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The economics of recycling in the US construction industry

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ABSTRACT: In a free-market society, business decisions are driven by economic incentives, i.e. mostly profit, subject to government regulations and interventions. Decisions about the use of recycled materials in construction are no exception. In fact, based on purely economic factors, virgin materials are usually preferable for various reasons. But the playing field is often skewed, because the US economy does not value sustainability issues such as disposal costs and life cycle assessment as it should. This becomes obvious when comparing the situation in the United States with that of Japan and many European countries with greatly different degrees of governmental interventions.

This paper addresses some of the economic drivers that influence the extent to which recycled materials are utilized in the American construction industry. It examines the major differences between the United States and other developed countries, which have a number of root causes. Recommendations are made regarding actions necessary for the United States to "catch up" with countries such as Germany, The Netherlands or Japan.

1 INTRODUCTION

The United States is the wealthiest nation on earth, and it has not become this by chance. It did so as the result of several factors, namely a vast, relatively thinly populated continent with immense natural riches, opened up by adventurous and entrepreneurial pioneers. To some extent similar conditions existed at approximately the same time in South America and in the Asian part of Russia. Here is not the place to analyze the causes of why, given the similar initial conditions, the outcomes as measured by economic wealth were so vastly different. But it is safe to state that in each case the development was based largely on a comparatively wasteful exploitation of natural resources, basically without any consideration of conservation and sustainable development. It might also be mentioned that, except for a disastrous Civil War, the development of the North American continent could proceed in relative peace, especially compared with Europe, where, for example, the shortages caused by two world wars made the recycling and reuse of resources at times a matter of survival.

In the United States, the concepts of recycling and the reuse of natural and other materials have traditionally been of low priority if not nonexistent. This is no longer the case. A dramatic change in attitude can be felt today throughout the country. This change came relatively suddenly, gaining significant momentum some time in the early 1970s. A key event was the celebration of Earth Day in 1975, when a large part of the American public became aware of the limits of the nation's resources and grew concerned about the deteriorating environment, whether soil, water, or air. If any single picture could capture the cause of this awakening, it was the famous photo taken by our astronauts of "Spaceship Earth", which dramatically illustrated the fact that our planet is indeed finite in size and in resources, that we had better learn how to live within our means, and that these problems were global in nature, affecting all of humanity.

2 ECONOMICS 101

The economics of recycling cannot be discussed without first stating a few elementary facts. Above all, in a free-market economy the price of a service or commodity is determined by supply and demand. But even in such a free-market economy, government can and regularly does intervene with incentives (for example, in the form of tax write-offs) and disincentives, such as fees, penalties, or outright prohibitions, if it thinks this is in the best interest of the public. In general, government, with its legislative power, defines the boundary conditions for both supply and demand to develop. If these boundary conditions remain constant, changes in supply and demand for certain goods and services take place at their natural and usually slow pace, unless important inventions or innovations with wide ranging consequences accelerate that pace. In an open society

with representative government, also changes in public perception will eventually lead to changes of the legislative framework, under which the economy develops. For example, once the causal relationships between industrial air pollution and public health were established beyond a doubt, it was just a matter of time until public pressure led to legislation of the Federal Clean Air Act.

At present we are experiencing a fundamental change in public attitudes, spearheaded by a vocal and growing environmental community that has taken a strong foothold in the building and construction industry. This development is best illustrated by the exponential growth of membership of and the significant influence exerted by the U.S. Green Building Council, to name just one, maybe the largest pertinent organization. Thanks to the USGBC and other similar organizations we are now witnessing a fundamental overhaul of basic paradigms and value systems that already show signs of changing the entire building and construction industry. The current U.S. Administration, rather than actively promoting change, has primarily been only a reactive player at best, but there are indications that both the legislature and the executive branches of government are increasingly accommodating "the will of the people".

One example to illustrate how government intervention can quickly change the balance between supply and demand is the requirement that manufacturers of certain products be required by law to take back their products at the end of their useful life. European car manufacturers have already learned years ago to redesign their automobiles such that they can be disassembled with ease and such that most of the parts and components are readily recycled or even reused. These car manufacturers did not do this out of concern for the environment or because of modest potential economic benefits, but simply because they were required by law to do so. In other situations it was possible for such manufacturers to reap economic benefits without legislative requirements. For example, the recovery of rare and precious metals can become economically attractive as soon as the market value of such materials exceeds a certain threshold, or traditional sources for such materials are suddenly becoming inaccessible.

Within the general national economy, the construction industry occupies a special place, because it moves by far the largest quantities of material, and these are generally bulk materials that cost relatively little, compared with most manufactured goods. Concrete, for example, is the most widely used material worldwide. In the United States it is estimated that well over 500 million cubic yards of it are produced annually. This translates to almost 2 cubic yards for every man, woman and child each year, and it may cost just $75 per cubic yard, or approximately 2 cent per pound (in New York City it retails for a little more, ranging from about $100 to $115 per cubic yard). There are not many examples of any commodities that inexpensive. (For comparison, at the time of this writing, regular gasoline costs about 30 cent per pound at the pump.) These parameters, namely extremely large quantities and very low costs (and profit margins), are characteristic of the construction materials industry and define both the difficulties and opportunities for any efforts of recycling.

3 CASE IN POINT: THE CONCRETE INDUSTRY

When analyzing the economics of recycling in the concrete industry, the various ingredients of concrete need to be analyzed separately with regard to their "value", as expressed by their market price, as well as the profit margin. Discounting for now the various chemical admixtures, cement is by far the most expensive ingredient, at about $ 110 per ton in the New York area. The aggregate retails for about $ 20 per cubic yard, but that depends to a large extent on the cost of transportation. This means, cement may cost 10 times as much as aggregate. Therefore any efforts to use supplementary cementitious materials that are less costly than Portland cement are likely to realize economic benefits, regardless of any other advantages, such as improved performance or environmental benefits. This explains why no governmental intervention was required for the industry to recognize the advantages of using fly ash or ground granulated blast furnace slag as partial replacement of Portland cement.

The economic situation is quite different for aggregate, because this is so much less expensive than cement. Based on current economics considerations alone, it will be difficult to justify the substitution of a recycled aggregate for virgin material, whether natural gravel or crushed stone. Let us consider several materials that might serve as substitute for natural aggregate.

3.1 *Recycled concrete aggregate*

Construction waste constitutes a sizeable fraction of all solid waste in developed countries. In the United States it is estimated that about 150 million tons of construction waste is generated annually, and concrete debris, whether from demolished buildings or highway pavements, constitutes slightly over 50% of this amount. Almost 60% of this amount, or 45 million tons, are landfilled, with tipping fees as high as $50 per cubic yard or more. Note that such disposal costs alone may amount to more than half of the cost of new concrete. Still, recycling such concrete in the form of aggregate for new concrete is more the exception than the rule in the United States. In Japan, on the other hand, landfill capacity is rapidly diminishing, and so is the availability

of suitable virgin limestone aggregate. These are sufficient reasons for the Japanese concrete industry to rely increasingly on recycled concrete aggregate.

The economic feasibility of recycled concrete aggregate may be described in simplified form by defining the cost of virgin aggregate, C_{va}, and of recycled concrete aggregate, C_{ra}, as follows:

$$C_{va} = C_{pv} + C_{tv} \ (+ C_d) \tag{1}$$

$$C_{ra} = C_{pr} + C_{tr} + C_{sd} \tag{2}$$

where:

C_{pv} = cost of processing virgin aggregate (e.g. crushing and grading),

C_{tv} = cost of transportation of virgin aggregate,

C_d = cost of disposal of demolished concrete (if there is such),

C_{pr} = cost of processing recycled concrete aggregate (sorting, cleaning, crushing, grading),

C_{tr} = cost of transportation of recycled concrete aggregate, and

C_{sd} = a strength or quality deficit that needs to be quantified, since it is known that the performance of concrete made with recycled concrete aggregate is generally inferior to that of concrete made with virgin aggregate.

Purely economic factors, i.e., discounting any additional factors such as local, State, or Federal rules or regulations, thus will make the use of recycled concrete aggregate a feasible proposition if and only if $C_{ra} < C_{va}$.

And even in this case, other factors such as old habits or business relationships with long-time suppliers may outweigh a slight economic advantage, thus preventing a concrete producer from switching supplies.

The cost of any bulk material in general and aggregate in particular depends to a large extent on the cost of transportation, which is basically proportional to the distance to the nearest source of suitable aggregate. Thus it is obvious that the distances to the sources of virgin and recycled concrete aggregate alone may be decisive in determining the economic feasibility of using recycled concrete aggregate.

3.2 *Specialty aggregates*

The economics can change considerably when considering specialty aggregates, which endow the concrete with properties that the regular aggregate does not. The most important example is lightweight aggregate, which is popular for either the reduction of dead weight or improved thermal properties or both. The improved performance has a certain economic value for which the customer is willing to pay a premium. For example, in the New York City area, lightweight aggregate may cost three times as much as regular aggregate.

Aggregates for special architectural concrete applications are governed by their own rules of economics. For example, terrazzo is a very popular material for floors in buildings, and producers can pay a premium for specialty aggregates such as marble ships imported from Italy, because they can pass on these cost premiums to the owners for the special architectural effects they produce. The cost of terrazzo concrete is a multiple of that of regular concrete largely a result of the increased labor cost involved), which allows the producer to pay a considerable premium for the marble chips.

This last example points the way in which the use of recycled materials may make economic sense. If it is possible to identify certain concrete properties made possible with the use of such recycled materials no further economic incentives will be necessary to promote their use. For example, preliminary studies at Columbia University have indicated that material dredged from the Port of New York and New Jersey (which is typically highly contaminated), after undergoing a special treatment process, can serve as a coating for wall panels with superior fire retarding and smoke suppressing properties. Other coatings with similar performance characteristics may cost an order of magnitude more than the dredged material, which otherwise needs to be deposed of at great cost. This example illustrates that targeted research may lead to breakthroughs that do not require government intervention to level the playing field.

4 CASE IN POINT: WASTE GLASS AS AGGREGATE

4.1 *Technical aspects*

The use of post-consumer glass has been contemplated for some time, but early attempts have failed because of the reaction between the alkali in the cement and the silica in the glass, the so-called alkali-silica reaction (ASR). The resulting ASR-product, a gel, swells in the presence of moisture, which can lead to severe damage of the concrete. This problem is a technical one and can be solved. As a matter of fact, extensive studies were undertaken at Columbia University, and many test results have been reproduced at other universities. Among the proven methods to avoid ASR or its damaging effects is the use of metakaolin or fly ash as partial substitute of Portland cement.

Before discussing specific concrete products made with recycled glass aggregate it is helpful to point to the various technical advantages of such aggregate:

1. Glass has no water absorption to speak of. This is a plus, because it improves the flow properties of fresh concrete and therefore allows the use of a lower water/cement ratio.

2. Glass has excellent hardness and abrasion resistance, which makes it an ideal aggregate for floor tiles and paving stones.
3. Glass is a very durable material and resistant to many chemicals.
4. Maybe most important is the esthetic potential of colored glass and the various effects produced by light reflection and refraction. If used in combination with white cement and color pigments, it gives architects and other design professional an important new tool with basically unlimited combinations of color-coordinated cement matrix and glass particles.
5. It has also been shown that very finely ground glass powder has pozzolanic properties. This means that part of the Portland cement may be replaced by glass powder.
6. Glass powder has been shown to be a very good filler material.

4.2 *Economic aspects*

The use of post-consumer glass as aggregate for concrete products is associated with a number of cost items. The largest cost factor in large metropolitan areas such as New York City is the collection. New York City pays recyclers well over $100 per ton to collect and dispose of the glass, which residents place at the curbside, commingled with metals and plastic containers. The glass needs to be separated from the other materials before it can be cleaned and crushed. Sorting the glass by color increases its market value. For example, the glass industry will take back only clear glass (flint) for remelting. Automatic equipment is available to sort glass particles by color. Cleaning and crushing operations are also performed automatically. Compared with the cost of collection, these other costs of recycling glass for use as an aggregate for concrete are often minor, while the cost of transportation, as stated earlier, is very much a function of distance between the point of collection and the concrete producer.

In spite of the various technical advantages of glass aggregate listed above, practical applications are subject to important economic constraints. To evaluate these, we have to categorize such applications as either commodity products or value-added products. Commodity products, such as concrete masonry units or paving stones, are characterized by large volumes, low values and low profit margins, and the use of glass as aggregate is not very likely to affect the market value of the end product. For that reason, a concrete producer will not use recycled glass aggregate if he has to pay more for it than for the aggregate it replaces, that is, very inexpensive sand and gravel or crushed stone. Although such commodity products have the potential of absorbing large amounts of waste glass (one single paving stone manufacturer in the New York area could single-handedly use all waste glass collected in New York City), the economic outlook is not very promising. To avoid costly ASR-suppressing admixtures such as metakaolin, one might grind the glass fine enough to pass mesh size #50. But in this case it is be impossible to see the glass, so that the potential of added value due to the esthetic aspects of colored glass aggregate would be lost.

Value-added products, such as terrazzo tiles and table top counters, are characterized by low volumes but high profit margins. In this case, the glass would replace much more expensive specialty aggregates. To make full use of the esthetic benefits, larger size glass particles are needed, which call for ASR-suppressing additives. But the market value of the end product is considerably higher than products using regular aggregate, so that the added costs are immaterial. It is known that customers are willing to pay substantial premiums for high-quality products, such as natural stone. A large slab of Italian marble for a conference table may retail for hundreds if not thousands of dollars. A similar table top counter made of glass concrete may not fetch the same kind of price, but still a price high enough so that the material costs become all but irrelevant. An added advantage is the fact that such a slab may not only be engineered to given specifications, it can also be reinforced with short and randomly oriented fibers (for example, recycled carpet fibers) to improve the material's toughness and energy dissipation potential. It also can be reinforced with textile fabrics – a new and very promising technology. Such fabrics of fiber meshes can even be prestressed to further enhance the mechanical performance of the products.

Other economic factors are even less quantifiable, such as the novelty aspect and the label of "environmental friendliness". For example, the LEED™ rating system of the U.S. Green Building Council is gaining increasing popularity among builders and developers, who recognize the value, both tangible and intangible, of a LEED rating. It is said that apartments in the Solaire, the first "green" high-rise residential building in the United States, fetch higher rents than comparable units in conventional high-rise buildings, simply because of the cachet associated with living in a "green building". The LEED rating is based on credit points for a variety of environmentally friendly attributes such as energy-saving measures and use of recycled materials.

5 CONCLUSIONS

Engineering research is most gratifying if it leads to tangible results, especially if these results are compatible with the demands of sustainable development. To the researcher, "problems" and "difficulties" pose challenges to be overcome. The true test of the viability of a solution is to what extent it satisfies the economic aspects without the need of governmental intervention,

so that the market can decide the economic viability strictly on the basis of supply and demand. The same holds true when considering the use of recycled materials in construction. The key to success lies in the ability to identify properties inherent in the recycled materials which are unique or superior to those of traditional materials. However, such superior qualities are often not sufficient to overcome economic barriers, which all too often are based on traditional value systems that disregard the demands of sustainable development. To create a sustainable economy, it is the duty of governing bodies to assure a level playing field by including environmental costs, for example, by performing scientific life cycle cost analyses of materials and structures.