping fee' is the primary income for these operations. C&D landfills are often private operations, many of which own pits where sand or other materials have been mined. The C&D waste serves the somewhat useful function of filling up these pits, allowing potential reuse of the land for other purposes. In some cases there is no pit, and the waste is simply piled up on open ground to limits set by the local jurisdiction. Eventually physical or legal restrictions force the C&D operators to seek ways of ridding their sites of materials so they can continue earning money via tipping fees. If required by local government to regularly move materials off the site, the operator must separate the mixed loads coming onto the site, find markets for saleable products, and dispose of the residue materials. These separated saleable products are sometimes called recycled or secondary materials, in contrast to primary or virgin materials, which are extracted from nature.

### C&D economics example: Orange County, Florida

C&D landfills in Orange County, Florida currently charge a tipping fee of approximately \$2.3/m$^3$ or about \$8.3/tonne if an average density for mixed C&D of 475 kg/m$^3$ is assumed. C&D operations that are forced to convert over to recycling by circumstances find a much more complicated economic picture than when they were solely a C&D landfill. For example, markets for secondary materials in Florida vary from locale to locale, but in general the markets are soft, because of the relatively low cost of primary materials. At the upper end of value in the secondary materials market are metals at about \$66.00/tonne (steel) to \$1 000.00/tonne (aluminium), crushed concrete at \$5.5–11.00/tonne, and wood fuel chips, for which a price of \$6.60–11.00/tonne can be earned. Cardboard currently receives up to \$150.00/tonne. On the lower end are wood chips for mulch, glass and dirt, receiving abut \$3.30–5.50/tonne in the marketplace. In fact, dirt products are often given away for landfill cover in some jurisdictions. Materials such as plastics, asphalt shingles and drywall have virtually no markets.

To be able to recover these materials, a C&D recycling operation must also invest in expensive machinery that can separate the mixed waste stream with sufficient quality for the materials to be resold. In the terms of a recycling operation, quality means minimizing contamination from other materials to keep the secondary materials stream as pure as possible. A good C&D recycling operation with high throughput and a high-quality product will have a processing cost of \$8.80–11.00/tonne of incoming materials.

An additional consideration for the C&D recycler is the need to consider the disposal of waste materials for which there is no market, much of which must be disposed of in an expensive Class I landfill. In Orange County the current price for Class I landfill disposal is \$35/tonne. This does not include the cost of loading and hauling the materials, which adds another \$5.50/tonne or more to the cost of disposal.

A simple cost model that states the relationship between all these economic factors is:

$$I = Q[I_t + rI_s - C_p - (1 - r)C_d] \quad (1)$$

where $I$ = gross income, \$; $Q$ = C&D materials intake, tonnes; $C_p$ = processing cost, \$/tonne; $C_d$ = disposal cost, \$/tonne; $I_t$ = tipping fee, \$/tonne; $I_s$ = income from secondary materials sales, \$/tonne; $r$ = recovery rate of secondary materials from waste, %.

An example using a medium-high recovery rate of 80%, a tipping fee of \$7.50/tonne, a disposal cost of \$35.00/tonne, a processing cost of \$10.00 per tonne, and an average market price of \$9.00 per tonne for secondary materials gives

$$I = Q[\$7.50 + (0.8)\$9.00 - \$10.00 - (1.0 - 0.8)\$35.00] \quad (2)$$

or

$$I = Q(-\$2.30)$$

This example indicates a loss of \$2.30/tonne under the given circumstances. In this case the only way to operate profitably is to increase the recovery rate, decrease the cost of disposal, decrease processing costs, or find higher prices for secondary materials. The tipping fee is unlikely to rise due to local competition. If, for example, the recovery rate were to rise to 90%, a very high rate, the result would be

$$I = Q[\$7.50 + 0.9(\$9.00) - \$10.00 - (1 - 0.9)\$35.00]$$
$$= Q(\$2.10)$$

With a high recovery rate and all other conditions remaining the same, the operator can now make \$2.10/tonne of incoming material. However, a 90% recovery rate is exceptionally high, and only a very few well-organized operators with highly constrained intake are able to achieve this level of recovery.

## Conclusions

At present, a properly functioning C&D recycling business must earn much of its money from tipping fees. The current economics of recycling operations are not very favourable. Recycling serves more to maintain throughput on sites with diminished capacity to landfill incoming waste than to be profitable, stand-alone businesses. An operation restricted in its on-site disposal options has a difficult circumstance because it must carefully balance the intake of C&D waste with the sale of secondary materials. The business must have a high recovery rate in order to maximize the quantity of secondary materials and minimize the residue that will have to be disposed of in a Class I landfill, an expensive proposition. A high recovery rate, high productivity, and high throughput require good equipment and a well-trained crew of supervisors, equipment operators and labourers for a profitable business. The markets must be developed by the business to ensure both a continuous intake of C&D waste and an end-user for the secondary materials produced.

## References

Federle, M.O. (1993) Overview of building construction waste and the potential for materials recycling. *Building Research Journal*, 2 (1), 31–7.

NAHB (1993) Recycling programs target construction waste. *Nation's Building News*, 8 November, 22.

Ruiz, J.A. (1993) Recycling overview and growth, in *The McGraw-Hill Recycling Handbook*, Herbert F. Lund (ed), McGraw-Hill, New York, pp. 1.1–1.10.

Schlauder, R.M. and Brickner, R.H. (1993) Setting up for recovery of construction and demolition waste. *Solid Waste and Power*, January–February, 28–34.

Steuteville, R. (1994) Innovators in C&D recycling. *BioCycle*, 35 (1), 30–3.

Steuteville, R. (1995) The state of garbage in America. *BioCycle*, 36 (4), 58–9.

Wood, R. (1992) C&D Debris: A crisis is building. *Waste Age*, 23 (1), 26–36.