

## Sustainability Considerations in Materials

from *Fundamentals of Building Construction Materials & Methods*, 5th ed., Allen and Iano (2008)

### CONSIDERATIONS OF SUSTAINABILITY IN WOOD CONSTRUCTION

#### Wood: A Renewable Resource

- Wood is the only major structural material that is renewable.
- In the United States and Canada, tree growth each year greatly exceeds the volume of harvested trees, though many timberlands are not managed in a sustainable manner.
- On other continents, many countries long ago felled the last of their forests, and many forests in other countries are being depleted by poor management practices and slash-and-burn agriculture. Particularly in the case of tropical hardwoods, it is wise to investigate sources and to ensure that the trees were grown in a sustainable manner.
- Some panel products can be manufactured from rapidly renewable vegetable fibers, recoverable and recycled wood fibers, or recycled cellulose fibers.
- Bamboo, a rapidly renewable grass, can replace wood in the manufacture of flooring, interior paneling, and other finish carpentry applications. In other parts of the world, bamboo is used for the construction of scaffolding, concrete formwork, and even as the source of fibrous material for structural panels analogous to wood-based oriented strand board (OSB), particleboard, and fiberboard.

#### Forestry Practices

- Two basic forms of forest management are practiced in North America: sustainable forestry, and clearcutting and replanting. The clearcutting forest manager attains sustainable production by cutting all the trees in an area, leaving the stumps, tops, and limbs to decay and become compost, setting out new trees, and tending them until they are ready for harvest. In sustainable forestry, trees are harvested more selectively from a forest in such a way as to minimize damage to the forest environment and maintain the biodiversity of its natural ecosystem.
- Environmental problems often associated with logging of forests include loss of wildlife habitat, soil erosion, pollution of waterways, and air pollution from machinery exhausts and burning of tree wastes. A recently clearcut forest is a shockingly ugly tangle of stumps, branches, tops, and substandard logs left to decay. It is crisscrossed by deeply rutted, muddy haul roads. Within a few years, decay of the waste wood and new tree growth largely heal the scars. Loss of forest area may raise levels of carbon dioxide, a green-

house gas, in the atmosphere, because trees take up carbon dioxide from the air, utilize the carbon for growth, and give back pure oxygen to the atmosphere.

- The buyer of wood products can support sustainable forestry practices by specifying products certified as originating from sustainable forests, those that are managed in a socially responsible and environmentally sound manner. FSC-certified wood products, for example, satisfy the requirements of LEED and all other major green building assessment programs.

#### Mill Practices

- Skilled sawyers working with modern computerized systems can convert a high percentage of each log into marketable wood products. A measure of sawmill performance is the lumber recovery factor (LRF), which is the net volume of wood products produced from a cubic meter of log.
- Manufactured wood products such as oriented strand board, particleboard, I-joists, and laminated strand lumber efficiently utilize most of the wood fiber in a tree and can be produced from recycled or younger-growth, rapidly renewable materials; finger-jointed lumber is made by gluing end to end short pieces of lumber that might otherwise be treated as waste. The manufacturer of large, solid timbers generates more unused waste and yields fewer products from each log.
- Kiln drying uses large amounts of fuel but produces more stable, uniform lumber than air drying, which uses no fuel other than sunlight and wind.
- Mill wastes are voluminous: Bark may be shredded to sell as a landscape mulch, composted, burned, or buried in a landfill. Sawdust, chips, and wood scraps may be burned to generate steam to power the mill, used as livestock bedding, composted, burned, or buried in a landfill.
- Many wood products can be manufactured with significant percentages of recoverable or recycled wood, plant fiber, or paper materials.

#### Transportation

- Because the major commercial forests are located in concentrated regions of the United States and Canada, most lumber must be shipped considerable distances. Fuel consumption is minimized by planing and drying the

lumber before it is shipped, which reduces both weight and volume.

- Some wood products can be harvested or manufactured locally or regionally.

### Energy Content

- Solid lumber has an embodied energy of roughly 1000 to 3000 BTU per pound (2.3 to 7.0 MJ/kg). An average 8-foot-long 2 × 4 (2.4-m-long 38 × 89 mm) has an embodied energy of about 17,000 BTU (40 MJ). This includes the energy expended to fell the tree, transport the log, saw and surface the lumber, dry it in a kiln, and transport it to a building site.
- Manufactured wood products have higher embodied energy content than solid lumber, due to the glue and resin ingredients and the added energy required in their manufacture. The embodied energy of such products ranges from about 3000 to 7500 BTU per pound (7.0 to 17 MJ/kg).
- Wood construction involves large numbers of steel fasteners of various kinds. Because steel is produced by relatively energy-intensive processes, fasteners add considerably to the total energy embodied in a wood frame building.
- Wood does not have the lowest embodied energy of the major structural materials when measured on a pound-for-pound basis. However, when buildings of comparable size, but structured with either wood, light gauge steel studs, or concrete, are compared, most studies indicate that those of wood have the lowest total embodied energy of the three. This is due to wood's lighter weight (or, more precisely, its lesser density) in comparison to these other materials, as well as the relative efficiency of the wood light frame construction system.

### Construction Process

- A significant fraction of the lumber delivered to a construction site is wasted: It is cut off when each piece is sawed to size and shape and ends up on the scrap heap, which is usually burned or taken to a landfill. On-site cutting of lumber also generates considerable quantities of sawdust. Construction site waste can be reduced by designing buildings that utilize full standard lengths of lumber and full sheets of wood panel materials.
- Wood construction lends itself to various types of prefabrication that can reduce waste and improve the efficiency of material usage in comparison to on-site building methods.

### Indoor Air Quality (IAQ)

- Wood itself seldom causes IAQ problems. Very few people are sensitive to the odor of wood.
- Some of the adhesives and binders used in glue-laminated lumber, structural composite lumber, and wood panel products can cause serious IAQ problems by giving off volatile organic compounds such as formaldehyde. Alternative products with low-emitting binders and adhesives are also available.
- Some paints, varnishes, stains, and lacquers for wood also emit fumes that are unpleasant and/or unhealthful.
- In damp locations, molds and fungi may grow on wood members, creating unpleasant odors and releasing spores to which many people are allergic.

### Building Life Cycle

- If the wood frame of a building is kept dry and away from fire, it will last indefinitely. However, if the building is poorly maintained and wood elements are frequently wet, wood components may decay and require replacement.
- Wood is combustible and gives off toxic gases when it burns. It is important to keep sources of ignition away from wood and to provide smoke alarms and easy escape routes to assist building occupants in escaping from burning buildings. Where justified by building size or type of occupancy, building codes require sprinkler systems to protect against the rapid spread of fire.
- When a building is demolished, wood framing members can be recycled directly into the frame of another building, sawn into new boards or timbers, or shredded as raw material for oriented-strand materials. There is a growing industry whose business is purchasing and demolishing old barns, mills, and factories and selling their timbers as *reclaimed lumber*.

A study commissioned by the Canadian Wood Council compares the full life cycle of three similar office buildings, one each framed with wood, steel, or concrete and all three operated in a typical Canadian climate. In this study, total embodied energy for the wood building is about half of that for the steel building and two-thirds of that for the concrete building. The wood building also outperforms the others in measures of greenhouse gas emissions, air pollution, solid waste generation, and ecological impact.

## CONSIDERATIONS OF SUSTAINABILITY IN HEAVY TIMBER CONSTRUCTION

In addition to the issues of sustainability of wood production and use that were raised in the previous chapter, there are issues that pertain especially to heavy timber frame construction:

It is wasteful to saw large, solid timbers from logs: In most instances, only one or two timbers can be obtained from a log, and it is often difficult to saw smaller boards from the leftover slabs.

Glue-laminated timbers and composite timbers utilize wood fiber much more efficiently than solid timbers.

Recycled timbers from demolished mills, factories, and barns are often available. Most of these are from old-growth forests in which trees grew slowly, producing fine-grained, dense wood. As a result, many have structural properties that are superior to those of new-growth timbers. Recycled timbers may be used as is, resurfaced to give them a new appearance, or resawn into smaller members. However, they often contain old metal fasteners. Unless these are meticulously found and removed, they can damage saw blades and planer knives, causing expensive mill shutdowns while repairs are made.

Continuous bending action of beams may be created by splicing beams at points of inflection rather than over supports, as shown in Figures 4.15, 4.20 and 4.21. This reduces maximum bending moments, allowing timber sizes to be reduced substantially.

Timbers do not lose strength with age, although they do sag progressively if they are overloaded. When a heavy timber building is demolished at some time in the future, its timbers can be recycled, even if they were obtained as recycled material for the building that is being demolished.

A heavy timber frame enclosed with foam core sandwich or stressed-skin panels is relatively airtight and well insulated, with few thermal bridges. Heating and cooling of the building will consume relatively little energy.

The glues and finish coatings used with glue-laminated timbers may give off gases such as formaldehyde that can cause indoor air quality (IAQ) problems. It is wise to determine in advance what glues and coatings are to be used, and to avoid ones that may cause IAQ problems.

## CONSIDERATIONS OF SUSTAINABILITY IN WOOD LIGHT FRAME CONSTRUCTION

In addition to the issues of sustainability of wood production and use that were raised in Chapter 3, there are issues that pertain especially to wood light frame construction:

- A wood light frame building can be designed to minimize waste in several ways. It can be dimensioned to utilize full sheets and lengths of wood products. Most small buildings can be framed with studs 24 inches (610 mm) o.c. rather than 16 inches (406 mm). A stud can be eliminated at each corner by using small, inexpensive metal clips to support the interior wall finish materials. If joists and rafters are aligned directly over studs, the top plate can be a single member rather than a double one. Floor joists can be spliced at points of inflection rather than over girders; this reduces bending moments and allows use of smaller joists. Roof trusses often use less wood than conventional rafters and ceiling joists.
- Laminated strand lumber and rim joists, wood I-joists, laminated veneer lumber beams and headers, glue-laminated girders, parallel strand lumber girders, and OSB

sheathing are all materials that utilize trees more efficiently than solid lumber. Finger-jointed studs made up of short lengths of scrap lumber glued together may replace solid full-length wood studs.

- Framing carpenters can waste less lumber by saving cutoffs and reusing them rather than throwing them automatically on the scrap heap. In some localities, scrap lumber can be recycled by shredding it for use in OSB production. The burning of construction scrap should be discouraged because of the air pollution it generates.
- Although the thermal efficiency of wood light frame construction is inherently high, it can be improved substantially by various means, as shown in Figures 7.17–7.21. Wood framing is much less conductive of heat than light-gauge steel framing. Steel framing of exterior walls is not a satisfactory substitute for wood framing unless the heat flow path through the steel framing members can be broken with a substantial thickness of insulating foam.

## CONSIDERATIONS OF SUSTAINABILITY IN BRICK MASONRY

### Brick Masonry Materials

- Mortar is made of minerals that are generally abundant in the earth. Portland cement and lime are energy-intensive products. (For more information about the sustainability of cement production, see Chapter 13.)
- Clay and shale, the raw materials for bricks, are plentiful. They are usually obtained from open pits, with the attendant disruption of drainage, vegetation, and wildlife habitat.
- Clay brick can include recycled brick dust, postindustrial wastes such as fly ash, and a variety of other waste products in their manufacture.

### Brick Manufacturing

- Brick manufacturing plants are usually located close to the sources of their raw materials.
- Brick manufacturing produces few waste materials. Un-fired clay is easily recycled into the production process. Fired bricks that are unusable are ground up and recycled into the production process or used as landscaping material.
- Brick manufacturing requires relatively large amounts of water. Water that doesn't evaporate can be reused many times. Little if any water need be discharged as waste.
- Because of the energy used in its firing, brick is a relatively energy-intensive product. Its embodied energy may range from about 1000 to 4000 BTU per pound (2.3-9.3 MJ/kg).
- The most common energy source for brick kilns is natural gas, although oil and coal are also used. Firing of clay masonry produces fluorine and chlorine emissions. Other types of air pollution can result from improperly regulated kilns.
- Most bricks are sold for use in regional markets close to their point of manufacture. This reduces the energy

required for shipping and makes much brick eligible for credit as a regional material.

### Brick Masonry Construction

- Relatively small amounts of waste are generated on a construction site during brick masonry work, including partial bricks, unsatisfactory bricks, and unused mortar. These wastes generally go into landfills or are buried on the site.
- Sealers applied to brick masonry to provide water repellency and protection from staining are potential sources of emissions. Solvent-based sealers generally have higher emissions than water-based products.

### Brick Masonry Buildings

- Brick masonry is not normally associated with any indoor air quality problems, although in rare circumstances it can be a source of radon gas.
- The thermal mass effect of brick masonry can be a useful component of fuel-saving heating and cooling strategies such as solar heating and nighttime cooling.
- Brick masonry is a durable form of construction that requires relatively little maintenance and can last a very long time.
- Construction with brick masonry can reduce reliance on paint finishes, a source of volatile organic compounds.
- Brick masonry is resistant to moisture damage and mold growth.
- When a brick building is demolished, sound bricks may be cleaned of mortar and reused (once their physical properties have been verified as adequate for the new use). Brick waste can be crushed and used for landscaping. Brick and mortar waste can also be used as on-site fill. Much such waste, however, is disposed of off-site in landfills.

## CONSIDERATIONS OF SUSTAINABILITY IN STONE AND CONCRETE MASONRY

### Stone and Concrete Masonry Materials

- Stone is a plentiful but finite resource. It is usually obtained from open pits, with the attendant disruption of drainage, vegetation, and wildlife habitat.
- The detrimental impacts of stone quarrying can long outlive the buildings for which the stone was extracted.
- Quarry reclamation practices, such as revegetation, land reshaping, and habitat restoration, can mitigate some of the adverse environmental impacts of stone quarrying and convert exhausted quarry sites to other beneficial uses.
- Concrete used in the manufacture of masonry units may include recycled materials such as fly ash, crushed glass, slag, and other postindustrial wastes. For more information regarding the sustainability of concrete, see Chapter 13.
- Mortar used for stone and concrete masonry is made from minerals that are generally abundant in the earth. However, portland cement and lime are energy-intensive products to manufacture. For more information about the sustainability of cement production, see Chapter 13.

### Stone and Concrete Masonry Processing and Manufacturing

- Stone is heavy. It is expensive and energy intensive to transport. Stone may originate from local quarries or from sources in many places around the world. Fabrication may take place close to the source of the stone, close to the building site, or in some other location remote from both the stone's source and destination. Where uniquely sourced stones are desired or where specialized fabri-

cation processes or skills are required, shipping over long distances may be required.

- The cutting, shaping, and polishing operations that take place during stone fabrication use large quantities of water that becomes contaminated with stone residue, lubricants, and abrasives. Water filtration and recycling systems can prevent contaminants from entering the wastewater stream and minimize water consumption.
- As much as one-half of quarried stone may become waste during fabrication. Depending on the type of stone, waste may be crushed and used as fill material on construction sites or as aggregate in concrete or asphalt. Stone with a strong color or other unique appearance qualities may be processed into aggregate for use in the manufacture of terrazzo, architectural concrete masonry units, or synthetic stone products. Much stone waste, however, is disposed of as landfill.
- The embodied energy of building stone can vary significantly with the source of the stone, fabrication processes, and distances and methods of shipping. Stone that is easily quarried and fabricated, and that is used locally, may have an embodied energy of as little as 300 to 400 BTU per pound (0.7–0.9 MJ/kg). On the other hand, stone that requires more effort and energy to extract and fabricate, and that is transported over long distances before arriving at the building site, may have an embodied energy 10 or even 20 times greater.
- Most concrete masonry units are manufactured in regional plants relatively close to their final end-use destinations.
- The use of lightweight concrete masonry reduces transportation-related costs and energy consumption.

- The embodied energy of concrete masonry units is slightly higher than that of the concrete from which they are made, due to the additional energy consumed in the curing of the units. Ordinary concrete masonry units have an embodied energy of approximately 250 BTU per pound (0.6 MJ/kg).

### Stone and Concrete Masonry Construction

- Relatively small amounts of waste are generated on a construction site during stone and concrete masonry construction, including, for example, stone cutoffs, partial blocks, and unused mortar. These wastes generally go into landfills or are buried on the site.
- Sealers applied to stone and concrete masonry to provide water repellency and protection from staining are potential sources of emissions. Solvent-based sealers generally emit more air pollutants than water-based products.

### Stone and Concrete Masonry Buildings

- Stone and concrete masonry are not normally associated with indoor air quality problems. In rare instances, stone aggregate in concrete or stone used in stone masonry has been found to be a source of radon gas emissions.
- The thermal mass effect of stone and concrete masonry can be a useful component of fuel-saving heating and cooling strategies such as solar heating and nighttime cooling.
- Stone and concrete masonry are dense materials that can effectively reduce sound transmission between adjacent spaces.

- Stone and concrete masonry construction are non-combustible. Lightweight concrete masonry units are especially effective for construction of fire resistance rated assemblies.

- Lightweight concrete masonry units have greater thermal resistance than more dense concrete units, stone, or brick.

- Construction with stone or concrete masonry can reduce reliance on paint finishes, a source of volatile organic compounds.

- Stone and concrete masonry are durable forms of construction that require relatively little maintenance and can last a very long time.

- Stone and concrete masonry are resistant to moisture damage and mold growth.

- When a building with stone or concrete masonry is demolished, the stone or masonry units can be crushed and recycled for use as on-site fill or as aggregate for paving. Some building stone can be salvaged for new construction.

### Concrete Masonry Sitework

- Concrete masonry permeable pavers can facilitate on-site capture of storm water.

- Light-colored concrete pavers can lessen urban heat island effects.

- Interlocking concrete masonry units used in earth retaining walls are easily disassembled and reused

## CONSIDERATIONS OF SUSTAINABILITY IN STEEL FRAME CONSTRUCTION

### Manufacture

- The raw materials for steel are iron ore, coal, limestone, air, and water. The ore, coal, and limestone are minerals whose mining and quarrying cause disruption of land and loss of wildlife habitat, often coupled with pollution of streams and rivers. Coal, limestone, and low-grade iron ore are plentiful, but high-grade iron ore has been depleted in many areas of the earth.
- The steel industry has worked hard to reduce pollution of air, water, and soil, but much work remains to be done.
- Supplies of some alloying metals, such as manganese, chromium, and nickel, are becoming depleted.
- The manufacture of a ton of steel from iron ore by the basic oxygen process consumes 3170 pounds (1440 kg) of ore, 300 pounds (140 kg) of limestone, 900 pounds (410 kg) of coke (made from coal), 80 pounds (36 kg) of oxygen, and 2575 pounds (1170 kg) of air. In the process, 4550 pounds (2070 kg) of gaseous emissions are given off, and 600 pounds (270 kg) of slag and 50 pounds (23) of dust are generated. Further emissions emanate from the process of converting coal to coke.
- The embodied energy of steel produced from ore by the basic oxygen process is about 14,000 BTU per pound (33 MJ/kg). In modern facilities, scrap steel is typically added as an ingredient during this process, resulting in recycled materials content of 25 to 35 percent.
- Today, most structural steel in North America is made from recycled scrap by the electric arc furnace process; its embodied energy is approximately 4000 BTU per pound (9.3 MJ/kg), less than one-third that of steel made from ore. The recycled materials content of steel made by this process is 90 percent or higher.
- In North America, virtually all hot-rolled structural steel shapes are manufactured by the electric arc furnace process. Steel plate and sheet, used in the manufacture, for example, of light gauge steel members, decking, and hollow structural sections, may be produced by either the electric arc furnace or basic oxygen processes.
- Ninety-five percent or more of all structural steel used in North American building construction is eventually recycled or reused, which is a very high rate. In a recent one-year period, 480 million tons (430 million metric tons) of scrap steel were consumed worldwide.

- Scrap used in the production of structural steel in mini-mills usually comes from sources within approximately 300 miles (500 km) of the mill. When the steel produced in such mills is then used for the construction of buildings not too far from the mill, the steel is potentially eligible for credit as a regionally extracted, processed, and produced material. This is most likely for the most commonly used steel alloys that are produced in the greatest number of mills. However, some less commonly produced steel alloys are only available from a limited number of mills or, in some cases, are produced solely overseas, and are not eligible for such a credit except for projects located fortuitously close to the mills where these particular types of steel are produced.

### Construction

- Steel fabrication and erection are relatively clean, efficient processes, although the paints and oils used on steel members can cause air pollution.
- Steel frames are lighter in weight than concrete frames that would do the same job. This means that a steel building generally has smaller foundations and requires less excavation work.
- Some spray-on fireproofing materials can pollute the air with stray fibers.

### In Service

- Steel framing, if protected from water and fire, will last for many generations with little or no maintenance.
- Steel exposed to weather needs to be repainted periodically unless it is galvanized, given a long-lasting polymer coating, or made of more expensive stainless steel.
- Steel framing members in building walls and roofs should be thermally broken or insulated in such a way that they do not conduct heat between indoors and outdoors.
- When a steel building frame is demolished, its material is almost always recycled.
- Steel seldom causes indoor air quality problems, although surface oils and protective coatings sometimes out-gas and cause occupant discomfort.

## CONSIDERATIONS OF SUSTAINABILITY IN LIGHT GAUGE STEEL FRAMING

In addition to the sustainability issues raised in the previous chapter, which also apply here, the largest issue concerning the sustainability of light gauge steel construction is the high thermal conductivity of the framing members. If a dwelling framed with light gauge steel members is framed, insulated, and finished as if it were framed with wood, it will lose heat in winter at about double the rate of the equivalent wood structure. To overcome this limitation, energy codes now require light gauge steel framed buildings constructed in cold regions, including most of the continental United States, to be sheathed with plastic foam insulation panels in order to eliminate the extensive thermal bridging that can otherwise occur through the steel framing members.

Even with insulating sheathing, careful attention must be given to avoid undesired thermal bridges. For example, on a building with a sloped roof, a significant thermal bridge may remain through the ceiling joist-rafter connections, as seen in Figure 12.4*b*. Foam sheathing on the inside wall and ceiling surfaces is one possible way to avoid this condition, but adding insulation to the inside of the metal framing exposes the studs and stud cavities to greater temperature extremes and increases the risk of condensation. It also still allows thermal bridging through the screws used to fasten interior gypsum wallboard to the framing. Though small in area, these thermal bridges can readily conduct heat and result in spots of condensation on interior finish surfaces in very cold weather.



## CONSIDERATIONS OF SUSTAINABILITY IN CONCRETE CONSTRUCTION

- Worldwide each year, the making of concrete consumes 1.6 billion tons (1.5 billion metric tons) of portland cement, 10 billion tons (9 billion metric tons) of sand and rock, and 1 billion tons (0.9 billion metric tons) of water, making the concrete industry the largest user of natural resources in the world.
  - The quarrying of the raw materials for concrete in open pits can result in soil erosion, pollutant runoff, habitat loss, and ugly scars on the landscape.
  - Concrete construction also uses large quantities of other materials—wood, wood panel products, steel, aluminum, plastics—for formwork and reinforcing.
  - The total energy embodied in a pound of concrete varies, especially with the design strength. This is because higher-strength concrete relies on a greater proportion of portland cement in its mix, and the energy required to produce portland cement is very high in comparison to concrete's other ingredients. For average-strength concrete, the embodied energy ranges from about 200 to 300 BTU per pound (0.5-0.7 MJ/kg).
  - There are various useful approaches to increasing the sustainability of concrete construction:
    - Use waste materials from other industries, such as fly ash from power plants, slag from iron furnaces, copper slag, foundry sand, mill scale, sandblasting grit, and others, as components of cement and concrete.
    - Use concrete made from locally extracted materials and local processing plants to reduce the transportation of construction materials over long distances.
    - Minimize the use of materials for formwork and reinforcing.
    - Reduce energy consumption, waste, and pollutant emissions from every step of the process of concrete construction, from quarrying of raw materials through the eventual demolition of a concrete building.
    - In regions where the quality of the construction materials is low, improve the quality of concrete so that concrete buildings will last longer, thus reducing the demand for concrete and the need to dispose of demolition waste.
- Portland Cement**
- The production of portland cement is by far the largest user of energy in the concrete construction process, accounting for about 85 percent of the total energy required. Portland cement production also accounts for roughly 5 percent of all carbon dioxide gas generated by human activities worldwide and about 1.5 percent of such emissions in North America.
  - Since 1970, the North American cement industry has reduced the amount of energy expended in cement production by one-third, and the industry continues to work toward further reductions.
  - The manufacture of cement produces large amounts of air pollutants and dust. For every ton of cement clinker produced, almost a ton of carbon dioxide, a greenhouse gas, is released into the atmosphere. Cement production accounts for approximately 1.5 percent of carbon dioxide emissions in the United States and 5 percent of carbon dioxide emissions worldwide.
  - In the past 35 years, the emission of particulates from cement production has been reduced by more than 90 percent.
  - The cement industry is committed to reducing greenhouse gas emissions per ton of product by 10 percent from 1990 levels by the year 2020. According to the Portland Cement Association, over concrete's lifetime, it reabsorbs roughly half of the carbon dioxide released during the original cement manufacturing process.
  - The amount of portland cement used as an ingredient in concrete, and as a consequence, the energy required to produce the concrete, can be substantially reduced by the addition of certain industrial waste materials with cementing properties to the concrete mix. Substituting such supplementary cementitious materials, including fly ash, silica fume, and blast furnace slag, for up to half the portland cement in the concrete, can result in reductions in embodied energy of as great as one-third.
  - When added to concrete, fly ash is most commonly substituted for portland cement at rates of between 15 and 25 percent. Mixes with even higher replacement rates, called *high-volume-fly-ash (HVFA) concrete*, are also finding increased acceptance. Concrete mixed with fly ash as an ingredient gains other benefits as well: It needs less water than normal concrete, its heat of hydration is lower, and it shrinks less, all characteristics that lead to a denser, more durable product. Research is underway to develop concrete mixes in which fly ash completely replaces all portland cement.
  - Waste materials from other industries can also be used as cementing agents—wood ash and rice-husk ash are two examples. Used motor oil and used rubber vehicle tires can be employed as fuel in cement kilns. And while consuming waste products from other industries, a cement manufacturing plant can, if efficiently operated, generate virtually no solid waste itself.

### Aggregates and Water

- Sand and crushed stone come from abundant sources in many parts of the world, but high-quality aggregates are becoming scarce in some countries.
- In rare instances, aggregate in concrete has been found to be a source of radon gas. Concrete itself is not associated with indoor air quality problems.
- Waste materials such as crushed, recycled glass, used foundry sand, and crushed, recycled concrete can substitute for a portion of the conventional aggregates in concrete.
- Water of a quality suitable for concrete is scarce in many developing countries. Concretes that use less water by using superplasticizers, air entrainment, and fly ash could be helpful.

### Wastes

- A significant percentage of fresh concrete is not used because the truck that delivers it to the building site contains more than is needed for the job. This concrete is often dumped on the site, where it hardens and is later removed and taken to a landfill for disposal. An empty transit-mix truck must be washed out after transporting each batch, which produces a substantial volume of water that contains portland cement particles, admixtures, and aggregates. These wastes can be recovered and recycled as aggregates and mixing water, but more concrete suppliers need to implement schemes for doing this.

### Formwork

- Formwork components that can be reused many times have a clear advantage over single-use forms, which represent a large waste of construction material.
- Form release compounds and curing compounds should be chosen for low volatile organic compound content and biodegradability.
- Insulating concrete forms eliminate most temporary formwork and produce concrete walls with high thermal insulating values.

### Reinforcing

- In North America, reinforcing bars are made almost entirely from recycled steel scrap, primarily junked automobiles. This reduces resource depletion and energy consumption significantly.

### Demolition and Recycling

- When a concrete building is demolished, its reinforcing steel can be recycled.
- In many if not most cases, fragments of demolished concrete can be crushed, sorted, and used as aggregates for new concrete. At present, however, most demolished concrete is buried on the site, used to fill other sites, or dumped in a landfill.

### Green Uses of Concrete

- Pervious concrete, made with coarse aggregate only, can be used to make porous pavings that allow stormwater to filter into the ground, helping to recharge aquifers and reduce stormwater runoff.
- Concrete is a durable material that can be used to construct buildings that are long-lasting and suitable for adaptation and reuse, thereby reducing the environmental impacts of building demolition and new construction.
- In brownfield development, concrete fill materials can be used to stabilize soils and reduce leachate concentrations.
- Where structured parking garages (often constructed of concrete) replace surface parking, open space is preserved.
- Concrete's thermal mass can be exploited to reduce building heating and cooling costs by storing excess heat during overheated periods of the day or week and releasing it back to the interior of the building during underheated periods.
- Lighter-colored concrete paving reflects more solar radiation than darker asphalt paving, leading to lower paving surface temperatures and reduced urban heat island effects.
- Interior concrete slabs made with white concrete can improve illumination, visibility, and worker safety within interior spaces without the expense or added energy consumption of extra light fixtures or increasing the light output from existing fixtures. White concrete is made with white cement and white aggregates.
- Photocatalytic agents can be added to concrete used in the construction of roads and buildings. In the presence of sunlight, the concrete chemically breaks down carbon monoxide, nitrogen oxide, benzene, and other air pollutants.

## CONSIDERATIONS OF SUSTAINABILITY IN PRECAST CONCRETE CONSTRUCTION

In addition to the issues of sustainability of concrete construction that were raised in Chapter 13, there are issues that pertain especially to precast concrete construction:

- Because of the higher-strength concrete mixes typically used in the production of precast concrete, its embodied energy is higher on a pound-for-pound basis than that of conventional concrete, generally falling in the range of 500 to 600 BTU per pound (1.1-1.4 MJ/kg).
- Precast concrete production encourages the reuse of formwork, reducing waste. Wood and fiberglass forms can be used up to 50 times without major maintenance. Concrete and steel forms can be reused hundreds or thousands of times.
- Because precast concrete is manufactured in a controlled, factory-like setting, raw materials are used more efficiently and less waste is produced. Gray water used in various production processes, sand used in finishing, and

large aggregate used to create voids in hollow planks can all be readily reused.

- In many cases, the optimized design of precast concrete results in elements that use less material than comparable sitecast concrete systems.
- Precast concrete elements with high-quality architectural finishes reduce the need for volatile organic compound-emitting paints or other finish coatings. Concrete is not easily damaged by moisture and does not support the growth of mold.
- Precast concrete wall panels with properly sealed joints have low permeability to air leakage, reducing building heating and cooling costs and contributing to good indoor air quality.
- Precast concrete wall panels can be reused when buildings are altered.

712 / Chapter 17 • Glass and Glazing

## CONSIDERATIONS OF SUSTAINABILITY RELATING TO GLASS

### Glass Production

- The major raw materials for glass—sand, limestone, and sodium carbonate—are finite but abundant minerals.
- The high embodied energy of glass manufactured using traditional methods, roughly 7000 BTU per pound (16 MJ/kg), can be reduced by as much as 30 to 65 percent as new, more energy efficient manufacturing technologies are introduced.
- Some glass production involves the generation of potentially unhealthful or pollution-causing waste materials. Traditional mirror glass manufacturing, for example, generates an acidic waste effluent with high concentrations of copper or lead. However, recently, mirror glass manufactured with more environmentally friendly production techniques has become available.
- Although glass bottles and containers are recycled into new containers at a high rate, there is little recycling of flat glass at the present time. Most old glass goes to landfills.
- Efforts are underway to find new uses for waste glass. For example, vitrified glass aggregate (glass that has been melted and rapidly quenched to trap heavy metals and other contaminants) can be reused in asphalt, concrete, construction backfill, roofing shingles, and ceramic tiles.

### Uses of Glass

- If it is not broken by accident or improper installation, glass lasts for a very long time with little degradation of quality, often much longer than most other building components.
- Glass is inert and does not affect indoor air quality. It is easily kept clean and free of molds and bacteria.
- The impact of glass on energy consumption can be very detrimental, very beneficial, or anything in between, depending on how intelligently it is used.
- If badly used, glass can contribute to summertime overheating from unwanted solar gain, excessive wintertime heat losses due to inherently low R-values, visual glare, wintertime discomfort caused by radiant heat loss from the body to cold glass surfaces, and condensation of moisture that can damage other building components.
- Well used, glass can bring solar heat into a building in winter and exclude it in summer, with attendant savings in heating and cooling energy. It can bring daylight into a building without glare, reducing both the use of electricity for lighting and the cooling load produced by that lighting.
- These benefits accrue over the entire life of the building, and the payoffs can be huge. Thus, glass is a key component of every energy-efficient building and a chief accomplice of the ill-informed designer in most energy-wasting buildings.

## CONSIDERATIONS OF SUSTAINABILITY IN ALUMINUM CLADDING

### Manufacture

- The ore from which aluminum is refined, bauxite, is finite but relatively plentiful. The richest deposits are generally found in tropical areas, often where rain forests must be clearcut to facilitate mining operations.
- Aluminum is refined from bauxite by an electrolytic process that uses huge quantities of electricity. Aluminum smelters are often located near plentiful supplies of inexpensive hydroelectric power for this reason.
- The embodied energy in aluminum is roughly 100,000 BTU per pound (230 MJ/kg), seven times that of steel, making it one of the most energy-intensive materials used in construction.
- Large volumes of water are required for smelting. Wastewater from aluminum manufacture contains cyanide, antimony, nickel, fluorides, and other pollutants.
- Aluminum is recycled at a very high rate, due largely to industry efforts. Recycled aluminum is produced using only a fraction of the energy, approximately 5000 BTU per pound (12 MJ/kg), required to convert ore to aluminum.
- Aluminum extrusions are easy to produce and to form into cladding components. Their light weight saves transportation energy.

- Powder coatings for aluminum, which release no solvents into the atmosphere, are preferable environmentally to solvent-based coatings.

### Construction

- Aluminum cladding is easy to erect because of its light weight and simple connections. Little waste or pollution is associated with the process. Scrap is readily recycled.

### In Service

- Aluminum cladding seldom needs maintenance, lasts for a very long time, and can be recycled when a building is demolished.
- Because aluminum is highly conductive of heat, cladding components must be thermally broken.
- Aluminum foils used as vapor retarders, components of insulation systems, and radiant heat barriers save large amounts of heating and cooling energy. They are so thin that they consume little metal relative to the energy they can save over the lifetime of the building.

## CONSIDERATIONS OF SUSTAINABILITY IN GYPSUM PRODUCTS

### Sources of Gypsum

- Naturally occurring gypsum is not renewable, but it is plentiful and widely distributed geographically.
- The majority of newly extracted gypsum is quarried in surface mines, with attendant risks of loss of wildlife habitat, surface erosion, and water pollution, as well as the problem of disposing of overburden and mine tailings.
- There is increasing use of *synthetic gypsum*, material recovered from power plant flue gases that would otherwise be sent to landfills, in the manufacture of gypsum construction materials. According to the Gypsum Association, approximately 1.5 million tons (1.4 million metric tons) of synthetic gypsum is used annually to produce about 7 percent of the U.S. construction industry's calcined gypsum. Some synthetic gypsums, however, contain toxic byproducts from the manufacturing processes in which they are produced and cannot be safely recycled into new construction materials.

### Gypsum Products Manufacturing

- The calcining of gypsum involves temperatures that are not much higher than the boiling point of water, which means that the embodied energy of gypsum is relatively low, about 1200 BTU per pound (2.8 MJ/kg) for plaster and 2600 BTU per pound (6.0 MJ/kg) for gypsum board.
- The calcining process emits particulates of calcium sulfate, an inert, benign chemical, as dust.
- The paper faces of gypsum board are composed primarily of recycled newspapers.
- Some manufacturers produce gypsum board products made with as much as 95 percent recycled materials, including synthetic gypsum and recycled postconsumer waste paper.

### Gypsum Products on the Building Site

- Approximately 15 million tons (14 million metric tons) of gypsum board are manufactured annually in the United States. On a typical construction site, about 10 to 12 percent of this material becomes waste.
- Gypsum board waste generated during construction can be minimized by sizing walls and ceilings to make efficient use of whole boards or by ordering custom-sized boards for nonstandard-size surfaces.

- Gypsum board scrap can be permanently stored in the hollow cavities of finished walls, eliminating disposal and transportation costs and reducing the amount of material destined for landfills (though care must be taken not to create interference with the pulling of electrical wires at a later date).
- Some dust is generated by the cutting and sanding of gypsum board and plaster. This dust has not been tied to any specific illnesses, but it is a nuisance and a source of discomfort until the work is done and all the dust has been swept up and removed from the building. Remodeling and demolition also create large quantities of gypsum dust.
- Most installed gypsum products have extremely low emissions. Some joint compounds, however, may also be sources of emissions.
- Additives used in the manufacture of moisture-resistant and fire-resistant gypsum board are potential sources of volatile organic compound (VOC) emissions.
- Paints, wallcovering adhesives, and other products used to finish gypsum surfaces can be significant emitters of VOCs, and thus require care in selection and specification.

### Gypsum Disposal and Recycling

- Gypsum board waste can be recycled back into the manufacture of new gypsum board products. Current efforts limit recycled content to no more than 15 or 20 percent, due to the amount of paper waste that can be safely introduced into the new gypsum without impairing its fire resistance.
- Gypsum board waste from the demolition of older buildings may be contaminated with nails, drywall tape, joint compound, and paint. Gypsum board demolished from buildings constructed prior to 1978 may be coated with lead-based paint. These foreign materials must be removed from the waste; their presence may limit the material's recycling potential.
- Gypsum board waste can be used as a soil amendment and plant nutrient. With the recent advent of mobile grinders, construction site recycling of gypsum board waste for use as a soil amendment on the same building site is now feasible.
- Gypsum is an ingredient in many manufacturing and industrial processes. Studies and small-scale tests currently underway to identify potential uses of gypsum board waste in such processes are likely to lead to additional recycling opportunities in the future.