

# Economic Comparison of Concrete Recycling: A Case Study Approach

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## Abstract

Recycling of construction material helps saving the limited landfill space. Among various types of materials, concrete waste accounts for about 50% of the total waste generation. The current practice for dumping construction materials to landfills generates a significant quantity of waste from construction sites. Recycling concrete waste as recycled aggregate is one of the methods to reduce the concrete waste. Therefore, this paper investigates the economical considerations in recycling concrete waste. A comparative study on costs and benefits between the current practice and the concrete recycling method is examined. The study shows that it has a negative net benefit for the current practice while a positive net benefit for the concrete recycling method. Therefore, recycling concrete as aggregate for new concrete production can provide a cost-effective method for the construction industry and help saving the environment.

Keywords: Benefit, cost, economical, recycling, concrete, construction

## 1 Introduction

The promotion of environmental management and the mission of sustainable development worldwide have exerted the pressure for the adoption of proper methods to protect the environment across all industries including building and construction. Construction by nature is not an environment-friendly activity. The hierarchy of disposal options, categorises environmental impacts into six levels, from low to high: to reduce, reuse, recycling, compost, incinerate and landfill (Peng *et al.*, 1997). Three main waste minimisation strategies of reuse, recycle and reduction, are

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collectively called the “3Rs”. To reduce construction waste generated on site, coordination amongst all those involved in the design and construction process is essential.

Recycling, being one of the strategies in minimizing waste, offers three benefits (Edwards, 1999, Kawano, 1995): i) reduce the demand for new resources; ii) cut down on transport and production energy costs; and iii) utilise waste which would otherwise be lost to landfill sites. Construction and demolition waste including demolished concrete, bricks and masonry, wood and other materials such as glass, insulation, roofing, wires, pipes, rocks and soil (Coventry, 1999), constitutes a significant component of the total waste. Among them, concrete waste accounts for about 50% of the total waste generation (Australian Government, 2006, Australian Government: Productivity Commission, 2006, Hendriks and Pietersen, 2000, Li, 2002, Mulheron, 1988). Regarding the huge generation of concrete waste, five major causes are identified, including (Cheung, 1993, Poon *et al.*, 2001; , 2001, Shen and Tam, 2002, Tam and Tam, 2006): i) over ordering; ii) damage during transportation; iii) loss during installation; iv) poor workmanship; and v) change of design. Therefore, this paper explores economical consideration in recycling concrete by a cost and benefit analysis.

## **2 Cost and Benefit Analysis**

To investigate the cost and benefit for concrete recycling, it has been visited three construction and demolition companies, four recycling plants and two landfills in South-Eastern Queensland, Australia. Site representatives have also been interviewed. For the current practice, construction waste is dumped in landfills and new products are produced from the rocks and supplied to the site for new concrete production. It wastes energy to dump the waste and produce new materials for the production. Therefore, concrete recycling method is proposed. The construction waste is sent to recycling plants for crushing it as aggregate for new concrete production, which can save energy for

dumping and producing new materials. This can also bring concrete materials as a closed-loop recycling process.

Detailed cost data for the current practice and the proposed concrete recycling method have been released by the Environmental Protection Agency (Environmental Protection Agency, 2007). However, some cost data are still not available from the Agency, in-depth interview discussions with site representatives from construction and demolition companies, recycling plants and landfills are thus conducted to estimate social and environmental cost required. Detailed interviews with companies are also conducted to validate the cost data and to ensure that consistent results are drawn. Detailed cost data are shown in Table 1 and Table 2 for the current practice and the proposed concrete recycling method respectively.

<Table 1>

<Table 2>

It should be noted that the estimated costs given in Table 1 and Table 2 are confidential and could not be verified using different sources. The only source used to collect these cost data is from in-depth interviews with company's on-site representatives. It is also believed that this practice is very common in the field of construction industry.

Based on the interview discussions, it is also found that average construction waste generated from each site is about 115,200 tons and a recycling plant has a production capacity of about 110,000 tons per year. The expected life of the plant is estimated to be about 10 years. These information are used for the cost and benefit analysis in the below sections.

## 2.1 The Current Method

In the current method, on-site construction waste is dumped to landfills and new products are produced from rocks and supplied on the construction site for new concrete production. Figure 1 shows the flow chart for the current method and Table 1 summarizes the cost and benefit for the current method. Details are summarized as below:

- **Construction waste** is the first stage to be considered in cost and benefit analysis. In this stage, construction waste is sent to landfills and hence cost incurred is in the form of landfill charge (about \$57 per ton), landfill space (about \$220 per ton), transportation cost (about \$5 per ton), air pollution (about 16.5% of landfill space charge), noise pollution (about 17.7% of landfill space charge), gas emission (about 17.4% of landfill space charge), and energy consumption (about 23% of landfill space charge).
- **Stripping** is the stage where rocks are cleared and leveled. Equipment such as bull dozer is required. Cost incurred in this stage including labor cost, fuel cost, and fixed overhead cost.
- **Blasting** is the process where blasting equipment is used and capital cost, equipment cost, working capital cost (about 15% of variable operating cost), operating cost including equipment maintenance cost, and labor cost, fuel cost and fixed overhead cost are estimated.
- **Stockpiling** is the stage where one labor is involved at the rate of about \$18 per hour.
- **Sorting** is the stage where equipment such as excavator is used and capital cost, equipment cost, working capital cost (about 15% of variable operating cost), operating cost including equipment maintenance cost, labor cost, fuel cost and fixed overhead cost are estimated.
- **Crushing process** includes primary crushing, magnetic separation, and secondary crushing process. It involves equipment such as primary crusher, secondary crusher and shaper. In addition, capital cost, equipment cost, working capital cost (about 15% of variable operating cost), operating cost including equipment maintenance cost, labor cost, fuel cost and fixed overhead cost are estimated. In this process, the only benefit is the maintenance cost which can be saved compared to the recycling process because there is more wear and tear of the

equipment blades. Hence, the difference between the maintenance cost for the equipment for the current method and the concrete recycling method is the benefit gained in this stage.

- **Washing, screening or air-sitting process** is the stage which involves fuel and recycled water (about \$0.005 per ton) to settle down dust and all particles.
- **Final product stage**, where the finished products of 7mm, 10mm, 20mm and 75mm aggregate are produced and sold at the rate of about \$15, \$25, \$25, and \$16 per ton respectively.

<Figure 1>

## 2.2 Concrete Recycling Method

In the concrete recycling method, construction waste from the site is dumped to recycling plant and new products are produced and supplied on the construction site. Figure 2 shows the flow chart of the concrete recycling method and Table 2 summarizes the cost and benefit for the proposed concrete recycling method. Details are summarized as below:

- **Construction waste** is the first stage to be considered in cost and benefit analysis. In this stage, dumping charge is the only cost which is being incurred at the rate of about \$25.30 per ton. Dumping the construction waste in the recycling plant had lot of benefits in the form of landfill charge (about \$57 per ton), landfill space (about \$220 per ton), transportation cost (about \$5 per ton), air pollution (about 16.5% of landfill space charge), noise pollution (about 17.7% of landfill space charge), gas emission (about 17.4% of landfill space charge), and energy consumption (about 23% of landfill space charge).
- **Stockpiling** is the stage where one labor is involved at the rate of about \$18/hour.
- **Sorting** is the stage where equipments such as pulveriser and excavator are used and capital cost, equipment cost, working capital cost (about 15% of variable operating cost), operating cost including equipment maintenance cost, labor cost, fuel cost and fixed overhead cost are estimated.

- **Crushing process** includes primary crushing, magnetic separation, and secondary crushing process. It involves equipment such as primary crusher, magnetic separator, and secondary crusher. Capital cost, equipment cost, working capital cost (about 15% of variable operating cost), operating cost including equipment maintenance cost, labor cost, fuel cost and fixed overhead cost are estimated. In this process, steel scrap is sorted out through magnetic separation process which adds to revenue and sold at about \$100 per ton.
- **Manual removal process** is the stage where the removal of pieces of wood, paper and plastics which are still along with the crushed materials. For this stage, one labor is involved at the rate of about \$18 per hour.
- **Washing, screening or air-sitting process** is the stage which involves fuel and recycled water (about \$0.005 per ton) to settle down dust and all particles.
- **Final product stage**, where finished products of 7mm, 10mm, 20mm and 75mm aggregate are produced and sold at the rate of about \$14.8, \$20, \$22, and 15.4 per ton respectively. As these products are sold at a lower price compared to natural products in the market, it has a profit of about \$45000, \$200000, \$3600, and \$33400 per year for 7mm, 10mm, 20mm and 75mm aggregate respectively. At this stage, the benefit gained is the difference between the price of the same quantity produced by this method and the current method.

<Figure 2>

### 2.3 Comparison

Table 3 compares the results of the cost and benefit analysis of the current method and the concrete recycling method. It should be highlighted that the concrete recycling method is more beneficial than the current method. The concrete recycling method receives a positive net benefit of about \$30,916,000 per year while the current method receives a negative net benefit of about -\$44,076,000 per year.

<Table 3>

There is no doubt that aggregate produced by the recycling methods is more economical in long-term than using natural materials. But, one of the factors affecting the viability of aggregate recyclers is the availability of feed materials. If construction debris or other sources of feed are not consistently available or if there is some seasonality to the availability of local feed materials that limits the recycler ability to operate at or near capacity, this can dramatically reduce operational profitability. The amount of material available for recycling is limited by sizes and changing conditions of the “urban deposit.” Recycled material suppliers fail to meet demand for aggregate, so natural material production continues to be the primary source of aggregate in road construction in applications where they can substitute. At best, the contribution of recycled material will gradually grow until all available supply is consumed. Product pricing is often controlled by factors outside the direct control of the recyclers. The amount of material presently available from natural resources overshadows the amount of material available from recycling.

Product quality and uniformity can also pose a risk to the potential recyclers. Natural material producers continue to supply bulk materials for buildings and road construction because they are able to supply sufficient high quality materials for a wide variety of high-grade applications. Unless the recyclers have established long-term contracts for consistent and high-quality feed material, it may be difficult for the recycler to maintain a predictable revenue stream because of uncertainty related to future feed availability and quality or market price fluctuations. Due to the above mentioned reasons, it affects the use of recycled materials in the industry.

### **3 Recommendations**

After information collected from the survey on concrete recycling situation, it is determined that there are several measures to improve the current concrete recycling situations.

- a) There should has a standard specification to encourage the implementation of recycled materials for non-structural and structural applications. For example, “Guidance on the

preparation of non-structural concrete made from recycled concrete aggregate”, “Recycled aggregate applications as subgrade and pavement” and “Guide for specification of recycled concrete aggregate for concrete production (H155-2002)” from Commonwealth Scientific and Industrial Research Organization (Commonwealth Scientific and Industrial Research Organization, 1998; , 2002; , 2006).

- b) One of the main burdens on the use of recycled materials is its low quality. Although there are literatures that to support high quality of recycled materials can be produced, the industry is still hesitated to use the recycled materials for new material production. It is encouraged that the government should widely initiated the use of recycled materials for their projects, which can then encourage its use to the industry.
- c) It should be highlighted that improving technology for producing recycled materials can significantly improve their quality. From that, the government and clients should provide funds and incentive schemes to support the development of technologies.
- d) Lack of in-house training on concrete recycling is another major issue affecting the use of recycled materials in the industry. It is encouraged that training programmes should be produced to all employees to enhance their environmental awareness, thus to improve the environment.

#### **4 Conclusion**

The huge generation of construction waste has reached a state that a warning signal is flicking as reflected from the running out of landfill areas. One of the best ways to manage this acute environmental problem is by recycling construction waste. As concrete waste forms the major source of construction solid waste, which contributes to about 50% of the total construction waste, recycling concrete waste is the best option to mitigate quantities of construction waste. This paper studied the cost and benefit on the current practice in dumping the construction waste to landfills and producing new natural materials for new concrete production, and the proposed concrete

recycling method to recycle the construction waste as aggregate for new concrete production. With the advent of the cost on the current practice, it is found that the concrete recycling method can result in a huge sum of saving. The benefits gained from the concrete recycling method can balance the cost expended for the current practice. Therefore, recycling concrete waste for new production is a cost-effective method that also helps protecting the environment and achieves construction sustainability.

## **5 Acknowledgement**

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Table 1: Cost and benefit analysis for the current method

	Cost (\$1,000/yr)	Benefits (\$ 1,000/yr)	Note*
<b>Construction waste</b>			
Landfill dumping charge	6566.4 <sup>2</sup>		<sup>2</sup> About \$57 per ton
Landfill space saved by not dumping waste	18777.6 <sup>1</sup>		<sup>1</sup> About (\$220 – \$57) per ton
Transportation	576.0 <sup>3</sup>		<sup>3</sup> About \$5 per ton
Air pollution	3136.3 <sup>4</sup>		<sup>4</sup> About 16.5% of landfill space charge
Gas emission	3267.3 <sup>5</sup>		<sup>5</sup> About 17.4% of landfill space charge
Energy consumption	4318.9 <sup>6</sup>		<sup>6</sup> About 23% of landfill space charge
Noise pollution	3323.6 <sup>7</sup>		<sup>7</sup> About 17.7% of landfill space charge
<b>Stripping</b>			
Equipment t	145.0 <sup>8</sup>		<sup>8</sup> Bull dozer equipment cost is about \$1,450,000
Labor	45.8 <sup>9</sup>		<sup>9</sup> 1 person at about \$45,760 per person per year
Fuel	17.2		
Fixed overhead	40.6		
<b>Blasting</b>			
Capital	137.8 <sup>10</sup>		<sup>10</sup> Blasting equipment cost is about \$1,378,000
Working capital	19.4 <sup>11</sup>		<sup>11</sup> 15% variable operating cost of about \$19390 per uni per /year (pulveriser equipment)
Equipment maintenance	30.1		
Labor	124.8 <sup>12</sup>		<sup>12</sup> 2 people at about \$45,760 per person per year
Fuel	15.9		
Fixed overhead	40.6		
<b>Stockpiling</b>	37.4 <sup>13</sup>		<sup>13</sup> 1 person at about \$37,550 per person per year
<b>Sorting Process</b>			
Capital	168.4 <sup>14</sup>		<sup>14</sup> Excavator equipment cost is about \$1,684,000
Working capital	19.4 <sup>15</sup>		<sup>15</sup> 15% variable operating cost of about \$19350 per unit per year (excavator equipment)
Equipment maintenance	35.2		
Labor	45.8 <sup>16</sup>		<sup>16</sup> 1 person at about \$45,760 per person per year
Fuel	7.8		
Fixed overhead	40.6		
<b>Crushing process</b>			
<b>Primary crushing</b>			
Equipment	165.1 <sup>17</sup>		<sup>17</sup> Primary crusher equipment cost is about \$1,651,000
Working capital	18.9 <sup>18</sup>		<sup>18</sup> 15% of variable operating cost of about \$18,930 per unit per year (primary crusher)
Equipment maintenance	30.1	10.2 <sup>19</sup>	<sup>19</sup> Different between the current method and the concrete recycling method
Labor	45.8 <sup>20</sup>		<sup>20</sup> 1 person at \$about 45,760 per person per year
Fuel	9.8		
Fixed overhead	40.6		
<b>Secondary crushing</b>			
Equipment	168.0 <sup>21</sup>		<sup>21</sup> Secondary crusher equipment cost is about \$1,680,000
Working capital	19.3 <sup>22</sup>		<sup>22</sup> 15% of variable operating cost of about \$19,260 per unit per year (secondary crusher)
Equipment maintenance	32.2	10.1 <sup>23</sup>	<sup>23</sup> Different between the current method and the concrete recycling method
Labor	45.8 <sup>24</sup>		<sup>24</sup> 1 person at about \$45,760 per person per year
Fuel	9.9		
Fixed overhead	40.6		

<b>Shaper</b>			
Equipment	90.0 <sup>25</sup>		<sup>25</sup> Shaper equipment cost is about \$ 900,000
Working capital	17.6 <sup>26</sup>		<sup>26</sup> 15% of variable operating cost of about \$17,630 per unit per year (shaper)
Equipment maintenance	22.3		
Fuel	8.9		
Fixed overhead	40.6		
Labor	45.8 <sup>27</sup>		<sup>27</sup> 1 person at about \$45,760 per person per year
<b>Washing, screening or air-sitting</b>			
Water	0.6 <sup>28</sup>		<sup>28</sup> About \$ 0.005 per ton
Fuel	7.8		
<b>Finished graded materials</b>			
20 mm aggregate	550.0 <sup>29</sup>		<sup>29</sup> About 23,000 tons /year of \$25 per ton
10 mm aggregate	1000.0 <sup>30</sup>		<sup>30</sup> About 40,000 tons /year of \$25 per ton
7 mm aggregate	270.0 <sup>31</sup>		<sup>31</sup> About 18,000 tons /year of \$15 per ton
75 mm aggregate	480.0 <sup>32</sup>		<sup>32</sup> About 29,000 tons /year of \$16 per ton
<b>TOTAL</b>	<b>44097.16</b>	<b>20.3</b>	
* Sources for cost data are from in-depth interview discussions with site representatives and information from Environmental Protection Agency (Environmental Protection Agency, 2007).			

Table 2: Cost and benefit analysis for the concrete recycling method

	Cost (\$ 1,000/yr)	Benefits (\$ 1,000/yr)	Note*
<b>Construction waste</b>			
Dumping charge from recycling plants	2914.6 <sup>1</sup>		<sup>1</sup> About \$25.30 per ton
Landfill dumping charge		6566.4 <sup>2</sup>	<sup>2</sup> About \$57 per ton
Landfill space saved by not dumping waste		18777.6 <sup>3</sup>	<sup>3</sup> About (\$220 – \$57) per ton
Transportation		576.0 <sup>4</sup>	<sup>4</sup> About \$5 per ton
Air pollution		3136.3 <sup>5</sup>	<sup>5</sup> About 16.5% of landfill space charge
Gas emission		3267.3 <sup>6</sup>	<sup>6</sup> About 17.4% of landfill space charge
Energy consumption		4318.9 <sup>7</sup>	<sup>7</sup> About 23% of landfill space charge
Noise pollution		3323.6 <sup>8</sup>	<sup>8</sup> About 17.7% of landfill space charge
<b>Stockpiling</b>			
Labor	37.4 <sup>9</sup>		<sup>9</sup> 1 person at about \$37,440 per year
<b>Sorting process</b>			
Capital	168.4 <sup>10</sup>		<sup>10</sup> Pulveriser equipment cost is about \$1,684,000
Working capital	19.4 <sup>11</sup>		<sup>11</sup> 15% variable operating cost at about \$19390 per unit per year (pulveriser equipment)
Equipment maintenance	35.2		
Labor	45.8 <sup>12</sup>		<sup>12</sup> 1 person at about \$45,760 per year
Fuel	7.8		
Fixed overhead	40.6		
<b>Excavation</b>			
Equipment	156.2 <sup>13</sup>		<sup>13</sup> Excavator equipment cost is about \$1,562,000
Working capital	19.4 <sup>14</sup>		<sup>14</sup> 15% variable operating cost at about \$19350 per unit per year (excavator equipment)
Equipment maintenance	34.9		
Labor	45.8 <sup>15</sup>		<sup>15</sup> 1 person at about \$45,760 per year
Fuel	7.8		
Fixed overhead	40.6		
<b>Crushing process</b>			
<b>Primary crushing</b>			
Equipment	163.2 <sup>16</sup>		<sup>16</sup> Primary crusher equipment cost is about \$ 1,632,000
Working capital	20.5 <sup>17</sup>		<sup>17</sup> 15% of variable operating cost of about \$20,450 per unit per year (primary crusher)
Equipment maintenance	40.2		
Labor	45.8 <sup>18</sup>		<sup>18</sup> 1 person at about \$45,760 per year
Fuel	9.8		
Fixed overhead	40.6		
<b>Magnetic separation</b>			
Equipment	120.8 <sup>19</sup>		<sup>19</sup> Magnetic Separator equipment cost is about \$1,207,900
Working capital	16.6 <sup>20</sup>		<sup>20</sup> 15% of variable operating cost of about \$16640 per unit per year (magnetic separator)
Equipment maintenance	15.9		
Labor	45.9 <sup>21</sup>		<sup>21</sup> 1 person at about \$45,760 per year
Fuel	8.7		
Fixed overhead	40.6		
Revenue from selling scrap (mainly steel)		187.2 <sup>22</sup>	<sup>22</sup> 1872 tons per year of about \$100 per ton
<b>Secondary crushing</b>			
Equipment	166.6 <sup>23</sup>		<sup>23</sup> Secondary crusher equipment cost is about \$1,666,000

Working capital	20.8 <sup>24</sup>		<sup>24</sup> 15% of variable operating cost at about \$20,780 per unit per year (secondary crusher)
Equipment maintenance	42.3		
Labor	45.8 <sup>25</sup>		<sup>25</sup> 1 person at about \$45,760 per year
Fuel	9.9		
Fixed overhead	40.6		
<b>Manual removal of remaining contaminants</b>			
Labor	37.4 <sup>26</sup>		<sup>26</sup> 1 person at about \$37,440 per year
Removal of large pieces of wood, paper, plastics etc to landfill	190.0 <sup>27</sup>		<sup>27</sup> About 3328 ton per year of about \$57 per ton
<b>Washing, screening or air-sitting</b>			
Water	0.6 <sup>28</sup>		<sup>28</sup> About \$ 0.005 per ton
Fuel	7.8		
<b>Finished graded materials</b>			
20 mm aggregate	506.0 <sup>29</sup>	45 <sup>33</sup>	<sup>29</sup> About 23,000 tons /year of \$22 per ton
10 mm aggregate	800.0 <sup>30</sup>	200 <sup>33</sup>	<sup>30</sup> About 40,000 tons /year of about \$20 per ton
7 mm aggregate	266.4 <sup>31</sup>	3.6 <sup>33</sup>	<sup>31</sup> About 18,000 tons /year of about \$14.8 per ton
75 mm rubble	462.0 <sup>32</sup>	33.4 <sup>33</sup>	<sup>32</sup> About 30,000 tons /year of about \$15.4 per ton
			<sup>33</sup> Difference between the current method and the recycling method
<b>TOTAL</b>	<b>6,738.06</b>	<b>37,654.61</b>	
* Sources for cost data are from in-depth interview discussions with site representatives and information from Environmental Protection Agency (Environmental Protection Agency, 2007).			

Table 3: Comparison of the current method and the concrete recycling method

	The current method (\$ 1,000/year)	The concrete recycling method (\$ 1,000/year)
Total cost	44,097.16	6,738.06
Total benefit	20.30	37,654.61
Net benefit	- 44,076.84	+ 30,916.55

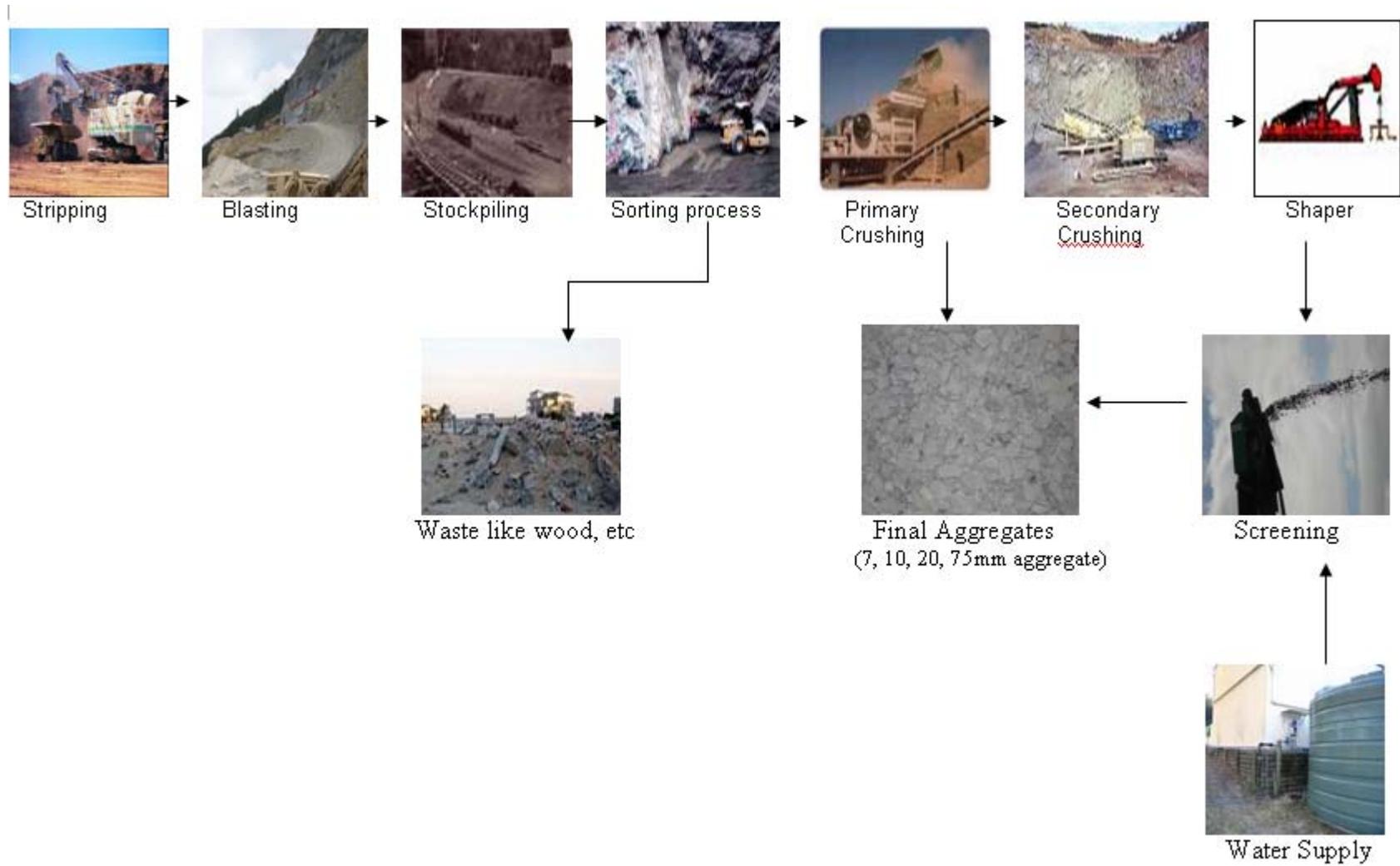


Figure 1: Flow chart of the current method

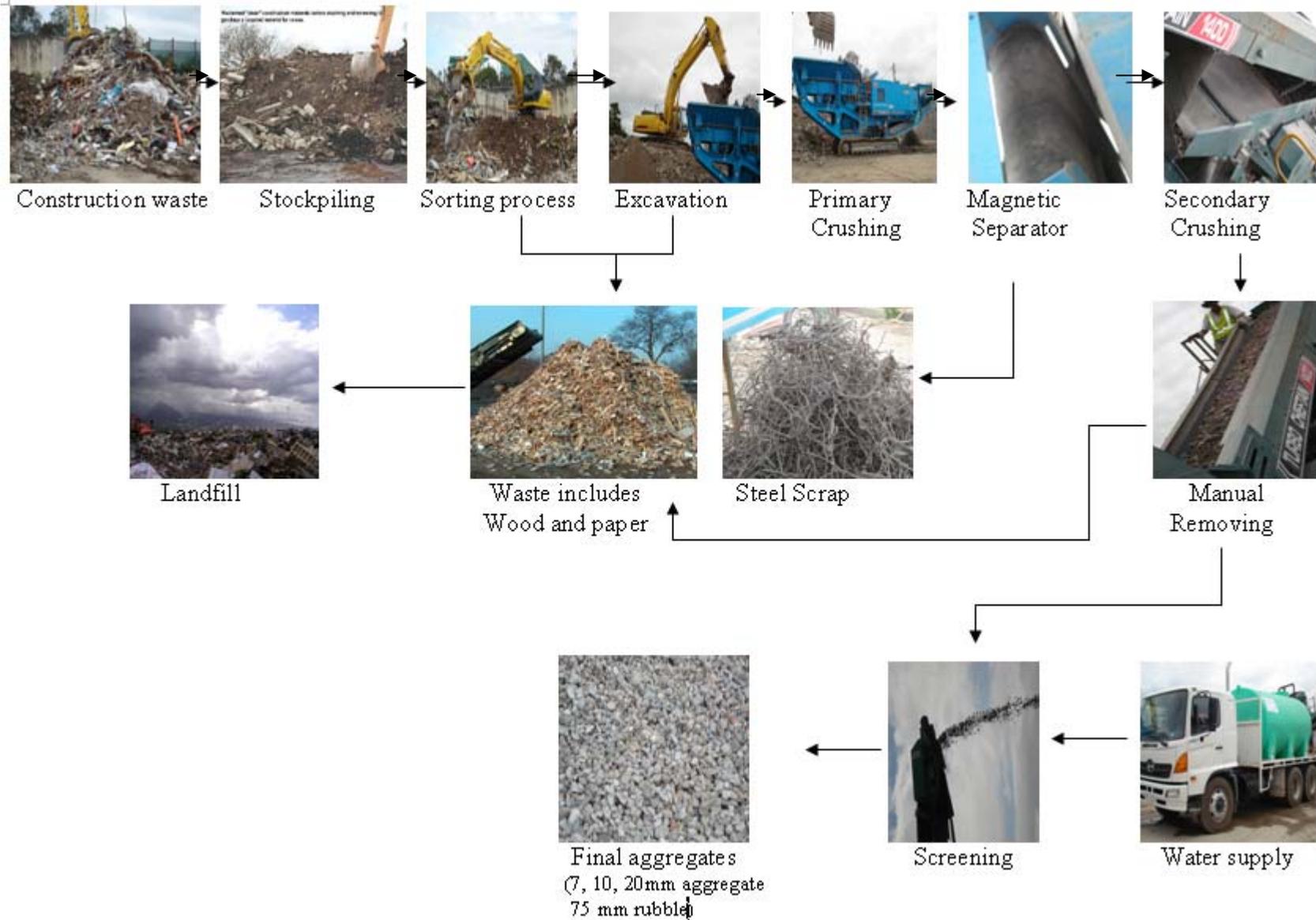


Figure 2: Flow chart of the concrete recycling method