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GERMANY'S CONSTRUCTION & DEMOLITION DEBRIS RECYCLING INFRASTRUCTURE: WHAT LESSONS DOES IT HAVE FOR THE U.S.?

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I. Introduction

Construction and demolition (C & D) debris represents a major component of municipal solid waste (MSW), ranging from 15-25% (in quantity, it is second only to paper). Rapidly filling landfills, tougher waste management and environmental regulations such as California's AB939, and increased public resistance have begun to limit the types and quantities of materials accepted at landfills and to increase the difficulty of permitting new landfills. As a result, the disposal of C & D debris has become not only an important environmental issue, but also a critical economic issue for the construction industry. For the first time, disposal costs are beginning to play a significant role in construction costs and thus a contractor's bottom line.

A functioning C & D debris recycling infrastructure in the U.S. is only now beginning to develop. While there are no state or national statistics available on the amount of C & D debris being recycled, a few municipalities have estimated this figure to be less than 5% for their communities (Steutcville, 1992). Regulatory and permitting obstacles, economic disincentives, and the absence of a comprehensive infrastructure all hinder the recycling of C & D debris. C & D debris that is recycled is typically used for applications with minimal quality requirements, such as using crushed concrete as sub-base or base course materials in highway construction, or using wood waste as a fuel source for power generation.

In Germany, C & D debris plays an even greater role in MSW composition. C & D debris comprises roughly 80% by weight and 60% by volume of Germany's annual MSW generation (Kohler, 1991a). Of the 12 countries in the European Economic Community (EEC), Germany generates more than a third of all C & D debris (Bruchner et al., 1992). With re-unification, the recycling of C & D debris has become increasingly important, as old Cold War structures are demolished, such as the Berlin Wall, which was recycled into road base material, and the government struggles to rebuild the infrastructure in the eastern part of the country.

A mature C & D debris recycling infrastructure already exists in Germany, where economic and regulatory incentives promote recycling. As a result, over 30% of C & D debris is currently recycled, and government objectives call for this to double by 1995 (Hanisch et al., 1991). The development of this infrastructure dates back to the end of World War II and the Trömmelfrauen, the women who salvaged usable bricks from bombing rubble. Due to shortages of construction materials, millions of tons of bombing debris were reused and recycled. Mechanical processing plants, some of which are still in operation today, crushed and screened damaged bricks and roofing tiles to produce aggregate mixtures used as road base, in the production of paving stones,

and in new concrete (Hiersche et al., 1990). Today there are more than 400 C & D debris recycling facilities scattered throughout Germany (Bruchner et al., 1992).

While Germany's C & D debris recycling infrastructure is well developed, there are other European countries, such as Belgium and the Netherlands, that have even higher recycling rates (Bruchner et al., 1992). Nonetheless, Germany's C & D debris recycling infrastructure presents an excellent model for studying the do's and don'ts of C & D debris recycling. Of particular interest are the myriad of proposed and enacted laws, regulations and specifications, as well as general market conditions. Despite inherent differences between the U.S. and Germany, there are components of Germany's C & D debris recycling infrastructure that, when properly applied to U.S. conditions, could promote increases in the level of C & D debris recycling in this country.

II. Germany's C & D Debris Recycling Infrastructure

A. Definition & Classification of C & D debris

In Germany there is a more detailed classification system for distinguishing between the different types of C & D debris than in the U.S., one that has also caused a large degree of confusion. The federal government, in an attempt to prevent such confusion and simplify regulatory protocol, established a few basic terms for classifying C & D debris. Although there are inconsistencies in specific terminology among federal and state regulatory agencies, as well as the C & D debris recycling industry, it is still useful to review the federal government's definitions.

The term construction wastes (*Baureststoffe*) is generally used as the generic term for describing wastes resulting from construction activities. In some classification systems, this is then divided into two groups based on the type of construction activity: highway and heavy civil construction wastes (*Tiefbaureststoffe*) and building construction wastes (*Hochbaureststoffe*). Wastes generated from highway and heavy civil construction are further divided into two categories: excavation materials (*Erdaushub*) and road construction demolition debris, also known as scarifying (*Straßenaufbruch*). Building construction wastes are also classified into two groups: demolition debris (*Bauschutt*) and construction debris (*Baustellenabfälle*). In the federal system, specific types of construction wastes are then classified in these four categories. Most other classification methods, however, omit the distinction between highway and heavy civil, and building construction wastes. A graphical representation of the characterization of construction wastes is given in Figure 1. Because there is no perfect translation for the German nomenclature, what is presented is a best attempt to correlate the German terminology with an appropriate U.S. C & D debris recycling vocabulary.

It is only in the past few years that a differentiation between demolition debris and construction debris has been made, and even today there is still disagreement about what this category does and does not include. The most common definition of demolition debris refers to clean, non-contaminated mineral materials, such as concrete and brick rubble. Construction debris, on the other hand, consists mostly of non-mineral materials, such as wood, plastics, paints, varnishes, metals, and cables. Confusion arises when classifying non-mineral wastes that result from demolition activities. Depending on the specific methodology, these are either classified as demolition debris, or as construction debris. Non-mineral construction wastes are the most difficult to recycle, due to the large variety of materials and a high degree of contamination.

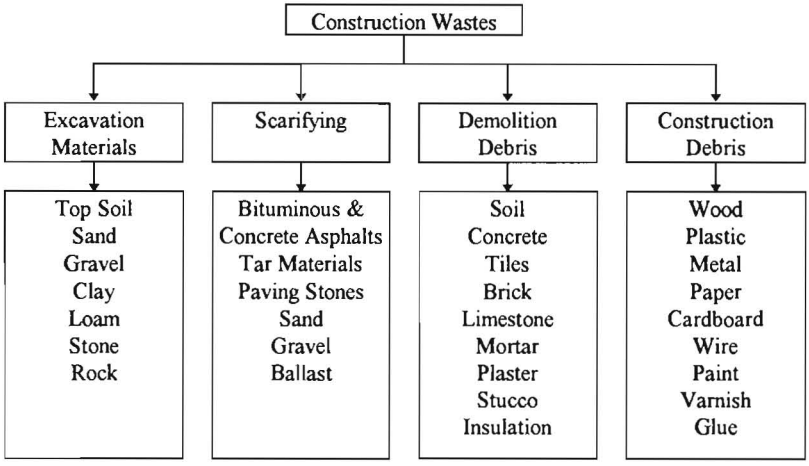

Figure 1. Classification of C & D Debris (Bilitewski, 1993)

B. Generation and Composition

In Germany, as in the U.S., there is a lack of reliable data that give a comprehensive estimate of the quantity and composition of C & D debris generated. According to the federal government's projections, roughly 220 million metric tons of C & D debris were generated in West Germany in 1989, the highest of any country in the EEC (Hanisch et al., 1991). Table 1 shows estimated waste generation in 1989 by category in millions of metric tons and as a percentage of total C & D debris generation. It also shows the actual recycling percentages for 1989 and the mandated recycling quotas to become effective in 1995. Because waste management statistics do not separate the generation of construction debris from that of light industrial waste, the 10 million metric tons of construction debris is an estimate (Hiersche, 1991). Although there are numerous discrepancies in these figures, they are the most commonly accepted in the literature.

Table 1. Generation and Recycling Rates of C & D Debris (Hanisch et al., 1991)

Type of Construction Waste	1989 Generation (10^6 metric tons)	1989 Generation (%)	1989 Recycling (%)	1995 Recycling Quota (%)
Excavation Materials	167.9	76.0	32	100
Demolition Debris	22.6	10.2	16	60
Scarifying	20.4	9.2	55	90
Construction Debris	10	4.6	0	40

Experts estimate that the generation of C & D debris in East Germany equals approximately 30% of that in West Germany (Positive Entwicklung, 1992). When this figure is added to 1989 generation rates for West Germany, the total generation of C & D debris for all of Germany

becomes more than 290 million metric tons. There is, however, much disagreement about the accuracy of this estimate.

In 1989 over 68 million metric tons of C & D debris was recycled. Of this, 14.9 million metric tons of demolition debris and scarifying was recycled. In comparison, 500 million metric tons of processed mineral materials are consumed yearly in West Germany, 200 million metric tons alone for highway construction (Hanisch et al., 1991). The high demand for mineral resources shows strong market opportunities for recycled C & D debris. While one of the main problems in the U.S. is stimulating adequate demand for recycled C & D debris, this is not a problem in Germany.

Excavation materials made up over 75% of all German construction wastes in 1989, by far the largest contribution of any single waste category. Currently, however, only 32% of excavation materials are recycled. There are virtually no technical difficulties with the recycling of excavation materials, however, excavation materials contaminated with toxic substances require a higher level of processing, including remediation activities, which can dramatically increase processing costs. Potential uses for recycled excavation materials include, among other things, landfill covers.

Scarifying, which is relatively easy to process and recycle, has the highest recycling rate at roughly 55%. Bituminous asphalt pavements can be processed into recycled aggregate on site and incorporated directly in new asphalt pavements. Concrete asphalt pavements are typically crushed and used as sub-base or road base material. In some cases, crushed concrete can also be used as aggregate in new concrete pavements.

Most demolition debris is easily processed into secondary construction materials with minimal technical difficulty, depending on the degree of contamination. The greater the contamination the more difficult it is to produce high quality mineral products. Demolition debris is typically used in highway construction, again as sub-base or road base materials. The current recycling rate of 16% is relatively low in relationship to the technical difficulty of processing this waste type. This is primarily due to the mixing of demolition debris with contaminated construction debris.

Construction debris makes the smallest contribution to the generation of construction wastes, with only 4.6%. Construction debris is, however, the most difficult to recycle due to high levels of contamination and a large degree of heterogeneity. Until now, construction debris has typically been landfilled, or in some cases even incinerated. Thus, there is very little practical recycling experience. Also, the market for non-mineral recycled construction products is still largely undeveloped.

C. Regulations

In Germany there are three proposed federal legislative acts currently being debated that address both the environmental and waste management issues associated with C & D debris:

- Definition of Objectives for the Prevention, Reduction, or Recycling of C & D Debris (*Zielfestlegung der Bundesregierung zur Vermeidung, Verringergung oder Verwertung von Bauschutt, Baustellenabfällen, Bodenaushub, und Straßenaufbruch*)
- Regulation on the Disposal of Construction Debris (*Verordung über die Entsorgung von Baurestabfällen*)
- Waste Charges Act (*Abfallabgabengesetz*)

These regulations deal with both the recycling of C & D debris and the proper disposal practices for the remaining waste, as well as the appropriate use of the processed C & D debris. As of June 1993, however, all of these regulations were still in draft form and it is highly questionable if any of them will survive the conference committee negotiation process and be approved by the Bundesrat, the lower house of the German parliament. While these regulations have yet to be enacted, their development has nonetheless motivated the construction industry to work towards developing a better C & D debris recycling infrastructure in anticipation of impending legislation. Moreover, the evolution of these proposed regulations has also prompted an examination of important issues by the construction industry and different regulatory agencies, including the issues of recycling feasibility and liability for the generation of waste.

The main goals and objectives of these proposed regulations are as follows (Willing, 1991):

- Develop construction materials that are recyclable and contain recycled C & D debris.
- Develop construction methods that allow for future recycling and the reduction of waste.
- Prevent and reduce C & D debris generated from demolition and construction activities.
- Reduce the reliance on landfills as a means of disposal.
- Separate recyclable C & D debris from non-recyclable waste materials directly at the construction site and collect these waste materials for proper disposal.
- Prevent recyclable C & D debris from being landfilled.
- Provide environmental protection from hazardous C & D debris.
- Increase the economic viability of waste prevention and recycling measures.
- Stimulate demand for recycled C & D debris by giving preference to their use over equivalent virgin materials on public projects.

Each proposed regulation has specific components designed to achieve certain goals. The Definition of Objectives for the Prevention, Reduction, or Recycling of C & D Debris sets strict recycling quotas for the different types of construction wastes by the year 1995. Although these proposed recycling quotas exceed actual recycling for all of the individual types of C & D debris, the most controversial quota is that for construction debris. Many experts feel the proposed recycling quota of 40% for construction debris is extremely unrealistic and believe that, despite the proposed separate collection requirements, the majority of this waste type will nonetheless be landfilled. There is generally less resistance to the proposed quotas for the other types of C & D debris, due to the fact that these waste types are generally much easier to process and recycle.

The Definition of Objectives for the Prevention, Reduction, or Recycling of C & D Debris and the Regulation on the Disposal of Construction Debris compliment each other and form a coherent legislative package. The former is the federal government's concept of measures needed to solve the C & D debris problem, including proposed recycling quotas to reduce the amount of waste landfilled, while the latter dictates specific waste management practices, such as separate collection of recyclable C & D debris from other contaminated construction wastes. It remains to be seen, however, how much regulatory power the final draft of these regulations contain, and if they are sufficient to motivate the German construction industry to reach the intended recycling quotas.

The proposed Waste Charges Act, which would impose a tiered fee structure on C & D debris based on the harmfulness of the waste, has the most significant and direct economic impact on the construction industry. Estimates indicate that these fees would increase the construction industry's operating costs by approximately 1.5 billion DM/year (roughly $940,000 @ 1.6 DM/$). It is not

surprising, therefore, that the construction industry, as well as other industry groups, lobbied heavily against this proposed regulation. It is highly unlikely this regulation will ever be enacted.

Currently there is much discussion about whether C & D debris should be classified as actual waste (*Abfall*), or whether C & D debris should instead be treated as an economic good (*Wirtschaftsgut*). This differentiation is important for determining what regulations apply for the processing of C & D debris. The classification of excavation materials is a good example of the controversy surrounding the definition of waste. According to the federal waste act, all excavation materials are classified as waste: there is no distinction between contaminated and non-contaminated excavation materials. This can increase construction costs, because additional backfill materials need to be imported, rather than re-using available on-site materials. In addition, valuable landfill capacity is used to dispose of re-useable excavation materials.

D. Standards & Specifications

There are numerous standards in Germany dealing with construction methods and materials. It is very difficult, if not impossible, to easily gain a comprehensive overview of all the different layers of specifications and standards. •When considering potential environmental impacts these standards become even more complicated and confusing. Because almost all recycled C & D debris is currently used in highway construction (and virtually all recycled C & D debris consists of mineral materials), the greatest emphasis concerning the development of appropriate standards for the use of recycled C & D debris has taken place in this area. There are, however, no specific standards related to the application of recycled C & D debris.

Due to the absence of specifications for recycled C & D debris, a protocol was developed in 1985 for using recycled C & D debris in highway construction. This protocol, known as the Directions for the Application of Secondary Industrial Products in Highway Construction, Part 4: Recycling of Construction Materials (*Merkblatt über die Verwendung von industriellen Nebenprodukten im Straßenbau, Teil 4: Wiederverwendung von Baustoffen*), dictates the specific testing sequence for different material properties and also specifies additional tests to determine the potential environmental impacts of using such materials (Kohler, 1991b).

Following the issuance of these directions, the C & D debris recycling industry formed an organization (*Gütegemeinschaft Recycling-Baustoffe e.V.*) to provide quality assurance for recycled C & D debris (Kohler, 1991b). This industry organization provides quality seals to processors of C & D debris that meet specific quality standards and has developed voluntary standards for recycled C & D debris used in highway construction (*RAL-RG 501/1: Recycling-Baustoffe für den Straßenbau*). These standards classify recycled C & D debris into three groups based on their intended application (Kohler, 1991b). For each group, a certain protocol is specified for guaranteeing the quality of the materials. In addition, the processed C & D debris must be tested for the suitability of their intended application, and the processor's processing facility, laboratory facilities, and protocol for in-house testing must be evaluated (Kohler, 1991b). This quality seal is used by C & D debris processors as a marketing tool and has helped to increase the acceptance of recycled C & D debris as viable secondary construction materials.

Aside from such industry standards in the area of highway construction, there are no other standards for the application of recycled C & D debris. One area that has remained largely unexplored is the development of standards for the use of recycled C & D debris in other areas, for

example, as aggregate in concrete. There are extensive German industrial standards that specifically address the selection and application of concrete aggregates (DIN 4226: Zuschlag für Beton), however the use of recycled concrete, or brick as aggregate is not sufficiently addressed. If a contractor or owner wants to specify the use of such materials as concrete aggregate on a project, individual tests must be conducted in order to obtain approval.

Moreover, the use of crushed brick as a concrete aggregate is now prohibited. Following World War II, much research was done on the use of crushed brick as a concrete aggregate. There were even industrial specifications developed to regulate the use of this material (*DIN 4163: Ziegel-splittbeton*), and crushed brick was widely used in concrete. After the collapse of a few buildings constructed with crushed brick aggregate, the specifications were removed from circulation. There still remains much conflict about the use of crushed brick as a concrete aggregate. However, there is general acceptance that it is not the material itself that poses a problem, but rather its effect on the water-cement ratio and thus strength development that presents a problem for its application in daily construction activities. The use of crushed brick in highway construction is also limited, because it is very porous and therefore does not provide adequate protection against freeze-thaw heaving. The lack of an adequate market for crushed brick is rapidly becoming a critical problem in the C & D debris recycling industry, especially since rehabilitation of East German facilities has produced mountains of old brick.

E. Market Aspects & Economics

Perhaps the primary reason the C & D debris recycling infrastructure is more developed in Germany than in the U.S. lies in the economic climate. In Germany, landfill capacity is much more scarce than in the U.S., and it is virtually impossible to get incinerator facilities permitted. As a result, tipping fees are generally much higher than in most locations in the U.S. More importantly, disposal fee schedules are not based on a fixed price per ton as in the U.S., but rather are material specific. The higher the degree of contamination, the difficulty of recovery, and the potential environmental hazards from the waste materials, the higher the tipping fee. Disposal costs for mixed C & D debris in Berlin, for example, start at roughly 150 DM/metric ton (roughly $94/metric ton @ 1.6 DM/$), while the disposal of segregated demolition debris costs only 25 DM/metric ton (approximately $16/metric ton @ 1.6 DM/$). Although there are no federal landfill taxes, many states impose waste specific landfill taxes. States, such as Berlin, also strictly regulate the disposal of C & D debris. Finally, there are federal and state programs, which include interest loans, to help subsidize the capital costs of C & D debris processing facilities.

III. Obstacles to the Development of a U.S. C & D Debris Recycling Infrastructure

There remain many obstacles to not only the further development of an adequate U.S. C & D debris recycling infrastructure, but also the adaptation of appropriate components from the German C & D debris recycling infrastructure. These obstacles can be classified in the following interrelated groups: economics, regulatory climate, construction methods and materials, geography, and cultural differences.

Economics is the most important obstacle to implementing a functioning C & D debris recycling infrastructure in the U.S. Current tipping fees simply do not incorporate the necessary environmental externalities: the true costs of consumption and disposal are not reflected. There is a lack of a life cycle pricing mechanism which includes the true costs of disposal: the loss of valuable

resources, the potential discharge of pollutants into ground water, and the clean up of possible hazardous waste contamination. In addition, there is a complicated network of hidden resource extraction subsidies and tax credits that save logging and mining companies alone several hundreds of millions (and perhaps even billions) of dollars every year. In the San Bernardino National Forest, as described in (Losos, et al., 1993), mining companies extract $200 million worth of calcium and limestone annually. The federal government receives no royalties for the extraction of these materials, a loss estimated at roughly $25 million per year. Moreover, the U.S. Forest Service budgets $200,000 every year to pay for the management of mining-related activities, while having no jurisdiction to enforce environmental standards

The regulatory climate in the U.S. is much different from that in Germany. Despite such wide-ranging legislative reform efforts as the Clean Air Act or the pending Desert Protection Act, the U.S. regulatory climate is generally not as proactive in promoting recycling as in Germany. One primary reason for this is a fundamental difference in priorities. In Germany, where there is a critical shortage of landfill capacity, the primary emphasis of waste management legislation is waste reduction. In the U.S., on the other hand, the emphasis is instead on environmental protection. As a result, current U.S. federal waste management legislation does not support the recycling of MSW, or C & D debris. With the re-authorization of the Resource Conservation and Recovery Act (RCRA) not scheduled until late 1995 or 1996, this situation will not change in the immediate future. While federal regulations governing the recycling of C & D debris in Germany are still in draft form, that is nonetheless more than has been achieved in the U.S.

Differences in construction materials and methodologies also impede the further development of a functioning C & D debris recycling infrastructure in the U.S. In Germany, where there is very limited use of wood, C & D debris is relatively homogeneous and consists primarily of mineral materials such as concrete and brick rubble. Due to heavy reliance on wood and wood products here in the U.S., C & D debris is much more heterogeneous and thus subject to a higher degree of contamination. Because tipping fees are higher in Germany, it is also more common to practice segregated demolition techniques, which reduce potential contamination and facilitate C & D debris recycling. Finally, the national standardization of codes and specifications in Germany more readily allows for the use of recycled content materials. There are, however, specific codes that prohibit the use recycled content construction materials in both countries.

The size of the U.S., more than 26 times that of Germany, is also a significant obstacle to implementing components of Germany's C & D debris recycling infrastructure. There are different regions with different boundary conditions governing the management of C & D debris throughout the U.S. It is impossible to simply copy the complete German C & D debris recycling infrastructure, since certain components are not applicable in certain regions. In the Northeast, where disposal fees are typically the highest, there is more recycling of C & D debris being done than in other parts of the country, such as California, where landfill capacity is still relatively plentiful. Adapting specific components of the German C & D debris recycling infrastructure would be most applicable in urban areas with high population densities currently lacking C & D debris recycling facilities.

Finally, there are also important cultural differences that inhibit the recycling of C & D debris, as well as MSW, in the U.S. In Germany, where there are deposits on plastic soda bottles and a fee for grocery bags, there is much more emphasis on the reuse of materials, as well as a better awareness of environmental issues. This derives, in part, from Europe's long history of reusing resources, from mining old Roman Empire structures for use as building materials during the

Middle Ages to salvaging bricks for new construction from bombing rubble after World War II. There is also a fundamental difference in the perception of waste versus resource. In Germany, recyclables are viewed as resources whereas in the U.S. they are regarded as waste materials. Germany, as a society, also seems to have a much different attitude towards regulations, viewing them as a necessary mechanism for maintaining order. In the U.S., however, regulations are typically viewed as an inconvenience and a potential threat to individual freedoms.

IV. Conclusions & Recommendations

In Germany, the C & D debris recycling infrastructure is much more developed than in the U.S. as a whole, as evidenced by much higher recycling rates. This is due not only to cultural and geographical differences, as well as differences in construction methods and materials, but also to differences in the regulatory and economic climate. Of these differences, it is easiest to modify the regulatory and economic climate to promote C & D debris recycling. While certain components of Germany's C & D debris recycling infrastructure, such as the lack of comprehensive standards for recycled content construction materials or complicated licensing procedures for processing facilities, can also hinder C & D debris recycling, other components are particularly beneficial in promoting C & D debris recycling. These beneficial aspects may be applicable to regions in the U.S. where an adequate C & D debris recycling infrastructure currently does not exist.

Developing economic incentives to appropriately allocate environmental externalities is the first step toward building a functioning C & D debris recycling infrastructure. These incentives, which could be modeled after those in Germany, will help to capture the true costs of landfilling C & D debris. For example, different types of waste fees similar to the landfill tax mechanism used by certain German states could be used to better assign a material's life-cycle costs, making C & D debris recycling a more viable economic alternative. Moreover, a program could also be developed to provide subsidies and low interest loans for processing equipment in order to assist in initial development of a physical infrastructure.

In addition to economic incentives, legislative measures could be used to foster demand for recycled content construction materials in order to sustain a functioning C & D debris infrastructure. Legislative measures, again modeled after those in Germany, could be used to overcome market barriers to recycled content construction materials. These barriers include the absence of a physical infrastructure, the lack of adequate R & D, and an uneducated public. Demand could be stimulated by requiring the use of recycled content construction materials on publicly funded projects, as certain German states do. In addition to requiring the use of scrap tires in bituminous asphalt pavements, as in the re-authorization of the 1991 Surface Transportation Act (Healey, 1994), legislation could also require states to use recycled content construction materials or lose their federal funding. Contractor incentives for using recycled content materials could also be developed.

The development of a C & D debris recycling infrastructure will conserve valuable natural resources, as well as reduce the reliance on landfills and future environmental problems. This, however, is only a small part of the overall solution. The simplest way to encourage C & D debris recycling and at the same time develop a market structure which reflects a resource's true life-cycle costs is to eliminate the complicated network of subsidies that exists for the extraction of natural resources. This will allow recycled content construction materials to compete with their virgin counterparts on a more even playing field. Moreover, the construction industry and engineering

community should work together not only to support the development of an efficient C & D debris recycling infrastructure and the use of recycled content construction materials, but also to encourage better use of resources. Together, they should promote more sustainable design and construction practices, which conserve resources, minimize waste generation, and allow for recycling over a facility's life-cycle. The economic and regulatory components of the German C & D debris recycling infrastructure provide a good starting point for obtaining these goals. Finally, C & D debris needs to be viewed as a resource, rather than as a waste. Fostering the development of cultural perspectives similar to those in Germany, for example, could help facilitate such a change.

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