The Cement Sustainability Initiative

Recycling Concrete

World Business Council for Sustainable Development

Contents

Executive summary

Concrete is everywhere. It is the second most consumed material after water and it shapes our built environment. Homes, schools, hospitals, offices, roads and runways all make use of concrete. Concrete is extremely durable and can last for hundreds of years in many applications. However, human needs change and waste is generated – more than 900 million tonnes per annum in Europe, the US and Japan alone, with unknown quantities elsewhere. Concrete recovery is achievable – concrete can be crushed and reused as aggregate in new projects.

As part of the Cement Sustainability Initiative (CSI), the cement industry has been looking at recycling concrete as a component of better business practice for sustainable development. This report provides some background on the current state of play worldwide. In some countries a near full recovery of concrete is achieved. However, in many parts of the world the potential to recover concrete is overlooked and it ends up as unnecessary waste in landfill. Further, concrete waste statistics are difficult to come by, which is partly explained by the relatively low hazard that the waste poses compared with some other materials, as well as low public concern. Even though concrete is a relatively harmless waste, the cement industry encourages initiatives to recover this resource and minimize waste.

Recycling or recovering concrete has two main advantages: (1) it reduces the use of new virgin aggregate and the associated environmental costs of exploitation and transportation and (2) it reduces unnecessary landfill of valuable materials that can be recovered and redeployed. There is, however, no appreciable impact on reducing the carbon footprint (apart from emissions reductions from transportation that can sometimes be achieved). The main source of carbon emissions in concrete is in cement production (the cement is then added to aggregates to make concrete). The cement content in concrete cannot be viably separated and reused or recycled into new cement and thus carbon reductions cannot be achieved by recycling concrete.

In all initiatives to recover concrete, a full life cycle analysis is needed. Often the drive is to achieve complete recycling; however, the overall impact and best use of the materials should always be considered. Refining the recovery may result in high-grade product but at an environmental processing cost. At present, most recovered concrete is used for road sub-base and civil engineering projects. From a sustainability viewpoint, these relatively low-grade uses currently provide the optimal outcome.

The main objective of this report is to promote concrete recycling as an issue and encourage thinking in this area. It provides some discussion of key issues without going into significant technical details. The report ultimately promotes a goal of "zero landfill" of concrete. However, it needs to be noted that cement producers can only have an indirect role in supporting this goal. With good initial planning and design, well considered renovation and managed demolition, sustainable development using concrete is achievable. The report recommends that all players adopt sustainable thinking when it comes to concrete. It also recommends a series of key indicators. There is a lack of reliable and consistent statistics. Improved reporting coupled with clear objectives will ultimately lead to improved performance and less concrete in landfills.

Concrete recovery fast facts

- Concrete is a durable building material that is also recoverable.

- It is estimated that roughly 25 billion tonnes of concrete are manufactured globally each year. This means over 1.7 billion truck loads each year, or about 6.4 million truck loads a day, or over 3.8 tonnes per person in the world each year.

- Twice as much concrete is used in construction around the world than the total of all other building materials, including wood, steel, plastic and aluminum.[1]

- About 1,300 million tonnes of waste are generated in Europe each year, of which about 40%, or 510 million tonnes, is construction and demolition waste (C&DW). The US produces about 325 million tonnes of C&DW, and Japan about 77 million tonnes. Given that China and India are now producing and using over 50% of the world's concrete,[2] their waste generation will also be significant as development continues.

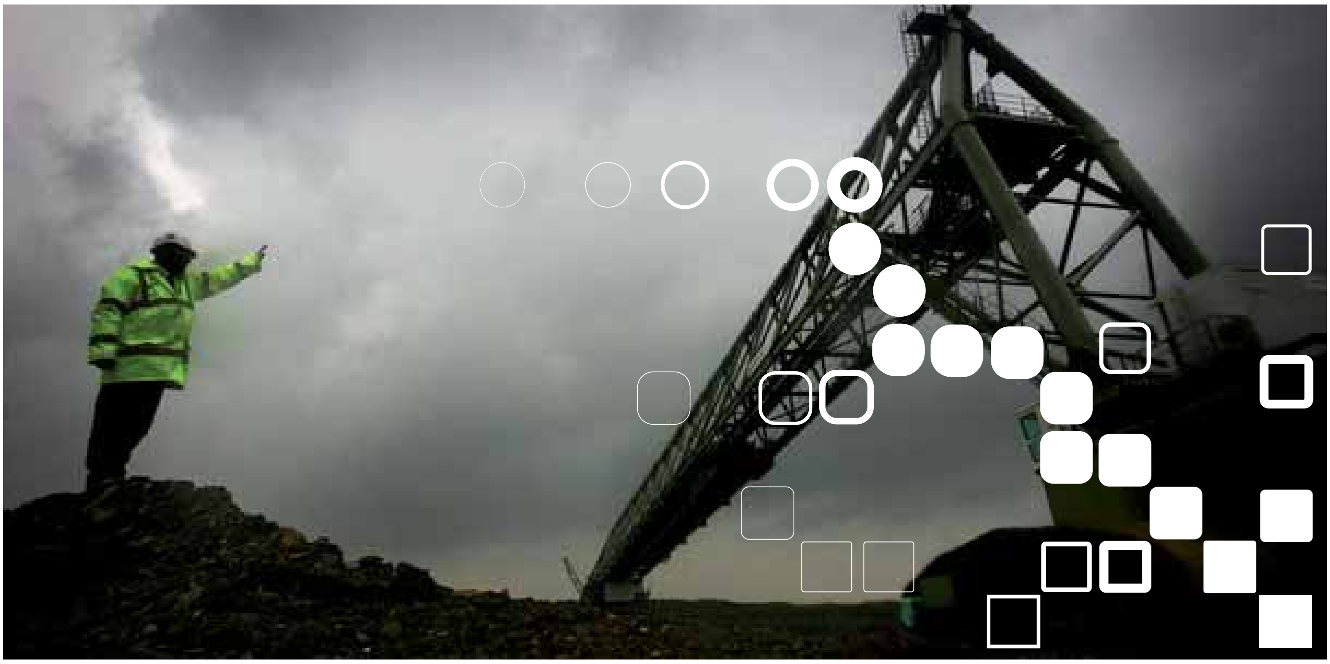
- Many countries have recycling schemes for C&DW concrete and very high levels of recovery are achieved in countries such as the Netherlands, Japan, Belgium and Germany. In some countries waste concrete is typically put in landfill. Variations in calculation methods and availability of data make cross-country comparison difficult at the present time.

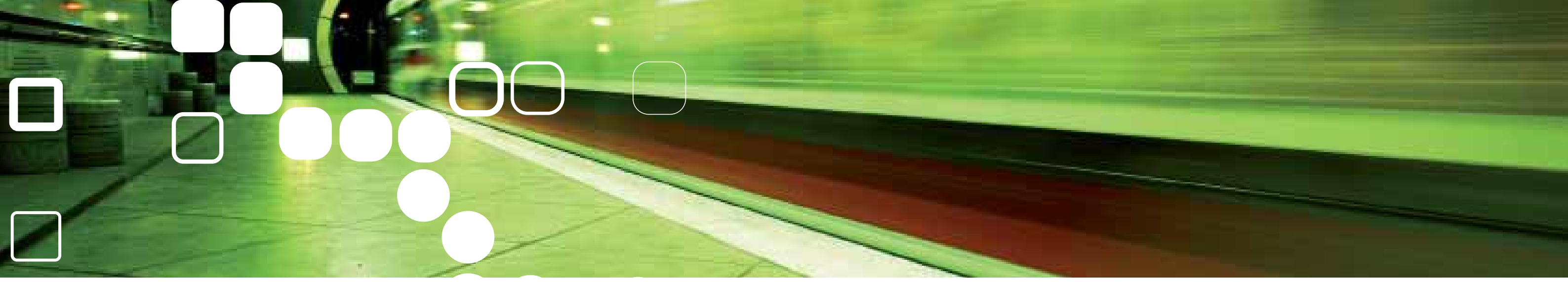
- Recovered concrete from C&DW can be crushed and used as aggregate. Road sub-base is the predominant use. It can also be used in new concrete.

- Returned concrete (fresh, wet concrete that is returned to the ready mix plant as surplus) can also be successfully recycled. Recovery facilities to reuse the materials exist on many production sites in the developed world. Over 125 million tonnes are generated each year.

- Recycling concrete reduces natural resource exploitation and associated transportation costs, and reduces waste landfill. However, it has little impact on reducing greenhouse gas emissions as most emissions occur when cement is made, and cement alone cannot be recycled.

- Green building schemes acknowledge C&DW recovery and encourage the use of recycled materials including recycled concrete.





Introduction

Why are we producing this report?

Cement companies take an active interest in sustainable development. One aspect is the recycling potential of concrete, the main downstream product for cement. This report is produced by the Cement Sustainability Initiative (CSI) –18 leading cement companies working together toward greater sustainability, under the auspices of the World Business Council for Sustainable Development (WBCSD).

The CSI aims to promote a positive perception that concrete is recyclable and is being recycled. This is regarded as general knowledge within the cement, concrete and construction industry, at least in some countries. However, the vast variations in recovery rates worldwide indicate that more work needs to be done to spread this message.

This report is the first time cement companies have compiled information and data at an international level about the recovery of the main downstream use of cement–concrete. The report draws on the knowledge and experience of CSI members and information that the task force was able to gather during the course of the project, particularly from their subsidiaries in the concrete and aggregates industries. The CSI also included a stakeholder consultation process whereby over 440 individuals from key stakeholder groups were invited to comment via an online process on a draft of this report. Detailed responses were received from about 40 participants and their input has been included.

This report is intended for people and bodies with an interest in concrete recycling, including local government authorities, regulators on waste recycling and landfill, cement and concrete trade associations, environmental bodies, architects, green building professionals and non-governmental organizations. A key audience is potential promoters and users of recycled concrete.

What is this report about and why recycle concrete?

This report provides a general overview and an international summary of current practice with respect to concrete recycling and encourages optimization of concrete recycling within an overall sustainable development strategy.

It also highlights the lack of standardized worldwide statistics and recommends indicators for concrete recycling. It is intended as a document to encourage concrete recycling discussion by all relevant stakeholders.

Concrete is an excellent material with which to make long-lasting and energy-efficient buildings. However, even with good design, human needs change and potential waste will be generated.

Concrete has fairly unique properties and its recovery often falls between standard definitions of reuse and recycle. Concrete is rarely able to be “reused” in the sense of being reused in its original whole form. Nor is it “recycled” back into its original input materials. Rather, concrete is broken down into smaller blocks or aggregate for use in a new life. In this report “recycled concrete” refers to concrete that has been diverted from waste streams and reused or recovered for use in a new product.

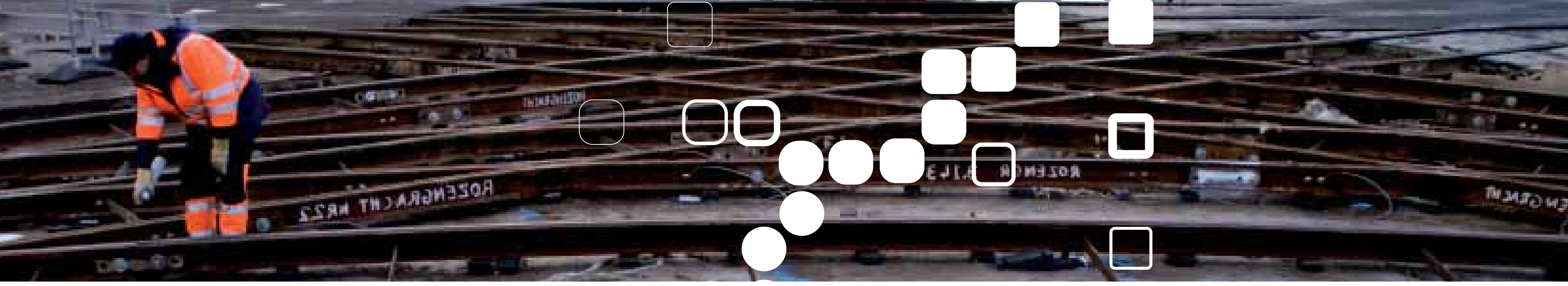
Concrete recycling is a well established industry in many countries and most concrete can be crushed and reused as aggregate. Existing technology for recycling by means of mechanical crushing is readily available and relatively inexpensive. It can be done in both developed and developing countries. With further research and development, the scope of applications for recycled aggregate can be increased. However, even with existing technology, considerable increases in recovery rates can be achieved in some countries with greater public acceptance of recycled aggregate and reduction of misconceptions or ignorance about its possibilities for use.

Some key benefits of recycling concrete include:

- Reduction of waste, landfill or dumping and associated site degradation
- Substitution for virgin resources and reduction in associated environmental costs of natural resource exploitation
- Reduced transportation costs: concrete can often be recycled on demolition or construction sites or close to urban areas where it will be reused
- Reduced disposal costs as landfill taxes and tip fees can be avoided
- Good performance for some applications due to good compaction and density properties (for example, as road sub-base)
- In some instances, employment opportunities arise in the recycling industry that would not otherwise exist in other sectors.

A note on the information in this report

The CSI has collected and included information that was available at the time of publication. References have been included where available. Anecdotal information has also been included from general knowledge from the industry when considered sufficiently reliable.



Some myths and truths about concrete recycling

Myths	Reality
• **Concrete cannot be recycled**	Although concrete is not broken down into its constituent parts, it can be recovered and crushed for reuse as aggregate (for use in ready-mix concrete or other applications) or it can be recycled through the cement manufacturing process in controlled amounts, either as an alternative raw material to produce clinker or as an additional component when grinding clinker, gypsum and other additives to cement.
• **Recycled concrete aggregate cannot be used for structural concrete**	It is generally accepted that about 20% (or more) of aggregate content can be replaced by recycled concrete for structural applications.
• **Although some concrete can be recycled it is not possible to achieve high rates**	Countries such as the Netherlands and Japan achieve near complete recovery of waste concrete.
• **Concrete can be 100% made by recycling old concrete**	Current technology means that recovered concrete can be used as aggregate in new concrete but (1) new cement is always needed and (2) in most applications only a portion of recycled aggregate content can be used (regulations often limit content as do physical properties, particularly for structural concrete).
• **Recycling concrete will reduce greenhouse gases and the carbon footprint**	Most greenhouse gas emissions from concrete production occur during the production of cement. Less-significant savings may be made if transportation needs for aggregates can be reduced by recycling.
• **Recycling concrete into low-grade aggregate is down-cycling and is environmentally not the best solution**	A full lifecycle assessment should be undertaken. Sometimes low-grade use is the most sustainable solution as it diverts other resources from the project and uses minimal energy in processing. That is not to say more refined uses might not also suit a situation.
• **Recycled aggregate is more expensive**	This depends on local conditions (including transportation costs).

Truths	Rationale
• **Cement cannot be recycled**	Once cement clinker is made, the process is irreversible. No commercially viable processes exist to recycle cement.
• **Demolition concrete is inert**	Compared to other wastes, concrete is relatively inert and does not usually require special treatment.
• **Recycled concrete can be better than virgin aggregates for some applications**	The physical properties of coarse aggregates made from crushed demolition concrete make it the preferred material for applications such as road base and sub-base. This is because recycled aggregates often have better compaction properties and require less cement for sub-base uses. Furthermore, it is generally cheaper to obtain than virgin material.
• **Using recycled aggregate reduces land-use impact**	By using recycled aggregates in place of virgin materials (1) less landfill is generated and (2) fewer natural resources are extracted.
• **Recycling all construction and demolition waste (C&DW) will not meet market needs for aggregate**	Even near complete recovery of concrete from C&DW will only supply about 20% of total aggregate needs in the developed world.
• **Figures are not complete for recovery rates**	Data are often not available. When data are available different methods of counting make cross-country comparisons difficult.

Concrete – What is it made of and how much is there?

Concrete is the second most consumed material after water and is the basis for the urban environment. It can be roughly estimated that in 2006 between 21 and 31 billion tonnes of concrete (containing 2.54 billion tonnes of cement)[3] were consumed globally compared to less than 2 to 2.5 billion tonnes of concrete in 1950 (200 million tonnes of cement).[4]

Concrete is made from coarse aggregate (stone and gravel), fine aggregate (sand), cement and water.[5] Primary materials can be replaced by aggregates made from recycled concrete. Fly ash, slag and silica fume can be used as cementious materials reducing the cement content. These materials can be added as a last step in cement production or when the concrete is made.

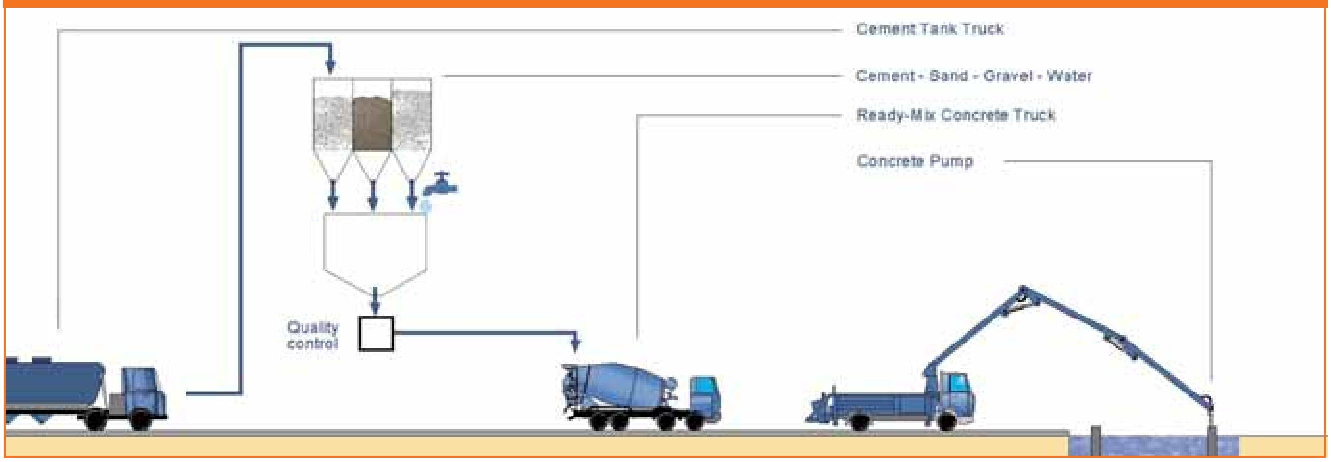
In the developed world most cement is made industrially into concrete and sold as ready-mix concrete. On a smaller scale, and more commonly in developing countries, concrete is made in situ on the construction site by individual users.

Concrete can be recycled from:

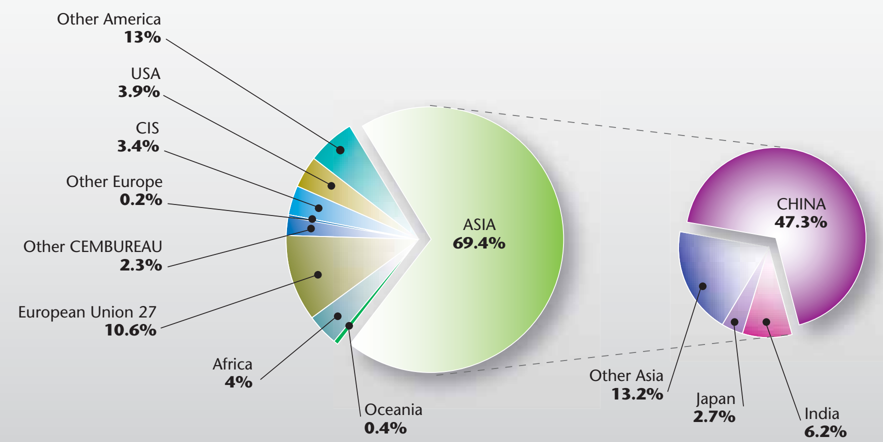
- **Returned concrete which is fresh (wet) from ready-mix trucks**
- **Production waste at a pre-cast production facility** [6]
- **Waste from construction and demolition.**

The most significant source is demolition waste.

Making concrete



2006 World Cement Production by Region: 2.54 billion tonnes



** Regional breakdown of cement production is similar to that of concrete production.*

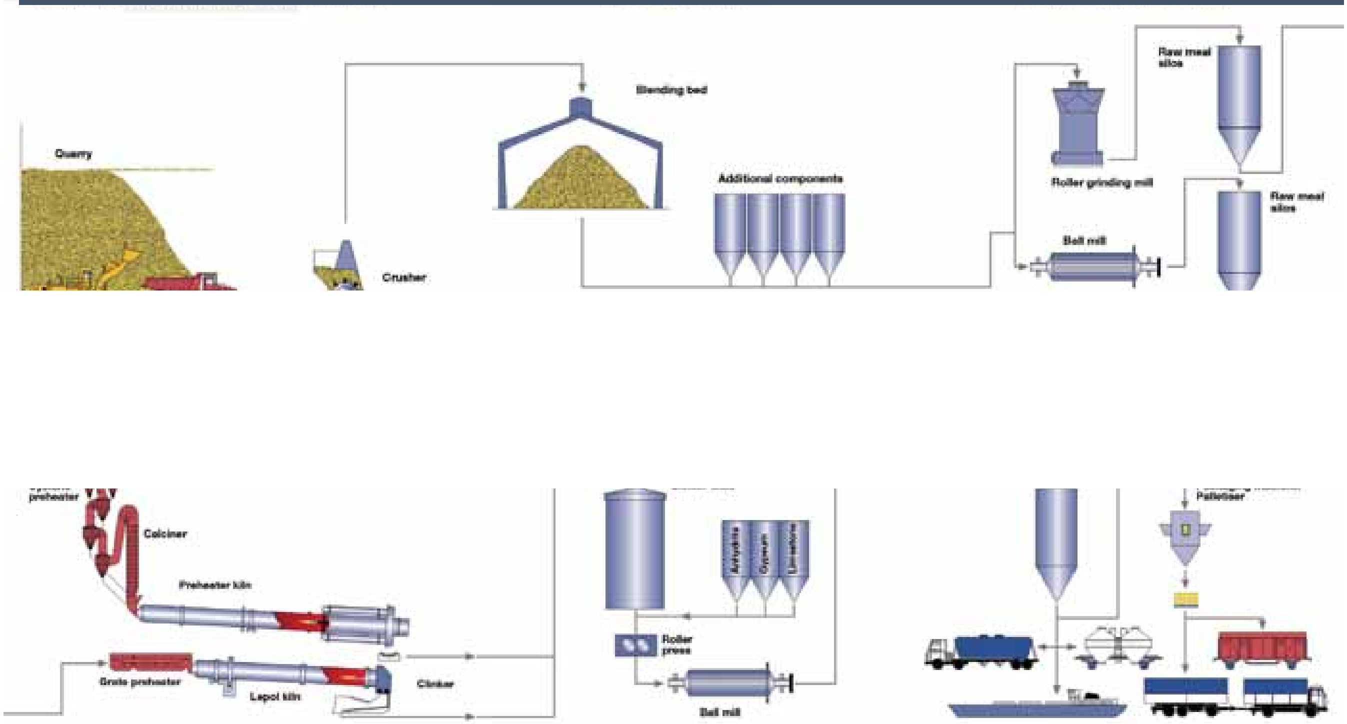
Cement – What is it and can it be recycled?

About 5% to 20% of concrete is made up of cement. Cement is made by crushing and blending limestone and clay (materials that contain oxides of calcium, silicon, aluminum and iron). The blend is then heated to about 1,500°C in a kiln and cement hydraulic materials, called clinker, are formed. Once the clinker is made, the materials are irreversibly bound. The clinker is then cooled and ground with a small proportion of gypsum and other additives to produce a dry powder – cement. Depending on the intended use, the ingredients in cement are varied in different products to improve properties such as strength, setting time, workability, durability and color. Cement production also uses recycled content such as slag and fly ash.

The most well-known form of cement is Portland cement, but many different types of cement with varying properties also exist. Special cements with custom properties are marketed for projects such as marine environments, dam construction and designer building projects. About 95% of all cement manufactured is used to make various kinds of concrete. The other uses for cement are mainly in soil stabilization and sludge pH stabilization.

Once concrete has been mixed, cement cannot be extracted from it for recycling. However, post-use or waste concrete can be recycled through the cement manufacturing process in controlled amounts, either as an alternative raw material to produce clinker or as an additional component when grinding clinker, gypsum and other additives to cement.

Producing cement



What is the world doing to recover concrete?

Some examples of what is happening around the world include:

38 states in the US use recycled concrete aggregate for road sub-base and 11 recycle it into new concrete.

The Netherlands is an example of where landfill of concrete waste is banned. All concrete is recycled except for some residual process waste.

Brazil has some recycling facilities (mainly in Sao Paulo and Belo Horizonte). Recycled aggregate is used mainly for road sub-base. Legislation exists promoting C&DW management.

In Finland strong legislation and enforcement means that all recyclable material from a demolition site must be recycled.

Chinese Taipei is seeing increasing interest in concrete recovery and it is estimated that about 90% of C&DW is recovered, with a rate of 95% for concrete.

Kosovo had 10 million tonnes of building debris following the end of hostilities. A project was established to produce and promote recycled aggregate for the rebuilding effort.

Belgian expertise has been applied in Pakistani Kashmir following the 2005 earthquake to promote reuse and recycling of building debris

Japan has near complete recovery of concrete from C&DW. Almost all is used for road sub-base.

Qatar and UAE have developing recycling programs to produce aggregate. The cost of virgin aggregates drives the process in Qatar. In the UAE, environmental concerns and government restrictions on waste are the main drivers.

Thailand uses some returned concrete in pre-cast concrete products for community projects. Further efforts are needed to divert C&DW concrete from landfill.

In Australia projects have been undertaken using recycled concrete in new concrete products, however, the industry view is that currently low-grade applications achieve better overall environmental outcomes.

South Africa has a small market in Cape Town for recycled aggregates. Limited information has been found to date to indicate any widespread recovery of C&DW or waste concrete in Africa.

Developing Countries and Rural Areas: Although many of the same issues are relevant for the entire world, countries in transition and developing regions have some unique issues. In newly developed regions, less concrete may be available for recycling. Conversely, in areas undergoing reconstruction following war, significant unsorted demolition waste will exist. In both situations the environmental impact of recycling methods requires even greater scrutiny as the countries may have fewer resources and infrastructure available, and possibly less knowledge, for low-impact processing. In areas of large geographical size and low populations, recycling infrastructure is often much less feasible.

How much waste is there?

As the most widely used manmade material, concrete makes up a considerable portion of the world's waste. Despite its long life, changing human requirements mean that there will always be a limited lifetime for initial use. Global data on waste generation are not currently available. Many countries do make construction and demolition waste (C&DW)* estimates, a significant proportion of which is attributable to concrete (along with asphalt, wood and steel and other products in smaller quantities). There are vast regional differences due to construction traditions, and the concrete content of C&DW can be anywhere between 20% to 80%.

Amount of waste (Mt)	Europe	USA	Japan
Construction and demolition waste (C&DW)	510[7]	317[8]	77[9]
Municipal waste	241[10]	228[11]	53[12]

MT = Million tonnes

Estimates for major regions include (in millions of metric tonnes):

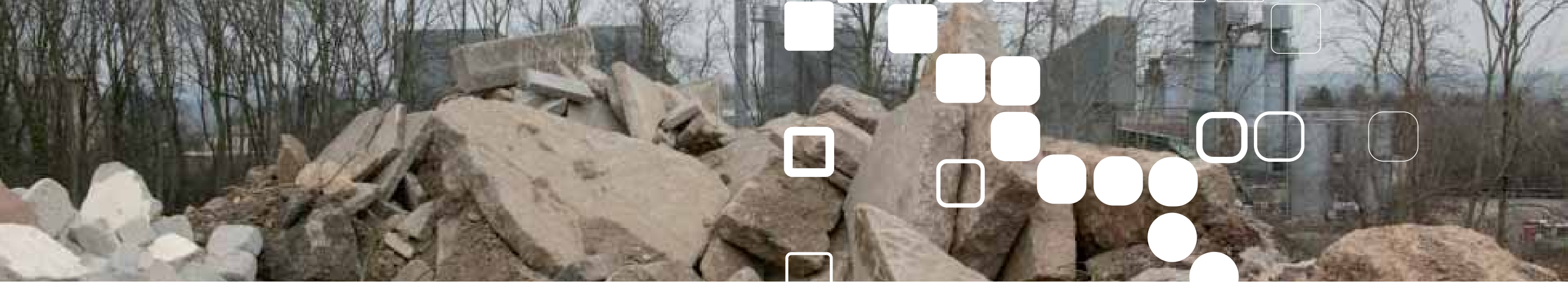
For the most part, C&DW is recoverable waste that can be recycled and reused for economic and environmental benefit.

How much is being recovered and since when?

Collection of recovery rate data is of more recent interest with growing concern regarding sustainable development and related indicators. That said, recycling concrete and C&DW is not new and has always been an element within construction due to the inert nature of concrete and the relative ease with which it can be processed into aggregate. Since early Roman times construction materials have been recycled and reused. In Europe large amounts of rubble after the Second World War were available for reuse in difficult economic times when infrastructure for exploitation and recovery of new materials was often restricted. Research began in the 1940s on the properties of recycled aggregate.[13] The 1973 oil crisis prompted research into the use of recycled aggregate in Japan by the Building Contractors Society and the Ministry of Construction.[14]

Current data on recovery rates are hard to find to piece together a global picture. Data collection is not systematic beyond general data of C&DW generation and even that is not always available for all regions. Even when data is available, the definitions used vary. In general, recovery rates refer to waste that is diverted from landfill. For C&DW recovery data, some countries include excavated soil whereas others do not consider this within the definition of recovery. Also, reuse on site is often overlooked (and contributes greatly to actual recovery amounts). The CSI has also noticed that some countries exclude civil engineering projects (roads and bridges) from building construction statistics.

** The CSI has chosen to use the term C&DW as this is in widespread usage. It should be noted that most of the waste generated is demolition waste rather than construction waste.*



Recovery data

Available data on concrete recovery is produced in the following table. However, different definitions and measurement methods make comparison often illusory as discussed previously. The CSI recommends that this data be used as a stepping stone to encourage dialogue for uniform reporting of C&DW generation and recovery rates. Many countries are not listed below, particularly developing and emerging economies, as data was not available to the CSI. It is recommended that data be made publicly available in as many countries as possible.

Furthermore, the CSI encourages efforts to improve recovery rates but recognizes that the hurdles for high recovery differ by region. For example, large, less-populated countries can be expected to have lower achievable recovery rates.

Country	Total C&DW (Mt)	Total C&DW Recovery (Mt)	% C&DW Recovery
Australia[15]	14	8	57
Belgium[16]	14	12	86
Canada[17]	N/A	8 (recycled concrete)	N/A
Czech Republic[18]	9 (incl. 3 of concrete)	1 (recycled concrete)	45 (concrete)
England[19]	90	46	50 – 90
France[20]	309	195	63
Germany[21]	201	179	89
Ireland[22]	17	13	80
Japan[23]	77	62	80
Netherlands[24]	26	25	95
Norway[25]	N/A	N/A	50 – 70
Portugal	4	Minimal	Minimal
Spain[26]	39	4	10
Switzerland[27]	7 (incl. 2 of concrete)	2	Near 100
Taiwan[28]	63	58	91
Thailand[29]	10	N/A	N/A
US[30]	317 (incl. 155 of concrete)	127 (recycled concrete)	82

Germany – an example of the facts behind the figures

In 2004 Germany produced a total of 201 million tonnes of C&DW, of which 89% was recycled. Soil excavation is included in the figures. This can be broken down as follows.

Type of C&DW	Amount created (2004) (Mt)	% Reused or Recycled
Soil excavation	**128**	**88**
Construction and building site waste	**51**	**91**
Road works	**20**	**99**
Other	**2**	**~25**

MT = Million tonnes

Source: Construction Industry Monitoring report (2007) by the Arbeitsgemeinschaft Kreislaufwirtschaftsträger Bau (ARGE KWTB). www.arge-kwtb.de

Sustainable development principles, life cycle thinking and recycling concrete

Recycling concrete is not an end in itself. An assessment of the overall sustainable development benefits of recycling concrete is needed. It is useful to place concrete in the context of the environmental impact of other materials. Concrete has a high environmental impact with respect to its input materials, namely in the cement production phase. Transportation and delivery at all stages of production is the second greatest source of impact.[31] It is, however, extremely durable and can bring many environmental advantages during the use phase.

Factors to consider when comparing recycled aggregate to virgin aggregate or other building materials include:

- **Transportation costs** including fuel usage and CO_2 emissions
  - C&DW is often already located in an urban area close to or on the construction site whereas virgin materials are often sourced from more distant quarries and natural areas. Conversely, transportation costs may sometimes increase when using recycled aggregate as it may not always be feasible to process aggregate on-site.
- **Noise, air and water pollution and the energy needs** of the processing systems to recover the concrete or use natural materials
  - Systems for different materials can be compared
  - Producing coarse aggregate will have less impact than further refining; however, future use of the aggregate has to be considered.
- **Land Use Impact** – Using recycled aggregate means
  - Less waste goes to landfill
  - Less land is disturbed as virgin alternatives can be conserved.
- **Environmental impacts during the use phase**
  - Recycled aggregate has similar properties to regular virgin concrete. As such there is usually less difference in impact from this perspective during the use phase. Compared with other building materials, the thermal mass of concrete means that energy savings can usually be made during the operation of a building built with concrete as less energy is needed for heating and cooling than for many other materials.
- **Useful life expectations**
  - The durability of concrete and recycled concrete means that its long useful life can be a sustainability benefit compared with other materials.

Recycling concrete – CO_2 neutral

Much sustainable development discussion focuses on reducing greenhouse gas emissions. However, as already discussed, recycling concrete creates few opportunities to reduce carbon emissions. Greenhouse gas emissions reductions can be made when a high carbon footprint material or process is substituted for a lower one. Recycling concrete into aggregate tends not to produce any such savings as compared to using natural aggregate except in so far as transportation requirements can be reduced. Research indicates that over long periods concrete, particularly crushed concrete can carbonate and as such reabsorb CO_2. However, there is no real practical data at this point and estimations and research are still fairly nascent.[32] Cement manufacture is the target area for carbon emissions reduction efforts as it is the stage of production where the most greenhouse gas impact occurs. Significant steps have been made by the industry as a whole in recent years.[33]


Comparative tools

Life cycle assessments (LCA) are used to consider and compare the environmental impacts of a range of materials and products. An LCA can be useful to determine the best use for C&DW and concrete waste in a given situation. However, LCAs can produce an overwhelming number of figures, and decisions are needed to balance the relative advantages and disadvantages of choices.

Case study

When the Edens Expressway was built in Chicago in the early 1950s, a study was undertaken to compare the outcome if about 300,000 tonnes of C&DW (mainly concrete) was recycled. In this case, significant energy reductions were found. Recycling was also considered the best alternative to allow the time schedule to be met.[34]

Saving energy in road construction by recycling C&DW

Without recycling		With recycling of C&DW	
350,000 t C&DW to landfill	350,000 t primary material	52,500 t to landfill	52,500 t primary material 297,500 t secondary materials
7,900 trips to landfill + 7,900 return trips to site	7,900 trips to quarry + 7,900 return trips to site	1,200 trips to landfill + 1,250 return trips to site	1,200 trips to quarry + 1,200 return trips to site
Transport		**Transport**	
1.64×10^{11} MJ	1.97×10^{11} MJ	0.249×10^{11} MJ	0.805×10^{11} MJ
Energy consumption for demolition		**Energy consumption for demolition and treatment**	
	0.0132×10^{11} MJ		$(0.0132 + 0.0008) \times 10^{11}$ MJ
Energy consumption without recycling :	**3.61×10^{11} MJ (100%)**	**Energy consumption with recycling :**	**0.818×10^{11} MJ (22.6%)**

Source: Pavement 154, 1989, Recycling of Portland Cement Concrete

Basic Assumptions :
- Recovery rate: 85%
- Payload of truck: 44 tonnes
- Energy consumption for transport of material: 1.22 MJ per ton and km
- Energy consumption for CDW treatment: 285 MJ per ton
- Energy consumption for demolition: 92 MJ per ton

Concrete in context – Recycling comparisons

Recycling comparisons can be useful in promoting recycling. An analysis of different recycling rates can highlight the benefits and barriers of recycling one product as compared to another. In the case of concrete, the recycling rates have tended to be lower than that of other construction materials in some countries. In other cases, high recycling rates of concrete have tended to be overlooked by the wider public. Economic incentives and ease of recovery have been key drivers for recycling of some materials, such as steel and aluminum. Environmental impacts supported by public interest and accompanying laws and regulation have also driven recovery of items such as tires and PET bottles. With generally abundant supplies of virgin aggregate, the inert nature of the waste and the relatively more limited environmental benefits, concrete recycling has not been a high priority. Also, concrete is often wrongly perceived as not being readily recoverable. As noted in this report, the long life of concrete and energy advantages in its use should also be recognized, as recycling is but one component of sustainable development.

A comparison of industry recycling rates can be interesting as it can help show sustainable development practices. However, comparisons must be made in context. While high recycling rates are "good", a higher rate when comparing one material to another does not necessarily mean that one material is "greener" than another due solely to the recycling rate. Factors to bear in mind include:

- Different recycling rate definitions
- The initial life of the material
- The resource impact of production of the virgin material vis-à-vis recycling.

Some reported figures for selected items are:

Material	Recycling rate Europe (%)[35]	Recycling rate US (%)	Recycling rate Japan (%)
Concrete/C&DW	30[36]	82[37]	80[38]
Aluminum beverage cans	58[39]	52[40]	93[41]
Aluminum in buildings	96[42]	Not available	80[43]
Glass containers	61[44]	22[45]	90[46]
Lead acid batteries	95[47]	99[48]	99[49]
Paper/cardboard	63[50]	56[51]	66[52]
PET bottles	39[53]	24[54]	66[55]
Tires	84[56]	86[57]	85[58]
Steel containers	66[59]	63[60]	88[61]
Wood	16 (UK)[62]	low	

Economic benefits of using recycled concrete

In addition to the environmental benefits, using recycled concrete can also be economical, depending on the situation and local conditions. Factors include:

1. **Proximity and quantity of available natural aggregates**
2. **Reliability of supply, quality and quantity of C&DW (availability of materials and capacity of recycling facility)**
3. **Public perceptions regarding the quality of recycled products**
4. **Government procurement incentives**
5. **Standards and regulations requiring different treatment for recycled aggregate compared to primary material**
6. **Taxes and levies on natural aggregates and on landfill**

The cost of sending waste to landfill can often be greater than the cost of sorting and selling concrete waste from a construction site to a recycler (or even paying a fee for collection), particularly when landfill fees exist. The cost of using demolition materials in a new construction on the same site can also be less than that of new materials. Depending on the recycling methods used, particularly the extent to which materials need to be sorted and other materials removed, the costs of recycling machinery and processing may increase.

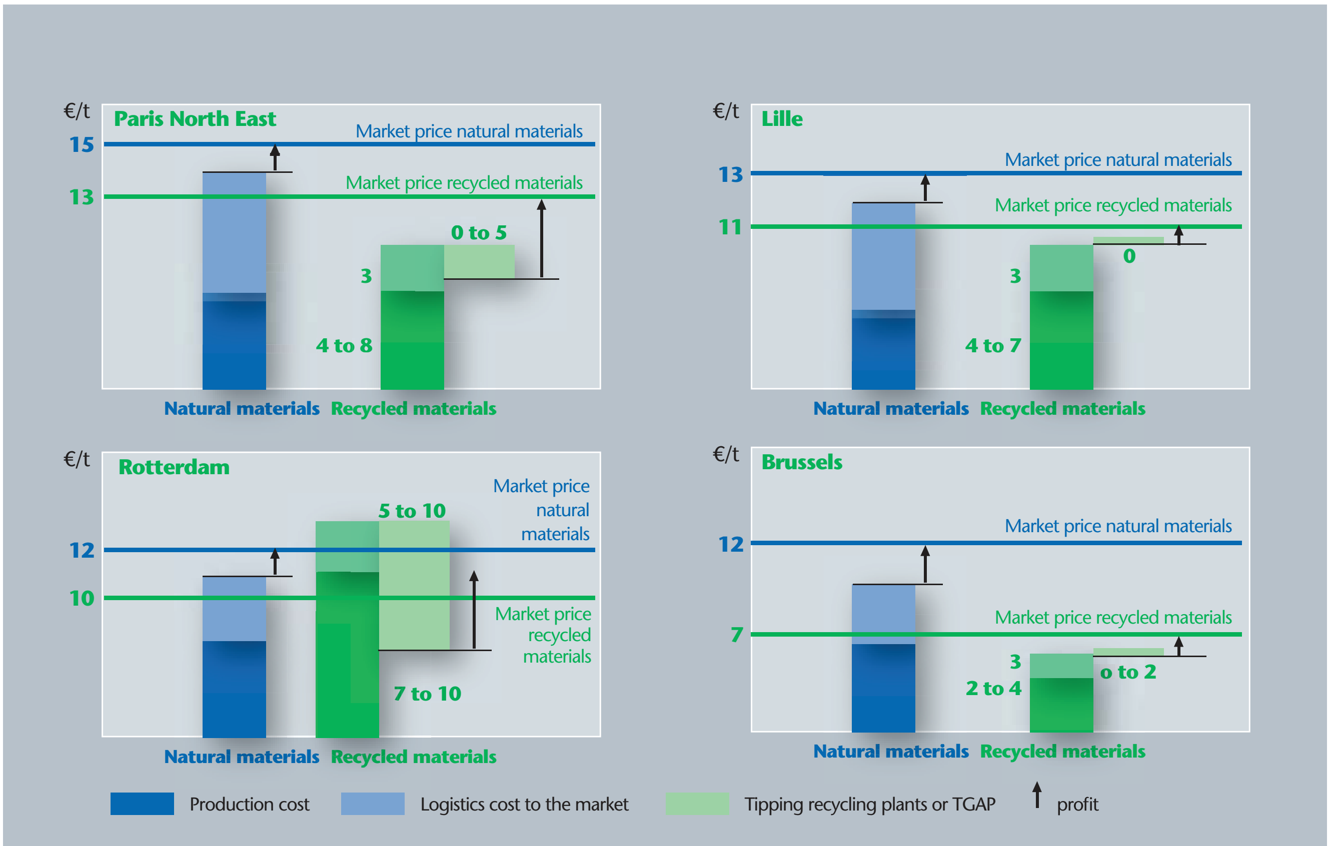
Some US states have estimated savings of up to 50% to 60% from using recycled aggregate compared to new aggregate.[63] Recycling is less costly than disposal in Germany, Holland and Denmark.[64] In countries without recycling infrastructure and abundant natural resources recycling can be more expensive.

Some examples of cost savings include:

- Almost 700,000 tonnes of aggregate was re-used on location in a freeway project in Anaheim, California. A portable crusher was used to recycle the old asphalt and concrete. An additional 100,000 tonnes of recycled aggregate base material was brought to the job to complete the project. Using the recycled aggregate saved around US$ 5 million over purchasing and hauling virgin aggregate, and paying to haul and dispose of existing aggregates.[65]
- AU$ 4 million savings were achieved on the Western Link Road construction project in Melbourne, Australia by sorting and diverting waste concrete, rock, asphalt, steel and timber from landfill. Over 15,000 m^3 of concrete was diverted.[66]
- The Holdfast Shores Development Project in Australia, consisting of a marina and residential, commercial and entertainment complex, conducted a waste audit. The procedure of waste sorting and establishing separate concrete bins (which were then bought by a concrete reclaimer for road base) resulted in a 29% decrease in the cost of waste bin disposal fees. It cost AU$ 186 on average to dispose of a general waste bin compared with AU$ 132 for a concrete-only bin. Some concrete was also used in the offshore reef as part of the marina development.[67]
- Recycled aggregates were used in a retail development in Port Glasgow, United Kingdom resulting in a £264,000 (or ~4%) cost reduction.[68]
- A plan to demolish the Aarhus Gasworks in Denmark estimates that the recycling of the C&DW will reduce waste management costs by up to 90%.[69]

Profit margins on using recovered concrete – Concrete recovery can help the bottom line

Industry studies in Europe have shown a variation in the comparable profit margin as is illustrated in the following example. In Paris, a lack of natural aggregates makes recycled aggregate an attractive alternative, and the recycling market there is driven mainly by civil works companies with vertical integration of recycling outfits. Similarly, in Rotterdam the profit margin for recycled aggregate is high but in this case it is due more to the selling price and despite higher production costs for recycled materials compared to virgin materials. In Brussels the lack of dumping possibilities means that construction and demolition companies drop the market price to find solutions for the waste, while in Lille the abundance of quarries make the higher production costs a limiting factor.



Source: UEPG, Aggregates from construction and demolition waste in Europe. 2006.

Industry studies have shown that in Europe recycled concrete aggregate can sell for 3 to 12 € per tonne with a production cost of 2.5 to 10 € per tonne. The higher selling price is obtained on sites where all C&DW is reclaimed and maximum sorting is achieved, there is strong consumer demand, lack of natural alternatives and supportive regulatory regimes.

How can recycled concrete be used?

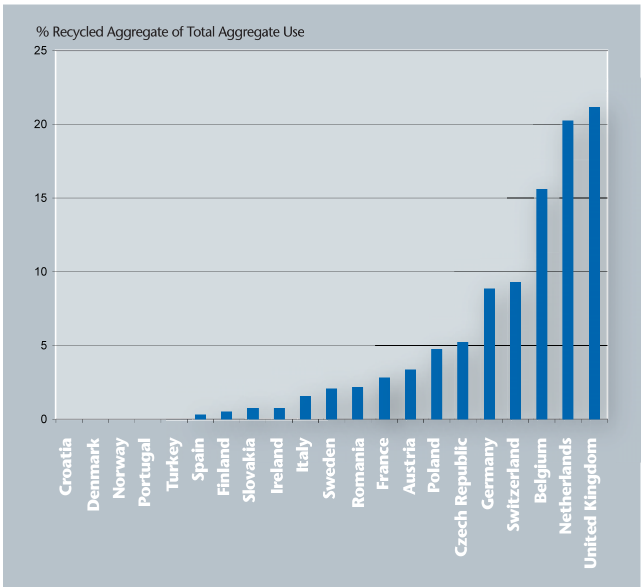
- **As aggregate (coarse and fine)**
- **As blocks in original or cut-down form**

"Recycled aggregate" is used in this report to mean aggregate made from old concrete.

Use as aggregate

Most recycled concrete is used as aggregate in road sub-base, and most commonly in unbound form. The quality of aggregate produced depends on the quality of the original material and the degree of processing and sorting. Contamination with other materials also affects quality. More refined aggregate may produce a product of higher value use but may also have a greater environmental impact in production. When well cleaned, the quality of recycled coarse aggregate is generally comparable to virgin aggregate and the possibilities for use are equally comparable although some limitations as to strength may exist. Material containing plasterboard can have more limited applications.

Recycled aggregate accounts for 6% to 8% of aggregate use in Europe, with significant differences between countries.[70] The greatest users are the United Kingdom, the Netherlands, Belgium, Switzerland and Germany. It was estimated in 2000 that ~5% of aggregate in the US was recycled aggregate.[71]



Source: UEPG 2005 and 2006 statistics published 2008[72]

1. As coarse aggregate

For road base, sub-base and civil engineering applications

Use for road base, pavement and sub-base is widespread and the most common use. In the US its use and acceptance has been promoted by the Federal Highway Administration, which has adopted a pro-use policy and undertaken research in the area. Finnish research has found that recycled concrete specified to an agreed quality and composition in the sub-base and base layers can allow the thickness of these layers to be reduced due to the good bearing properties of the material.[73] When used as a base and sub-base the unbound cementitious material in recycled aggregate has been found to have a bonding that is superior to that from fines in virgin aggregate such that the strength is improved providing a very good construction base for new pavements.[74] It can also be used bound in asphalt mixtures.[75] Various civil engineering projects can also make use of coarse aggregate.

For concrete

A common misperception is that recycled concrete aggregate should not be used in structural concrete. Guidelines and regulations often consider the physical limitations of recycled concrete aggregate, but ideally they should also promote its use. A study by the National Ready Mixed Concrete Association (NRMCA) in the US has concluded that up to 10% recycled concrete aggregate is suitable as a substitute for virgin aggregate for most concrete applications, including structural concrete.[76] UK research indicates that up to 20% of recycled concrete aggregate can be used for most applications (including structural).[77] Australian guidelines state that up to 30% recycled aggregate content in structural concrete can be up to 30% without any noticeable difference in workability and strength compared with natural aggregate.[78] German guidelines state that under certain circumstances recycled aggregate can be used for up to 45% of the total aggregate, depending on the exposure class of the concrete.[79]
As recycled concrete aggregate has cement in it, when reused in concrete it tends to have higher water absorption and can have lower strength than virgin aggregate. Sometimes more cement is needed.

Significant potential remains for increasing the use of coarse recycled aggregate in concrete. In some countries, notably Germany, Switzerland and Australia, concrete containing recycled aggregate is now being marketed. For example, Boral "green" concrete is premixed concrete using recycled aggregate that has been used in a number of building projects in Australia, including the world leading green building Council House 2, a 10-storey office block in Melbourne. A notable example from Germany is the Waldspirale complex containing 105 residential dwellings designed by Friedensreich Hundertwasser in Darmstadt. Completed in 2000, the building makes use of recycled aggregate in the concrete. Zürich's largest school in Birch has led the way for the use of recycled aggregate in concrete in Switzerland. In Spain, Horcimex used recycled aggregate content in the structural concrete for a housing project in Madrid.

To the extent that recycled aggregate is used in concrete, it tends to be mainly in ready-mix concrete. Some examples from France exist for use in pre-cast concrete; however, the CSI is not currently aware of any widespread use.

2. As fine aggregate

Fine aggregates can be used in place of natural sand. However, the mortar content can affect workability, strength and shrinkage due to high water absorption, which could increase the risk of settlement and dry shrinkage cracking. Fine aggregates also often contain plaster from C&DW and it is more costly, both economically and environmentally, to clean the material. Fine aggregates can be a good fill for sub-grade corrections as they can act as a drying agent when mixed with sub-grade soil.[80] Fine aggregates can be used in sub-base and in all-in aggregate uses. Given the impact of extraction of sand from rivers and seas, alternative sources are of increasing importance and use may increase as a result of this.

Reuse in original form

Reuse of blocks in original form, or by cutting into smaller blocks, has even less environmental impact; however, only a limited market currently exists. Improved building designs that allow for slab reuse and building transformation without demolition could increase this use. Hollow core concrete slabs are easy to dismantle and the span is normally constant, making them good for reuse.

Some examples of varied uses include:

- Recycled concrete from construction and road rubble has been found to be a good material for artificial reefs in Chesapeake Bay, US, to aid oyster restoration programs. The irregular surfaces and pore spaces of crushed concrete provide good protection to small oysters from predators. Artificial fishing reefs on the east coast of the US also commonly use scrap concrete.
- St. Lawrence Cement (Holcim) crushed 450,000 tonnes of concrete rubble for reuse as road base for new aprons at Toronto airport.
- Thailand uses concrete waste to make paving blocks, pots and benches for community use.
- The development of Gardermoen Airport in Oslo allowed reuse of more than 90% of the recovered materials from the demolition site.

Leaching issues

The quality of recovered aggregate is largely dependent on the quality of the original concrete and any exceptional conditions the concrete may have endured in its first life. In a Dutch study, some leaching of bromine and chromium was found in some recycled concrete.[81] In Japan it has been noted that hexavalent-chromium and lead can be found in concrete waste as they are originally contained in cement – this could potentially cause soil contamination.[82] On the other hand, recent research by Waste & Resources Action Programme (WRAP) in the UK indicates no differences, on average, relative to virgin material.[83] A Swiss study found that no significant pollution increases occur (particularly with respect to underground water) when recycled building materials are used.[84] However, Swiss regulations do require groundwater protection measures when using recycled demolition materials, and use in filtration and drainage beds is prohibited (due to potential contamination with chromium and pH-value impact).[85] Pavement concrete used in cold climates where de-icing salts are often applied may have increased sodium chloride content that may limit recovery for use in new concrete due to the risk of an alkali-silica reaction or steel corrosion.[86]

The quality of recycled aggregate depends on the original material: Demolition waste can present challenges

Concrete can be recycled from production waste, waste returned in ready mix trucks, construction wastes and demolition wastes. Demolition waste is the most significant source; however, this is also the most challenging source as (1) the concrete is usually mixed with other C&DW and (2) the make up and history of the original concrete mix is less likely to be known. Strong building codes improve quality at all stages of use.

Recycled aggregates can be used in a variety of construction applications as illustrated below.

1. **Concrete road**
2. **Bitumen road**
3. **Hydraulically bound road**
4. **Ground improvements**
5. **Earthworks – embankments**
6. **Earthworks – cuttings**
7. **Shallow foundations**
8. **Deep foundations**
9. **Utilities**
10. **Utilities reinstatement in roads**
11. **Concrete substructures**
12. **Concrete structures**
13. **Buildings (industrial)**
14. **Buildings (residential)**

Source: AggRegain (www.aggregain.org.uk/opportunities)

How can concrete be recovered?

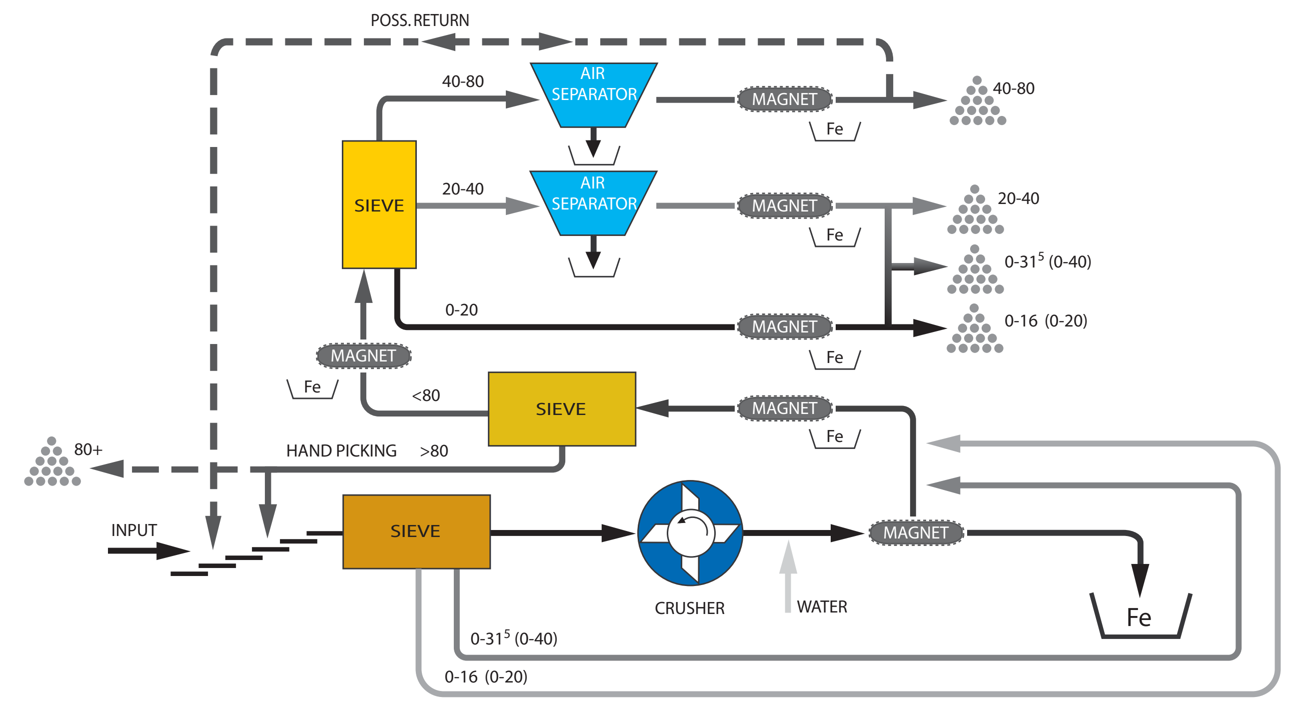
Key issues in best practice for concrete recovery include:

1. **Sorting of C&DW materials**
2. **Energy-efficient processors with attention to noise, atmosphere and water pollution potentials**
3. **Comparative review of on-site versus off site processing**

Current technology

By far the most common method for recycling dry and hardened concrete involves crushing. Mobile sorters and crushers are often installed on construction sites to allow on-site processing. In other situations, specific processing sites are established, which are usually able to produce higher quality aggregate. Sometimes machines incorporate air knives to remove lighter materials such as wood, joint sealants and plastics. Magnet and mechanical processes are used to extract steel, which is then recycled. A typical crusher system is represented below:

C&DW recycling diagram from a Dutch recycling company [87]



Source: Van Bentum Recycling Centrale

Closed circuit wet washing systems, in addition to crushing, are also sometimes used to recover purer products and/or to allow the reuse of the fines.[88]

Surveys regarding the use of recycled aggregate have been conducted in England and have found that a higher value of use of C&DW is achieved by recyclers who mix on-site work (that is, at the demolition site) with access to a fixed recycling center (where materials that would have otherwise been wasted or used as low-grade fill can be better refined and used).[89] The optimum level of sorting and processing can depend on individual circumstances. For example, although greater sorting and refining can produce a higher grade product, in England one benefit of not sorting concrete from brick rubble is that the mixed product can then be used for road sub-base and base. If the brick was extracted it would be unsuitable for such applications.

Case studies

(i) Taiheiyo Cement Corporation has developed TRASS, the Taiheiyo Recycled Aggregate Solution System, which incorporates a dry screw grinding system with twin cones that can produce quality aggregate from concrete blocks without removing the cement paste and thus preventing damage to the aggregate. Aggregate can be produced for required size specifications. The machines have low vibration and noise emissions compared with rod mills or impact crushers and have energy-saving small motor loads. Furthermore, the system is sectional and hence is easily transportable.

(ii) Coleman and Company's Urban Quarry: Currently producing 9,000 to 10,000 tonnes of aggregates and sand per month from C&DW in Birmingham, this "urban quarry" finds demand outstripping supply. The uses include concrete, drainage and decorative aggregate distributed through garden centers.

(iii) Tokyo Electric Power Company (TEPCO) owns about 5,800 buildings and estimates that 7.8 million tonnes of construction waste will be generated by their eventual demolition.

TEPCO investigated the existing aggregate refining methods used in Japan to create high-quality aggregate; these methods involve removal of the mortar, which is economically and environmentally costly (increases CO_2 emissions). TEPCO has obtained approval for an aggregate replacing method that does not remove the original mortar but involves crushing and a wet grinding method. Recycled concrete aggregate (both coarse and fine) can be made using general purpose facilities that can even be mobile, and 55% to 73% can be recovered and used for structural concrete, the remaining amounts can be used for precast concrete products.

Emerging technologies

Although not commercially feasible at present, some emerging technologies include:

1. Closed-cycle construction using mechanical and thermal energy

The University of Delft, together with TNO, is working on a novel closed-cycle construction concept whereby concrete rubble and masonry debris are separated back into coarse and fine aggregates and cement stone using mechanical and thermal energy supplied by the combustible fraction of C&DW.

2. Electrical decomposition of concrete

To break down concrete (or rocks), high shear stress is needed by way of a shock wave. Conventional technology uses mechanical force. Alternatively heat (see above) or electrical energy can be used. Electrical energy can be used to create pulsed power. At the present time, high initial outlay costs are a barrier to use; however, niche applications can benefit from this technology where high repetition actions are needed. The environmental impacts of using electricity also need to be considered.

3. Microwave

Microwave technology can also be used to crush concrete.[90]

Returned concrete

Returned concrete is the unused ready-mixed concrete that is returned to the plant in the concrete truck as excess material. This can be small amounts of concrete leftover at the bottom of the drum in the truck, or more significant quantities not used by the customer on the construction site.

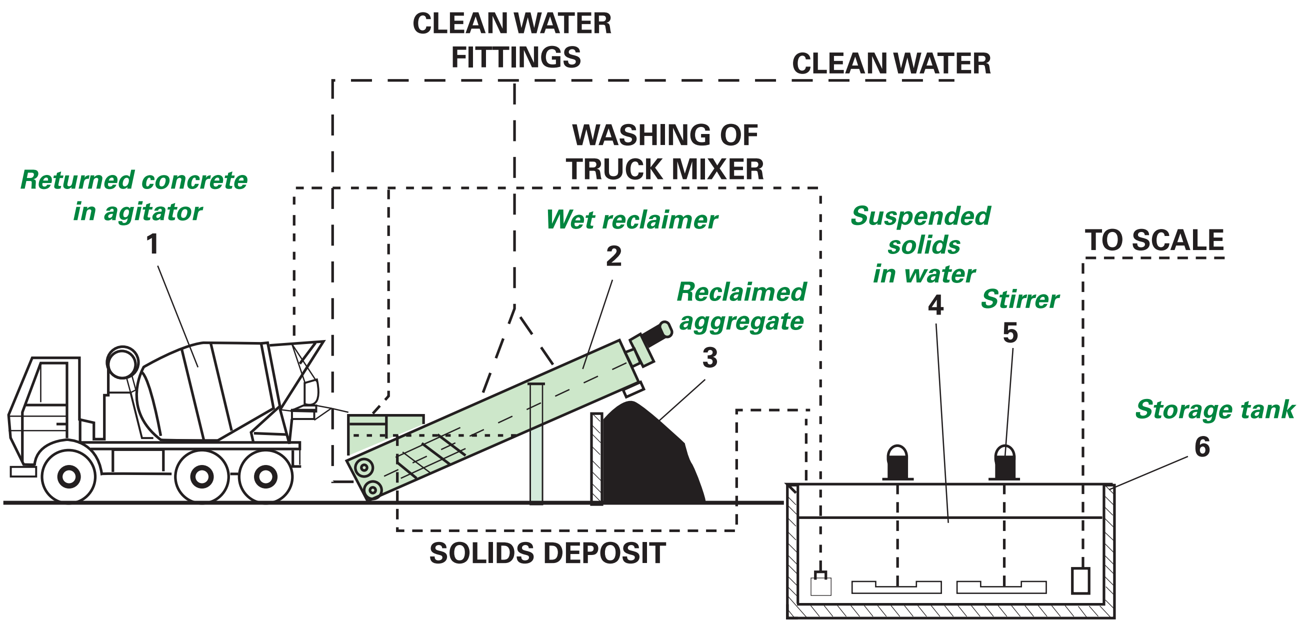
Typically the amount of waste concrete generated by ready-mix deliveries can be as low as 0.4% to 0.5% of total production. However, during peak periods, when pressure for supply is greatest, the waste can increase to 5% to 9%. Waste can be recovered by washing and reuse in concrete production or, if it has already hardened irreversibly, it can be crushed and reused as aggregate. It is not common practice in the industry to have company-wide policies on this matter; however, the practice of recovering returned concrete is widespread.

Most washing is done by wet washing as in the figure below. Sometimes "dry washing" is used before this procedure, which involves first mixing remaining waste concrete with virgin aggregates and then the mixture can be returned to the aggregates pile for use in new concrete.

Most of the aggregate made from the hardened concrete is used for purposes other than new concrete. If the quantities returned are high, it is often standard practice to let it harden, crush it and use as landfill. Sometimes, if the concrete is still wet, pre-cast concrete "lego" blocks are made which can then be used on site, donated to local municipal projects or sold.

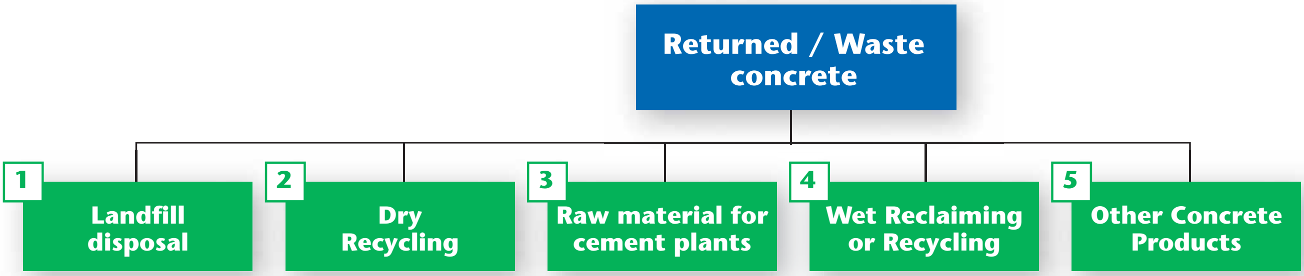
Once made, concrete needs to be used within a few hours. Ready-mix (RMX) trucks with rotating drums can keep it malleable, but only for a limited time. Many companies are using GPS systems in trucks with a central control station so that concrete can be redirected as orders change and waste minimized. In Mexico the introduction of this system by one company reduced a 3-hour delivery time to 20 minutes.

Below is a typical system for reclaiming wet concrete.



Source: Boral Concrete, Australia

The options for managing waste concrete can be considered diagrammatically:



Stakeholders

Concrete recycling is of interest to many stakeholders and can be influenced by the relative attitudes and interests of the following groups:

- **Cement manufacturers**
- **Ready-mix manufacturers**
- **Precast manufacturers**
- **Aggregates producers**
- **Recycling enterprises**
- **Demolition enterprises and experts**
- **Road builders and engineers**
- **Construction enterprises, builders and engineers**
- **Local governments/town planners**
- **Waste regulators**
- **Trade associations**
- **Environmental agencies and NGOs**
- **Architects**
- **Norms and standards bodies**
- **Research bodies and universities**
- **Green building industry**
- **Government at all levels responsible for procurement**
- **Consumers and the general public**

Policy frameworks

Laws, regulations, standards, government procurement policies and community attitudes in the following areas all impact on the approach taken to recycling concrete in a given country:

- **Waste laws and regulations**
  - – Landfill restrictions
  - – Landfill taxes
  - – Classification of C&DW as a "waste" with permit requirements and restrictions on transport
- **Road and building construction laws, building codes and standards and public attitudes**
  - – Restrictions on use of recycled materials as per standards
  - – Government green procurement strategies
- **Environmental laws and regulations**
  - – Positive incentives to reuse and recycle
- **Natural resources laws and regulations**
  - – Restrictions on virgin materials supply
- **Public perceptions regarding the quality of recycled products**
- **Research and development infrastructure and funding**

There is no single best solution, and policies and structures vary from country to country. The objective should include consideration of the optimal sustainable development practice for the given circumstances. Within a country, regions can have variations, particularly between urban areas (where recycled material and the infrastructure to recycle exist) and low-density areas (where transportation costs are relevant). Climate and the types of products in demand are also factors. A flexible approach that supports recycling and public knowledge of recycling successes should be pursued. Viewing old concrete as a resource – not a waste – is important. Misconceptions about the properties of recycled materials also need to be overcome in many cases.

In the US much of the recycling activity has been driven by the Federal Highway Administration's endorsement of recycled concrete as aggregate in road sub-base and base.[91] The American Society for Testing and Materials (ASTM) and the American Association of State Highway and Transportation Officials (AASHTO) have accepted recycled concrete as a source of aggregate in new concrete. The Federal Aviation Administration (FAA), Army Corps of Engineers, Environmental Protection Agency (EPA), state Departments of Transportation (DOTs) and many municipalities are now using recycled aggregate to varying degrees.[92] Some elements of state policy include, for example, allowing higher material costs if recycled materials are used in government contracts (e.g., Michigan) or excluding or modifying waste regulations (e.g., California, Texas, Virginia and Minnesota).

In **Europe**, waste policy is aimed at waste recovery. Landfill is increasingly discouraged and some countries have banned C&DW from landfill. As part of a Strategy on the Prevention and Recycling of Waste, a Revised Waste Framework Directive has been adopted. The European Union is also pursuing a sustainable use of natural resources strategy. The introduction in 2004 of European standards for aggregates that focuses on fitness "for purposes", as opposed to "source", paves the way for growth in the use of sustainable aggregates.

In the UK, an Aggregates Levy and landfill tax has been used to encourage use of recycled aggregate and includes grants for recycling infrastructure projects, investigates ways to reduce regulatory barriers and undertakes research through the WRAP program. In Denmark taxes on waste disposal have encouraged recycling.[93]

Japan has well-developed sustainable development laws and there is strong interest in limiting landfill and reusing and recycling materials. In 2000, the Construction Material Recycling Act entered into force requiring the obligatory sorting of C&DW and the reuse/recycling of concrete, asphalt and wood.

Standards

It is important to set standards that do not arbitrarily exclude recycled aggregate. Standards should highlight and encourage the use of recycled aggregate. Some useful standards include:

- New ISO standards, which are being developed on "Environmental Management for Concrete and Concrete Structures". The project will include a review of concrete production, building construction and maintenance, demolition and reuse of buildings, recycling of concrete, product labels and environmental design of structures.
- The EHE Spanish standard, which recommends a 20% replacement of coarse aggregate by recycled concrete.

Various European standards exist,[94] and Japanese and Australian standards[95] are also well developed. The International union of laboratories and experts in construction materials, systems and structures (RILEM) has also been involved in standards development.[96]

Building practices

Building and construction typically generates 5% to 15% of GDP and consumes the largest share of natural resources, through land use and materials extraction.[97] In recent years green building and related concepts have emerged to limit the impact of the urban world. Today, the green building market is estimated to be a US$ 12 billion industry in the US.[98] The sustainable use of concrete in buildings encompasses several green building issues, namely:

1. **Sustainability in initial design.** Durable, flexible designs improve the life of a building and allow future adaptations. Off-site prefabrication can be considered. Design for deconstruction should also be considered.

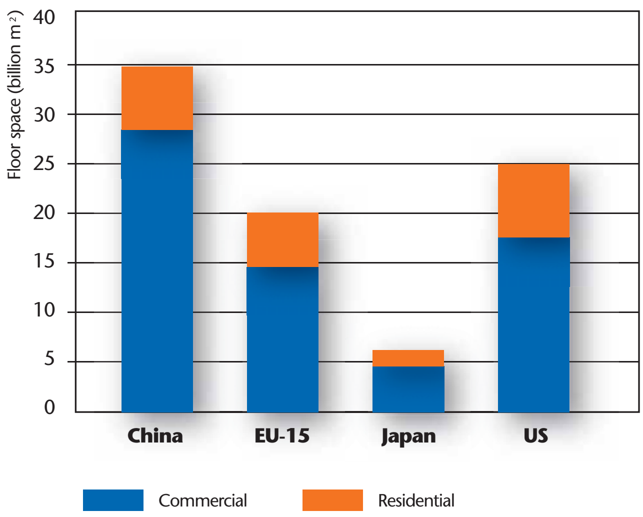
2. **Optimum use of input materials in design.** Reuse and recycling of materials can often be the optimal solution for sustainability. Concrete use can also improve building energy efficiency in some designs.

3. **On site waste management plans.** These maximize the potential for materials reuse and recycling and minimize negative environmental and health effects. In particular, sorting can improve recovery and quality of recovered products.

Green building design encompasses a range of balancing issues to achieve optimum life cycle sustainability. There is no single design method that is best. A good design needs to take into account a whole range of issues including:

- The impact of production and processing and transportation of input materials (including embodied energy costs in production) and the level of waste associated with their use
- The environmental costs of operation during use phase
- The length of anticipated use
- The possibilities for reuse or low-cost recovery after use (i.e., the ease with which materials can later be separated and reused or recycled).

Existing building floor space (2003)



Source: Energy Efficiency in Buildings, Business Realities and Opportunities, WBCSD, August 2007, page 11.

Over 85 billion m^2 of buildings exist… which means 85 billion m^2 pt equivalent of potential C&DW…. and China's construction boom is adding 2 billion m^2 every year:

Green building ratings systems

The ability to maximize concrete recycling is influenced by the extent to which building codes and green rating schemes recognize recycled concrete. In general there are few legal restrictions on using recycled concrete as aggregate in building projects for filling, sub-base, asphalt and in outdoor landscaping. There are, however, often limitations on the amount that can be used in structural concrete. Often the main reason for limited use is misguided public perception with regard to the quality of recycled concrete, or even a lack of consideration of the possibilities for its use. Green building schemes and ratings systems can change this perception, especially if recycling concrete and using recycled concrete as a material is specifically addressed in the scheme.

The main features of a green building rating system include, pertinently:

1. **Requirements for on-site waste management plans for demolition of existing structures.**
   Key features should include maximizing salvage, and thereby minimizing waste, associated transport costs and potential landfill, and maximizing the reuse or recycling of salvaged materials for use on site in a new construction.

2. **Requirements for use of existing materials or materials made from recycled components**

A project will be rated on the above and other criteria. Most schemes have accredited professionals who independently audit and rate a project. Rating schemes are usually voluntary although public authorities are increasingly requiring projects to meet a specified rating. In the UK the Code for Sustainable Homes is a rating scheme that will become mandatory in 2008 for all new dwellings.[99]

The Green Building Council (GBC) is a leading international umbrella organization pulling together 11 local GBCs with about the same number of other countries expressing interest in joining.[100] Most GBCs adopt the LEED or BREEAM rating systems.

LEED

The Leadership in Energy and Environmental Design (LEED) Green Building Rating System is the primary tool for green building systems in the US and has considerable activities worldwide. It is a voluntary system that has been widely adopted in government and private projects. LEED is a points-based system that provides graded certifications. The program considers the following five key areas:

1. **Sustainable site development (including responsible management of C&DW)**
2. **Water savings**
3. **Energy efficiency**
4. **Materials selection (including use of recycled materials)**
5. **Indoor environmental quality**

For new constructions, 8 of the 85 available points relate to C&DW handling and use of recycled materials. In LEED projects good management of C&DW waste is common, as is the use of recycled concrete aggregate. However, no known projects have included recycled concrete in the structure.

BREEAM

Well-established in the UK and internationally, the Building Research Establishment Ltd (BREEAM) has a suite of tools for measuring the environmental performance of buildings. Credits can be earned for recycling C&DW and for the use of recycled aggregate. BREEAM also promotes SMARTWaste to minimize waste generation.

Other rating systems include CASBEE in Japan, HQE (Haute Qualité Environnementale) in France, GreenStars in Australia and New Zealand, and Green Globes.

Example: Council House 2 in Melbourne, Australia with 6 Green Stars. The concrete used in the structure contains recycled concrete aggregate.

Product labeling

Green Building initiatives have given rise to building product labeling schemes such as the well known "FSC" labels for sustainable forestry products. Another example is Belgium bluestone, which is now sold with an environmental declaration setting out the life cycle impact.[101] Also in Europe, the Natureplus labeling system for building products[102] exists although it does not currently list any recycled concrete products. The Green Building Guide of BREEAM is another example. Such labels are akin to the "Nutritional Facts" label on food products, although instead of listing calories and fat, the consumer is provided with data on energy use and ozone depletion impact. Such labeling systems could include information on recycled content.

Independently of ratings schemes and environmental labeling programs, some companies are marketing green products. Boral Limited in Australia markets Boral Green Concrete made from recycled concrete and Envirocrete aggregate produced with recycled concrete content.

Current barriers and benefits for greater use of recycled concrete

Some key barriers and benefits include:

Issue	Barriers	Benefits
Material cost vis-à-vis natural aggregate	Low economic cost of virgin aggregate in some countries.	Aggregates levies and transportation costs for natural aggregates can be higher. Overall project costs can be reduced as less landfill taxes/fees are paid on C&DW as the material is recovered instead of being landfilled.
Availability of material	Non-regular supply of C&DW.	C&DW is usually found in urban areas near construction and development projects. Virgin materials often need to be transported over greater distances.
Processing infrastructure	C&DW on-site waste management plans are needed. C&DW may need to be sorted. High-value recovered concrete requires costly processes.	Once infrastructure is established mobile sorting units and dedicated facilities can provide good returns.
Public attitudes	Misconception that recovered concrete is of lower quality. New materials are perceived as being of better quality.	Increasing environmental concerns leading to increased demand for eco-friendly products and reuse of materials.
Laws, regulations and industry accepted standards	Classification of recovered concrete as waste can increase reporting and permit requirements. Extra limitations can be placed on use.	Positive recycling laws, landfill taxes and green procurement policies by large users can all promote recycled concrete use.
Environmental impacts	Processing technology for recovery of concrete should consider possible air and noise pollution impacts as well as energy consumption, although there is little difference to natural aggregates processing.	Within a life cycle analysis, use of recovered concrete can lower overall environmental impact. • Failing to use recovered materials increases landfill and associated environmental and health costs • Failing to use recovered materials means virgin materials are used instead • Recovered concrete is generally inert • In some cases, transportation needs for recycled concrete can be lower than virgin materials (often not located in urban development areas) and as such fuel consumption, CO_2 emissions and road and vehicle use can be reduced.
Physical properties	For specialized applications (e.g. high performance concrete) there are some limitations on fitness for use. Technology can also limit recycling options.	For most uses, recycled concrete performs well.

Design for deconstruction

Considering deconstruction at the time a building is designed improves the chances of closed loop construction. The benefits are two-fold: eventual C&DW is minimized and the demand for new materials for a future project is reduced. Designs should consider ways to maximize possibilities for reuse, or at least possibilities for recycling of the structure and its components. As a first step, designs that allow for eventual adaptation or renovation of a structure can allow partial replacements that lengthen the ultimate life of the building. Keeping components separate or separable is key for component reuse or recycling. Evaluation of any possible contamination issues is also relevant.

One of the most important characteristics of concrete is its durability. The best design for deconstruction for concrete is to allow for on-site reuse: concrete can be an ideal building material as buildings made with concrete can be adapted and renovated for future use for many decades.

In situ and pre-cast concrete materials both play a role in design for deconstruction plans:

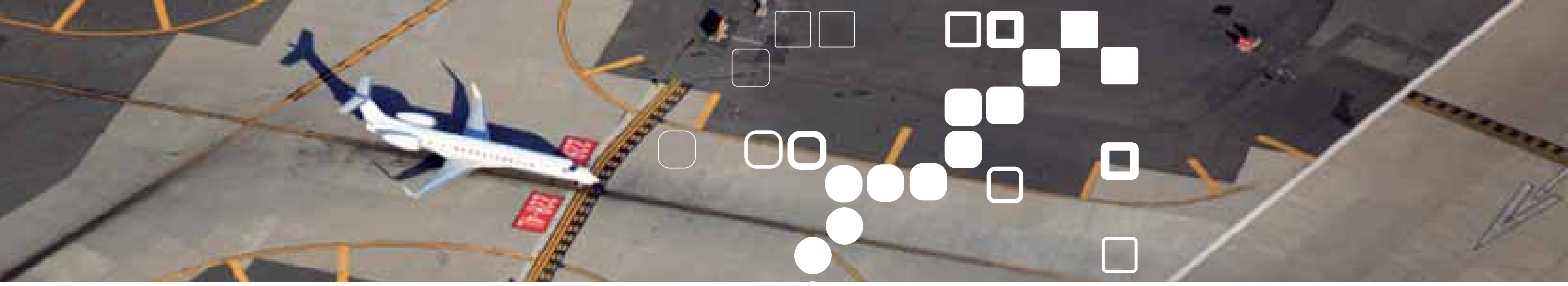
In situ concrete – In situ concrete is sometimes mistakenly believed to have few reuse or recovery possibilities. However, buildings with post-tensioned slabs can be reused and altered as required.[103] If the building is demolished, having a record or tag on the concrete detailing its components may aid in possible future recycling. Sometimes designs note that this is "downcycling" as the recycled concrete aggregate is used for projects such as road sub-base. However, as noted elsewhere, the best overall environmental solution does not necessarily require refined reprocessing and a closed loop material use can still be achieved.

Pre-cast slabs – Designs should consider the use of pre-cast slabs that can be dismantled and reused. It may be that fillers such as polystyrene should not be used to avoid hampering later recycling efforts.[104]

Some examples: [105]

1. **The reconstruction of the Porthania building at the University of Helsinki**
2. **The reuse of old silos in Copenhagen for dwellings (IRMA) (see picture below)**

3. **During construction of the Ghent St Peter railway station in Belgium a temporary multi-storey parking lot was needed. A 700 car construction was built using iron beams supporting prefabricated concrete. Every plate was designed to allow easy disassembly and rebuilding in another location. (see picture below)[106]**



Recommendations

This report establishes that concrete can be recovered and is being recovered. The ultimate goal should be set for **"zero landfill"** of concrete. The Cement Sustainability Initiative (CSI) supports initiatives targeted at this goal.

However, it needs to be noted that cement producers can only have an indirect role in supporting concrete recycling (concrete being the main downstream product of cement) and a goal of "zero landfill" of concrete. The objectives of this report include promoting discussion and encouraging recycling of concrete by all stakeholders. Cement producers can be particularly involved with the work of subsidiaries in the concrete, aggregate and construction industries. Cement producers can also, by way of this report, encourage recycling initiatives by other stakeholders listed below.

Towards the zero landfill goal, the following recommendations are made:

- Key stakeholder dialogue to develop reliable and consistent statistics. Guidelines on definitions are needed.
- Governments and other key stakeholders to publicize C&DW data and provide details to allow the public to determine C&DW and concrete recovery rates and publication of other key performance indicators as proposed in the following section.
- Set targets for use in public and private works (in both road construction and building industries).
- Develop economic incentives to allow infrastructure to develop.
- Employ overall benefit strategy analysis to determine the best use of recovered concrete in a given market (including life cycle thinking for environmental impact, business case and other benefits and barriers).
- Adopt legislation to promote reuse with the highest value added economically, technically and environmentally.
- Research and development to consider further recovery techniques and uses.
- Green building schemes to further encourage good C&DW management and the use of recycled concrete aggregate.
- Key stakeholders publicity to change public misconceptions.

Many of the above recommendations are already being pursued by some stakeholders. The time is now right for further advances to be made. The stakeholders that can make a difference and pursue the above recommendations are:

- Ready-mix manufacturers
- Precast manufacturers
- Aggregates producers
- Recycling enterprises
- Demolition enterprises and experts
- Road builders and engineers
- Construction enterprises, builders and engineers
- Local governments/town planners
- Waste regulators
- Trade associations
- Environmental agencies and NGOs
- Architects
- Norms and standards bodies
- Research bodies and universities
- Green building industry
- Government at all levels responsible for procurement
- The consumers and the general public

Following are suggested indicators that recommend specific responsibilities.

Indicators

The CSI proposes the following indicators for adoption by key stakeholders. The indicators are suggestions to improve reporting and, eventually, performance. Two sets of indicators are suggested: (a) indicators for cement, concrete and aggregates industries and (b) indicators for all stakeholders.

Set A: Indicators for cement, concrete and aggregates industries

The CSI proposes to implement in the aggregates, concrete and cement companies the following indicators when possible:

Indicator	Measure	Formula	Responsibility Level
Use of recycled aggregate as a replacement for natural aggregate (COMPANY INDICATOR)	Amount of recycled aggregate produced as a % of total aggregate produced	Recycled aggregates produced by the company (in tonnes)/total aggregates produced by the company (in tonnes)	Aggregates producers
Use of recycled concrete as aggregate in concrete (COMPANY INDICATOR)	a) % of precast concrete products on the market containing recycled concrete. b) % of total concrete production that uses a recycled aggregate component	a) Precast concrete products (in tonnes)/total precast concrete products (in tonnes) b) Concrete production that uses a recycled aggregate component (in m^3)/total concrete production (in m^3)	RMX companies
Returned concrete reduction (COMPANY INDICATOR)	% of concrete returned to RMX plant per year on delivered concrete	concrete returned to RMX plant (in m^3)/total concrete delivery (in m^3)	RMX companies**
Returned concrete recovery (COMPANY INDICATOR)	% recovery of concrete returned (wet and dry)	concrete recovered (in m^3)/ concrete returned to RMX plant (in m^3)	RMX companies

** Returned concrete reduction: RMX companies can monitor the amount of concrete returned, which is valuable information; however, reducing the amounts is very much dependent on the ordering and use practices of customers.


Set B: Indicators for all stakeholders

The CSI also proposes the following indicators for adoption by key stakeholders. These indicators are suggestions to improve reporting and eventually performance.

Indicator	Measure	Formula	Responsibility Level
C&DW recovery (NATIONAL LEVEL)	a) % recovery of C&DW b) % landfilled (with figures by material type if possible)	a) C&DW recovered (tonnes)/total C&DW (tonnes) b) C&DW landfilled (tonnes)/total C&DW (tonnes)	Governments or trade associations with input from various key stakeholders
Use of recycled aggregate as a replacement for natural aggregate (NATIONAL LEVEL)	Use of recycled aggregate as a % of total aggregate use	Recycled aggregates produced in the country (in tonnes)/total aggregates produced in the country (in tonnes)	Aggregates trade associations or Governments
Use of recycled concrete as aggregate in concrete (NATIONAL LEVEL)	a) % of precast concrete products on the market containing recycled concrete b) % of total concrete production that uses recycled aggregate component	a) Precast concrete products (in tonnes)/total precast concrete products (in tonnes) b) Concrete production that uses a recycled aggregate component (in m^3)/total concrete production (in m^3)	Governments and trade associations
Recognition of C&DW recovery in Green Building Programs (LEED, BREEAM, CASBEE)	% of reported projects with C&DW recovery plans	a) Number of projects with C&DW recovery plans/total number of projects b) Number of projects with recycled concrete aggregates/total number of projects	Green building organizations
Recognition of recycled concrete aggregate in Green Building Programs (LEED, BREEAM, CASBEE)	Number of reported projects containing recycled concrete aggregate (specifically mentioned as opposed to C&DW in general)		Green building organizations
R&D on improving concrete recycling	Number of new technologies commercially adopted		Government and industry
R&D on improving concrete recycling	Funding allocated to R&D on concrete recycling		Government and industry

Useful references and web links

Some relevant organizations

Arbeitsgemeinschaft Kreislaufwirtschaftsträger Bau (ARGE KWTB) www.arge-kwtb.de

Asian Institute of Technology 3R Knowledge Hub www.3rkh.net

CDE (Engineering specialists in recycling equipment) www.cdeglobal.com

Cembureau (Representative Organization of European Cement Industry) www.cembureau.be

Cement Association of Canada www.cement.ca

Construction Materials Recycling Association (CMRA, a US organization of member companies and agencies) at www.cdrecycling.org. See also www.concretethinker.com

Institut für Hochleistungsimpuls-und Mikrowellentechnik www.fzk.de/ihm

International Recycling Federation www.fir-recycling.nl

UEPG (European Aggregates Association) www.uepg.eu

Government sites

Canadian Minerals Yearbook – cement chapter at www.nrcan.gc.ca/mms/cmy/com_e.html

Czech Republic: Ministry of the Environment www.env.cz

Japan: Ministry of Land, Infrastructure and Transport www.mlit.go.jp

United Kingdom: www.defra.gov.uk.

USA: EPA, see www.epa.gov, for statistics see also www.nssga.org and www.usgs.com (particularly minerals.er.usgs.gov/minerals/pubs/commodity/)

Some selected papers

FHWA Transportation Applications of Recycled Concrete Aggregate, Sept 2004

Natural Resources Canada An Analysis of Resource Recovery Opportunities in Canada and the Projection of Greenhouse Gas Emission Implications (March 2006) at www.recycle.nrcan.gc.ca/summaries_e.htm#8

Obla K et al, Crushed Returned Concrete as Aggregates for New Concrete, Final Report to the RMC Research and Education Foundation Project (2007)

Integrated Decontaminated and Rehabilitation of Buildings, Structures and Materials in Urban Renewal (IRMA), "City Concept, Sustainable Value Creation within Urban Renewal" see further projweb.niras.dk/irma/index.php?id=643

Sjunnesson, J, Life Cycle Analysis of Concrete, Masters Thesis, 2005, University of Lund, www.miljo.lth.se/svenska/internt/publikationer_internt/pdf-filer/LCA%20of%20Concrete.pdf

Yasuhiro Dosho, "Sustainable Concrete Waste Recycling", Construction Materials 161 Issue CM2, Proceedings of Civil Engineers, pp. 47-62, May 2008.

Green Building Codes and projects and Design for Deconstruction

Australia's Guide to Environmentally Sustainable Homes, Your Home Technical Manual online at www.greenhouse.gov.au/yourhome/technical/fs34f.htm

www.recyhouse.be (example of a recycled building project will information discussing recycled aggregate)

A current state-of-the-art report on recycled concrete was published in German. It can be downloaded at www.tfb.ch/htdocs/Files/Sachstandsbericht_RC-Beton_%20Juli_07.pdf

Terms used in this report

Aggregates are granular materials used in construction. They can be natural, manufactured or recycled.

C&DW means construction and demolition waste. This includes concrete, steel, glass, brick, masonry, asphalt and other materials found on a building construction or demolition site or civil engineering sites such as road and bridge building sites.

C&DW concrete means concrete in all forms found in construction and demolition waste. This includes concrete elements, parts, pieces, blocks recovered during construction and demolition activities. It can be retrieved directly from the site or from construction and demolition materials after sorting.

Deconstruction means careful and planned dismantling of buildings to recover valuable materials and minimize wastes.

Embodied energy means the energy required to make a product, including the energy required for all the component parts including extraction of natural resources, transportation and processing energy requirements.

Fresh concrete means concrete that is still wet and has not hardened. It is sometimes also called concrete in a plastic state.

In situ concrete means concrete delivered in ready-mix trucks and poured on site.

Precast concrete means concrete hardened into required form prior to delivery to building site. It includes simple blocks, bricks and pavers as well as steel reinforced and pre-stressed beams and slabs.

Ready-mix concrete (RMX) means concrete manufactured under industrial conditions and delivered fresh to the customer or construction site.

Recovered concrete means concrete that has been recovered from waste concrete or C&DW that can be reused or recycled.

Recovery rate means the amount of material that has been diverted from landfill and reused or recycled. Note: some data collection does not distinguish between amounts of material that have been collected for recycling and the amount of material that was ultimately recycled.

Recycled aggregate, unless otherwise specified, means aggregate made from C&DW, C&DW concrete or waste concrete (and includes coarse and fine aggregate unless specified).

Recycled concrete aggregate means aggregate made from recycled aggregate.

Recycled concrete means waste concrete or C&DW concrete that has been diverted from waste streams and reused or recovered for use in a new product.

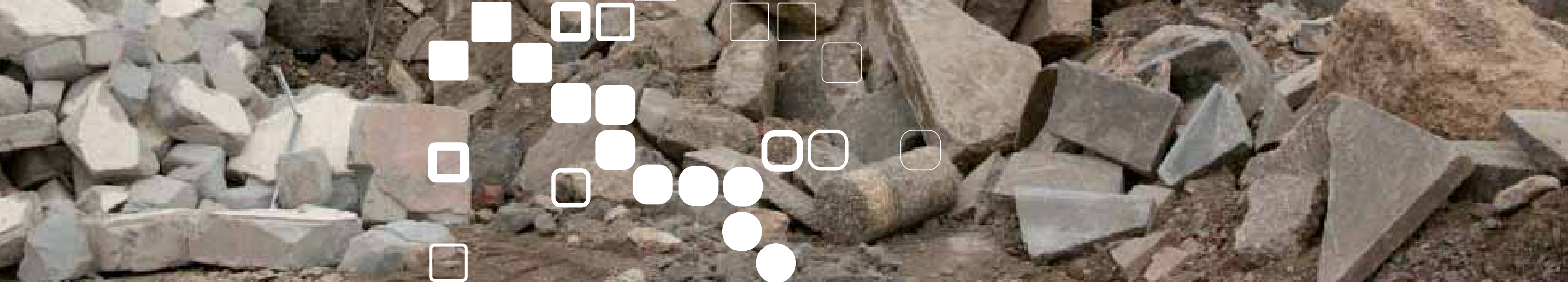
Recycling of concrete/Concrete recycling means a process to avoid disposal of concrete (e.g., waste landfill or dumping).

Residual concrete means fresh concrete from cleaning trucks and equipment (that can be either on the ready-mix production site or the job site).

Returned concrete is the unused ready mixed concrete that is returned to the plant in the concrete truck as excess material. This can be small amounts of concrete leftover at the bottom of the drum in the truck or more significant quantities not used by the customer on the construction site.

Tonnes means metric tonnes.

Waste aggregate concrete means concrete containing recycled aggregates.



Notes

[1] www.ecosmartconcrete.com/enviro_statistics.cfm
[2] Extrapolated from Cembureau 2006 figures of cement production for China (47.3%) and India (6.2%).
[3] 2006 figures Cembureau. It is estimated that cement production figures equate to about 8 to 12% of concrete production. For a particular region (1) the amounts could be higher if other cementious materials are used to make concrete or (2) the amounts could be lower if more cement is now used for non-concrete applications.
[4] Using the same 8-12% ratio for 1950. Figures from WBCSD report Summary of International Cement Industry Structure and Practice, 2003.
[5] Other materials are also added in smaller quantities to enhance performance.
[6] This tends to be minimal as most material is reclaimed.
[7] 2002, Eurostat.
[8] Estimates provided by W. Turley, Construction Materials Recycling Association (CMRA) (350 million US tons per annum of C&DW, of which just under 60% is probably concrete). See also www.concretethinker.com/Papers.aspx?DocId=25
[9] FY 2005, Ministry of Land, Infrastructure and Transport, Japan.
[10] 2002, Eurostat.
[11] 2006, Municipal Solid Waste Generation, Recycling and Disposal in the United States: Facts and Figures for 2006, EPA (251 million US tons per annum equivalent to about 228 million metric tonnes).
[12] FY 2005, Ministry of Environment, Japan.
[13] Buck (1977) as cited in Dosho (2007), see below.
[14] Dosho, Y, "Development of a Sustainable Concrete Waste Recycling System – Application of Recycled Aggregate Concrete Produced by Aggregate Replacing Method" (2007) 5, Journal of Advanced Concrete Technology no. 27 at page 28.
[15] Australian Bureau of Statistics, 2002-2003 data as taken from Australia's Environment: Issues and Trends, 2007. The figure for recycling could be higher depending on source used.
[16] 2005 as reported in UEPG study (2007) based on estimation of VVS and FDERECO 2005.
[17] See also Cement Association of Canada 2003 presentation by A. Wilson. For information on Alberta see Construction, Renovation and Demolition Waste Materials: Opportunities for Waste Reduction and Diversion, Final Report prepared by Sonnevera, 27 April 2006, www.environment.gov.ab.ca/info/library/7703.pdf.
[18] C&DW figures include excavated soil. Recovery amounts are estimates for concrete recovery only. Waste Management Department Ministry of the Environment of the Czech Republic
[19] 2005 Department for Communities and Local Government survey states 51% recovery. Note: a further 15 million tonnes of C&DW was spread on exempt sites (usually land reclamation, agricultural improvement or infrastructure projects). See www.defra.gov.uk. Note: UEPG study (2007) incorporates the exempt site use and states a recovery rate of 89.9%.
[20] 2001 as reported in Ben Arab, UEPG study (2007) based on survey data by FNTP & Ademe. These figures are high as they include soil recovery. The UNPG (Union Nationale des Producteurs de Granulats) reports that 17.43 million tonnes of C&DW was recycled into aggregates in 2007 (compared with 14million tonnes in 2006) which was mainly concrete.
[21] Construction Industry Monitoring Report (2007) by the Arbeitsgemeinschaft Kreislaufwirtschaftsträger Bau (ARGE KWTB). www.arge-kwtb.de.
[22] 2006 as reported in EPA National Waste Report. The recovery figures include soil and stones from road building projects. The C&DW recovery excluding soil and stones (that is the mainly concrete material) is about 1 million tonnes.
[23] 2005, Ministry of Land, Infrastructure and Transport, Japan. Japan achieves a 98% recovery rate for concrete bricks (in 2005 31.5 million tonnes were recovered from 32.2 million tonnes of waste), lower rates are achieved for mixed concrete waste. Data can be found in Japanese at www.mlit.go.jp/sogoseisaku/region/recycle/index.htm. In Tokyo landfill is forbidden and uses must be found for C&DW.
[24] 2001, FIR (International Recycling Federation), www.fir-recycling.nl. Data do not include excavated soils.
[25] Estimate of Skanska Norge AS.
[26] 2003 as reported in Vázquez, "Present Situation in Spain", EcoServe Seminar Paper May 2006
[27] This information was provided to the CSI by Dr. Frank Jacobs, TFB. The 1.9 million tonnes of concrete in C&DW is almost completely recovered, 1.1 million tonnes are used for concrete production and the rest as unbound aggregate.
[28] 2007. Data taken from Environmental Protection Administration (EPA) and Construction and Planning Agency of Ministry of the Interior (CPAMI). Taiwanese law (The Waste Disposal Act and Resource Recycling Act) requires C&DW quantities to be declared to EPA and CPAMI. Overall C&DW recovery rate in 2003 was 83%.
[29] 2007. Estimate from on-going research based on waste generation rates by the Pollution Control Department and Construction Area records of the National Statistical Office, Thailand. No recovery figures are available, in general, more valuable C&DW is recovered (e.g., metals) and currently most concrete is discarded.
[30] CRMA estimates for 2005. Concrete recovery is estimated at 127 million tonnes.
[31] See for example, Sjunnesson, J, Life Cycle Analysis of Concrete, Masters Thesis, 2005, University of Lund www.miljo.lth.se/svenska/internt/publikationer_internt/pdf-filer/LCA%20of%20Concrete.pdf
[32] See for example, the CO_2 uptake project from the Nordic Innovation Centre at www.nordicinnovation.net/_img/03018_c02_uptake_in_concrete_executive_summary.pdf
[33] See further information on WBCSD Cement Sustainability Initiative (CSI) at www.wbcsdcement.org
[34] The CSI decided to include this case study as an illustrative example of possible benefits of recycling. As noted above, the actual benefits in any given project will vary widely and consideration needs also to be given to the best parameters for comparison in a given situation. Details of this project came from ntlsearch.bts.gov/tris/record/tris/00924124.html and a Presentation at a Stakeholder Workshop on C&DW, Thailand July 2007 attended by a CSI delegate.
[35] Countries included in Europe vary. Where known, the countries are specified in the notes.
[36] Amount Recovered/Amount Arising. This is the overall EU estimate. Figures vary significantly between countries from nearly full recovery in countries like the Netherlands to much lower rates elsewhere. Published statistics can also be variable depending on whether or not excavation soil is included in the recovery rates as is discussed above.
[37] Amount Recovered/Amount Arising (2005) estimate from Construction Materials Recycling Association (CMRA). Concrete recovery is estimated at 127 million tonnes.
[38] Amount Recovered/Amount Scrap Arising (2005) Ministry of Land, Infrastructure and Transport, Japan. Japan achieves a 98% recovery rate for concrete bricks (in 2005 31.5 million tonnes were recovered from 32.2 million tonnes of waste), lower rates are achieved for mixed concrete waste. Data can be found in Japanese at www.mlit.go.jp/sogoseisaku/region/ recycle/index.htm.
[39] Collection/Production (2006) European Aluminium Association for EU 25 and EFTA. Higher rates have been achieved in some individual countries, for example, 93% in Norway and 88% in Switzerland and Finland (www.world-aluminium.org).
[40] Collection/Production (2006) Aluminum Association Inc as reported in 2006 Minerals Yearbook, US Department of the Interior at 5.1. The EPA indicates 45% for aluminum cans (www.epa.gov/epaoswer/non-hw/muncpl/recycle.htm#figures).
[41] Collection/Consumption. (2007) Japan Aluminium Association.
[42] Average collection rate for aluminum from a study by Delft University of Technology of selected building demolitions in 6 European countries. Collection of Aluminium from Buildings in Europe, A Study by Delft University of Technology, 2004.
[43] (2005) Includes aluminum sash, exterior and interior building materials. Japan Aluminium Association.
[44] Collection/Consumption (2006), European Container Glass Federation (www.feve.org) for Austria, Belgium, Bulgaria, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Spain, Sweden, Switzerland, Turkey and the United Kingdom. Collected tonnage corresponds to glass actually recycled. OECD Environmental Data 2007 provides a 2005 rate of 65%.
[45] (2005) OECD Environmental Data 2007.

[46] (2003) OECD Environmental Data 2007. The Japan Steel Can Recycling Association Report cites a 2006 rate of 94.5% for amount of cullet used/amount of glass bottles produced, see www.steelcan.jp/english/index.html.

[47] Estimate only. Data is not collected in Europe although the recovery rate is thought to be high and there is a strong market in recycled lead. See International Lead Association www.ila-lead.org and The Association of European Storage Battery Manufacturers www.eurobat.org for more information about recycling in Europe. The UK published a rate of 90%: www.guardian.co.uk/world/2006/may/05/qanda.recycling. 93% is the rate in Ireland (www.returnbatt.ie).

[48] Recycled/Consumption (2006) EPA Municipal and Solid Waste Generation Facts and Figures for 2006 at page 3. See also www.batterycouncil.org. See also National Recycling Rate Study, June 2005, prepared by SmithBucklin Corporation at bci.dev.web.sbs.com/BCIRecyclingRate StudyReport.pdf.

[49] Amount Collected/Amount Scrap Arising. Battery Association of Japan

[50] Recovered Paper Used/Total Paper Consumption (2006) Confederation of European Paper Industries for EU 27 plus Norway and Switzerland. See www.paperrecovery.org. Updated figures are made available on their website annually. Some paper is not collectable (libraries, archives, etc) and some paper is not recoverable (hygiene paper, etc) and as such the theoretical maximum for paper recycling is estimated at 81%. A further study by BIR can be seen at www.bir.org/aboutrecycling/paper (table 10 provides some figures for import and export of recovered paper worldwide which could be investigated further).

[51] Recovery/Consumption (2007) American Forest & Paper Association (www.afandpa). 50% was reported for 2005 in OECD Environmental Data 2007.

[52] (2003) OECD Environmental Data 2007. See also Paper Recycling Promotion Center, www.prpc.or.jp.

[53] Collection/Consumption (2006) Petcore for EU27 plus Norway, Switzerland, Iceland and Turkey.

[54] Collection/Amount Scrap Arising (2006) Napcor Report. The EPA indicates 31% for plastic soft drink bottles (www.epa.gov/epaoswer/non-hw/muncpl/recycle.htm#figures).

[55] Collection/Consumption (2006) Council for PET Bottle Recycling, Japan.

[56] Recovery/Amount Scrap Arising, (2006) ETRMA (European Tyre & Rubber Manufacturers' Association) for EU 27 plus Norway and Switzerland.

[57] Recovery/Amount Scrap Arising, (2005) RMA (Rubber Manufacturers Association).

[58] Recovery/Amount Scrap Arising (2006) Japan Automobile Tyre Manufacturers Association Inc).

[59] Collection/Consumption (2007) Association of European Producers of Steel for Packaging (APEAL) for EU 27 plus Switzerland and Norway.

[60] Collection/Consumption (2006) Steel Recycling Institute, www.recycle-steel.org

[61] Amount Used in Recycling /Consumption (2006) Japan Steel Can Recycling Association. 2007 annual report is available at www.steelcan.jp/english/index.html.

[62] Amount Recovered/Amount Scrap Arising (2007). This is a significant increase on the 2% rate in 1996. See further www.woodrecyclers.org/recycling.php. Most is recycled to make chipboard/particle board and MDF products; however markets are increasing for landscaping products and animal and poultry bedding.

[63] ECCO.

[64] Lauritzen, E "Recycling Concrete- An Overview of Development and Challenges" (2004) RILEM Conference Paper.

[65] www.concreterecycling.org/histories.html

[66] onsite.rmit.edu.au

[67] onsite.rmit.edu.au

[68] www.aggregain.org.uk/case_studies/2716_use_of_recy.html

[69] Part of the summary of results of the EU financed project Integrated Decontaminated and Rehabilitation of Buildings, Structures and Materials in Urban Renewal (IRMA), "City Concept, Sustainable Value Creation within Urban Renewal" see further www.projweb.niras.dk/irma

[70] UEPG 2006 statistics published 2008 have a figure of 6%. QPA (October 2007) has higher figures and gives 2006 stats as 8% European average and 26% in GB

[71] USGS Fact Sheet FS-181-99 (Feb 2000). In 2006, 2.95 billion metric tonnes of aggregate were produced in the US. (www.nssga.org and www.usgs.com).

[72] (see www.uepg.eu/index.php?pid=141 in final draft need to generate table and remove * from Ireland and Denmark)

[73] Lohja Rudus, Use of Reclaimed Concrete in Pavement Structures, Design Manual and Construction Specifications 2000 at page 7.

[74] FHWA Transportation Applications of Recycled Concrete Aggregate, Sept 2004 at page 18.

[75] As of 2004, eight US states were reported as using recycled aggregate in hot mix asphalt (FHWA). The high absorption rate of recycled aggregate increases the requirements for asphalt cement (bitumen) and therefore use has been limited (FHWA Sept 2004 report at page 26). CRH currently reuses waste asphalt products back into sub-base asphalt products.

[76] Obla, K et al, Crushed Returned Concrete as Aggregates for New Concrete, Final Report to the RMC Research and Education Foundation Project 05-13 (2007).

[77] WRAP Performance Related Approach to Use of Recycled Aggregates (2007).

[78] Clark, in Australia's Guide to Environmentally Sustainable Homes, Your Home Technical Manual online at www.greenhouse.gov.au/yourhome/technical/fs34f.htm

[79] DAfStb Richtlinie : Concrete acc. DIN EN 206-1 and DIN 1045-2 with recycled aggregates acc. to DIN 4226-100

[80] FHWA State if the Practice National Review Transportation Applications of Recycled Concrete Aggregate (2004) US Dept of Transport

[81] MONITORING BOUWSTOFFENBESLUIT, Monitoring kwaliteit bouwstoffen 2003-2004, Report by Intron for the Dutch Environment, Land Use and Planning Agency (VROM) 2005

[82] Dosho, TEPCO Japan 2007. TEPCO have developed a system of crushing and wet grinding to reduce this potential problem.

[83] WRAP, Testing of Concrete to Determine the Effects on Groundwater (2007)

[84] Consultest AG (1998)

[85] See Eco-Efficient and Ready Mix Concrete Plants and Concrete Production, A handbook by the Association of the Swiss Aggregates and Concrete Industry, 2003.

[86] www.concretethinker.com/Papers.aspx?DocId=25

[87] www.bentumrecycling.nl/uk/brc_C&DWrecyclingschema.htm

[88] See for example, www.cdeglobal.com.

[89] See pages 24 and 28 of Capita Symonds Ltd for the Department for Communities and Local Government Survey of Arisings and use of Alternatives to Primary Aggregates in England, 2005, Published February 2007.

[90] For further information about using microwave techniques, see for example, www.fzk.de/ihm and search for FRANKA. IHM is the "Institut für Hochleistungsimpuls-und Mikrowellentechnik" and FRANKA is a machine developed for the fragmentation of waste.

[91] See FHWA State of the Practice National Review, September 2004.

[92] See FHWA report (2004) and CMRA (Construction Material Recycling Association) www.cdrecycling.org. The EPA does not however include recycled concrete aggregate in the recommended recovered materials content for new concrete in the Comprehensive Procurement Guidelines Program. See www.epa.gov/epaoswer/non-hw/procure/products/cement.htm.

[93] Lauritzen, E "Recycling Concrete - An Overview of Development and Challenges" (2004) RILEM Conference Paper.

[94] See www.Aggregain.Org.Uk/Quality/Aggregates_Standards/European.Html

[95] Australian Standard (Guideline) "HB 155" breaks recycled concrete waste into a number of use categories and develops specifications for the materials acceptable use in construction

[96] International Union of Laboratories and Experts in Construction Materials, Systems and Structures www.rilem.org

[97] UNEP, Buildings and Climate Change (2007) at page 1.

[98] 2007 figures from US Green Building Council.

[99] www.planningportal.gov.uk/england/professionals/en/1115314116927.html

[100] www.worldgbc.org

[101] www.pierrebleuebelge.be

[102] www.natureplus.org

[103] See for examples comments at www.sustainableconcrete.org.uk/main.asp?page=127.

[104] www.envirocentre.co.uk/downloads/rsc/6_SDP_4_Design_for_Deconstruction.pdf, page 6-1

[105] See also, for example, Design for Disassembly and Adaptability Guidelines of the Canadian Standards Association at www.csa.ca/sustainablebuilding

[106] www.ifdbouwen.be/media/docs/voorbeeldprojecten/Voorbeeldproject6.pdf

www.wbcsdcement.org

CSI members

ASH GROVE USA	Holcim Switzerland
Camargo Corrêa Brazil	Italcementi Italcementi Group Italy
CEMEX Mexico	LAFARGE France
CEMENTOS MOLINS Spain	SECIL Portugal
LIZ CIMENTOS Spain	SCL India
CIMPOR Portugal	SCG CEMENT Thailand
CRH Ireland	TAIHEIYO CEMENT Japan
GRASIM Grasim Industries Limited India	TITAN Greece
HEIDELBERGCEMENT Germany	Votorantim Cimentos Brazil

About the WBCSD

The World Business Council for Sustainable Development (WBCSD) is a unique, CEO-led, global association of some 200 companies dealing exclusively with business and sustainable development. The Council provides a platform for companies to explore sustainable development, share knowledge, experiences and best practices, and to advocate business positions on these issues in a variety of forums, working with governments and non-governmental and intergovernmental organizations.
www.wbcsd.org

About the CSI

The Cement Sustainability Initiative (CSI) is a global effort by 18 leading cement producers. Headquartered in 14 countries, they have operations in more than 100 countries. Collectively, these companies account for about 30% of the world's cement production and range in size from very large multinationals to smaller local producers.
All CSI members have integrated sustainable development into their business strategies and operations, as they seek strong financial performance with an equally strong commitment to social and environmental responsibility. Over its 10-year history, the CSI has focused on understanding, managing and minimizing the impacts of cement production and use by addressing a range of issues, including: climate change, fuel use, employee safety, airborne emissions, concrete recycling and quarry management.
www.wbcsdcement.org

Project Director
Howard Klee

World Business Council for Sustainable Development – WBCSD

Chemin de Conches 4
1231 Conches-Geneva
Switzerland
Tel: +41 (0)22 839 31 00
Fax: +41 (0)22 839 31 31
E-mail: info@wbcsd.org,
Web: www.wbcsd.org

WBCSD North America Office

1744 R Street NW
Washington, D.C. 20009
United States
Tel: +1 202 420 7745
Fax: +1 202 265 1662
E-mail: washington@wbcsd.org

Design: Atelier Point Virgule
Photo credits: CSI participating companies, Istockphoto

ISBN: 978-3-940388-49-0