VISION 2030:

A VISION FOR THE U.S. CONCRETE INDUSTRY

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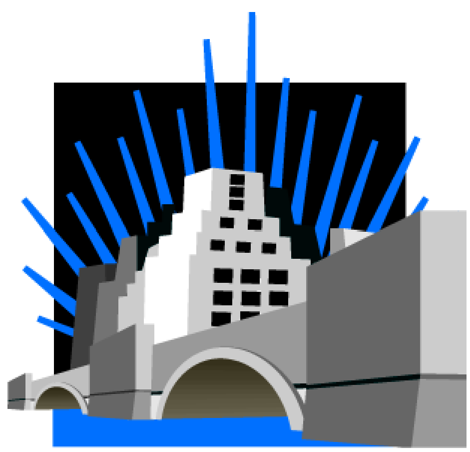

FOREWORD

On September 27, 2000 the concrete industry's Strategic Development Council hosted a Concrete Vision Workshop in Chicago, Illinois. Meeting participants included over 50 concrete, cement, and other allied industry chief executive officers, presidents, vice-presidents, laboratory and industry research managers, and government representatives. Participants discussed the state of the concrete industry 30 years ago, the state of the industry today, and their vision for the United States concrete industry in 2030. Moreover, they identified specific goals to achieve the industry's *Vision 2030*. Participants defined the industry broadly to include concrete feedstocks, manufacturing, delivery, and concrete construction.

This document, *Vision 2030*, is the product of that workshop and the comments received after a broad industry review. The development of *Vision 2030* represents a major event in the history of the U.S. concrete industry. It brings together diverse participants to form a unified vision for the future and establishes the foundation for guiding industry research partnerships over the next thirty years. *Vision 2030* also is a living document. The industry will continuously revisit and reinvigorate *Vision 2030* so that it reflects the ongoing progress of the concrete industry as well as the dynamics of competitive, regulatory, institutional, and societal changes. *Vision 2030* communicates the fact that the U.S. concrete industry is:

- *Committed to being a model of sound energy use and environmental protection.*

- *Committed to making concrete the preferred construction material based on life-cycle cost and performance.*

- *Committed to improving efficiency and productivity in all concrete manufacturing processes while maintaining high safety and health standards.*

Vision 2030 establishes goals and describes the future for the concrete industry, concrete products, suppliers, and customers. It outlines eight areas where research is needed and where government-industry partnerships can play a role. For each, the concrete industry has united to establish specific 2030 goals. ***By achieving these goals, the concrete industry will turn this Vision into a reality.***

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THE U.S. CONCRETE INDUSTRY

Concrete is the most widely used man-made product in the world, and is second only to water as the world's most utilized substance. Slightly more than a ton of concrete is produced each year for every human being on the planet — some six billion tons a year — and Americans use in excess of two and one half tons per person per year. Concrete is an affordable and reliable material that is applied throughout the infrastructure of our nation's construction, industrial, transportation, defense, utility, and residential sectors.

More than 6,100 companies manufacture cement, ready mixed concrete, concrete pipe, concrete block, precast and prestressed concrete, and other concrete products. These companies employ nearly 200,000 people.[1] The concrete industry consists of a preponderance of small businesses. More than 95 percent of concrete-related companies employ less than 100 people.

Gross product of concrete and cement manufacturing exceeds $35 billion annually.[2] Concrete and cement manufacturing consume considerable amounts of energy, with cement−manufacturing accounting for about 80 percent of the total industry's electricity use and approximately 66 percent of its fuel consumption. Additionally, significant amounts of energy are required to transport aggregate and other ingredients to manufacturing sites and to deliver finished products to market.

In addition to concrete and cement manufacturing, the industry includes aggregate and material suppliers, designers, haulers, constructors, and repair and maintenance companies. Over two million jobs relate to the U.S. concrete construction industry alone. While there is significant diversity of services within this industry, all corners of the concrete industry share a common objective — a sincere desire to deliver a high-quality, long-lasting, competitive, and sustainable product.

In its simplest form, concrete is a mixture of cement paste and aggregates. The paste, composed of cementitious materials and water, coats the surface of fine and coarse aggregates (sand, gravel, and other materials) and binds them together as it cures and hardens into a rock-like mass known as concrete. A key advantage to the use of concrete is that it can be molded or formed into virtually any shape when newly mixed, and is strong and durable when hardened. These qualities explain why concrete can be used to build skyscrapers, bridges, sidewalks, superhighways, houses, and dams.[3] Although concrete is widely used today, concrete technology continues to advance.

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[1] Source: U.S. Department of Commerce, U.S. Bureau of Census, Manufacturing Industry Series, 1997 NAICS codes: Concrete pipe (327332), Concrete block and manufacturing (327331), Ready mixed concrete (327320), Cement manufacturing (327310), Other concrete products (327390).

[2] Source: U.S. Department of Commerce, U.S. Bureau of Census, Manufacturing Industry Series, 1997

[3] Source: Portland Cement Association, *Concrete Basics*

The key to achieving a strong, durable concrete lies in the careful control of its basic and process components. These are:

- **Cement** - Portland cement, the most widely used cementitious ingredient in today's concrete, is comprised of phases that consist of atoms of calcium, silicon, aluminum, iron, and oxygen.

- **Aggregate** - Aggregates are primarily naturally-occurring, inert granular materials such as sand, gravel, or crushed stone. However, technology is broadening to include the use of recycled materials and synthetic products.

- **Water** - The water content and the minerals and chemicals dissolved in it are crucial to achieving quality concrete.

- **Chemical Admixtures** - Chemical admixtures are the ingredients in concrete other than portland cement, water, and aggregate that are added to the mix immediately before or during mixing to reduce the water requirement, accelerate/retard setting, or improve specific durability characteristics.

- **Supplementary Cementitious Materials** - Supplementary cementitious materials, also called mineral admixtures, contribute to the properties of hardened concrete through hydraulic or pozzolanic activity. Typical examples are natural pozzolans, fly ash, ground granulated blast-furnace slag, and silica fume.

After concrete is placed, these components must be cured at a satisfactory moisture content and temperature must be carefully maintained for a sufficiently long time to allow adequate development of the strength of the concrete.

Concrete manufacturing processes and the materials of concrete are discussed in more detail in the Appendix to this report, *Concrete Basics*.

Currently, industry research programs focus on a wide variety of concrete research topics. In 1997, the concrete industry founded the Strategic Development Council to focus on collaborative problem-solving in technology development. This organization sponsors a number of research consortia examining a variety of areas, including advanced cement manufacturing processes, high-performance concrete, automated construction systems, and an industry-wide service life prediction model.

In addition, several government programs are involved in concrete-related research. Sponsoring agencies include the U.S. Department of Defense and its Army Corps of Engineers, Naval Facilities Engineering Command, and U.S. Air Force Civil Engineering Support Agency. Research also is being performed by the U.S. Department of Commerce, National Institute of Standards and Technology; the U.S. Department of Interior, Bureau of Reclamation; and the U.S. Department of Energy, National Laboratory system. Other federal agencies and entities performing research include the U.S. Department of Transportation, Federal

Highway Administration, and the Nuclear Regulatory Commission. These agencies conduct broad-spectrum concrete research, basic and applied, to improve concrete and repair materials technologies. This research is designed to enable cost-effective application of high-performance concrete with extended service life, and to advance concrete technology by providing a sound materials science base. Additionally, there are numerous other state and federal programs that strive to advance the nation's knowledge of concrete.

CHALLENGING OUR INDUSTRY

Fundamentally, concrete is an economical, strong, and durable product that predates the Roman Empire. Although concrete technology across the full width of the industry continues to rise to the demands of a changing marketplace, the industry recognizes that considerable improvements are essential in productivity, product performance, energy efficiency, and environmental performance. Realizing these improvements within the 2030 time frame — achieving *Vision 2030* — will require a concerted and focused effort. The industry will need to face and overcome a number of institutional, competitive, and technical challenges.

Meeting challenges is not new to the concrete industry. For example, though the basic technology for cement manufacturing has been in place for decades, recent advances in modern cement manufacturing technologies have resulted in spectacular improvements in energy efficiency. Since the mid-1970s, the average amount of energy used to produce a ton of cement has been reduced by over 30 percent. Promising opportunities for vast process and technology improvements are now possible, and the cement industry is excited about bringing them into use. Research in new materials, processing technologies, delivery mechanisms, and applications of information technology, could transform the industry.

The concrete industry is known for being fragmented and diverse. There are thousands of concrete operations across the country, and the majority are small businesses. Due in part to this fragmentation, the industry has been slow to investigate new technology options, reluctant to invest in research, and hesitant to adopt new technology as it becomes available. Additionally, concrete is often used in situations where failure to meet design criteria could result in significant liability. Producers, users, and designers are reluctant to shift from tried and proven processes and materials to adopt promising new technologies until long use histories have been substantiated. By industry estimates, it now takes more than 15 years to get a new technology from concept to adoption. These demographics underscore the importance of a unified industry vision.

Throughout the industrial sector, including the concrete industry, the cost of environmental compliance is high. The concrete industry recognizes its responsibility as well as the business need to become more proactive in responding to societal expectations and addressing fair environmental concerns. Reducing energy consumption from cement and concrete transportation alone can result in significant improvements in overall industry energy efficiency and environmental performance. Transportation costs account for 20 percent to 50 percent of the final cost of ready mixed concrete, and delays in concrete delivery can create significant labor downtime in concrete construction. Moreover, the “not-in-my-back-yard” syndrome is causing cement and concrete plants and aggregate sources to move further from demand centers, increasing the number of vehicle miles required to move industry products. By relocating concrete facilities to remote areas, transportation energy requirements and opportunities for associated environmental harm are increased.

Cement production is the most energy-intensive phase of the concrete production chain. Cement production requires high process temperatures to produce the necessary chemical transformations. Approximately one ton of carbon dioxide is emitted for every ton of clinker produced. Roughly one-half results from the combustion of hydrocarbon fuels, and the remainder comes from the chemical decomposition of limestone, the principal raw material used in cement making.

Advances in materials and process technologies needed to produce high-performance concrete are advancing slowly, and are not entering the marketplace quickly. There is no central resource for performance data and service life of current concrete products. This limits the ability of designers and constructors to communicate life-cycle benefits of concrete products to the user community.

Greater materials improvements will enable the industry to better demonstrate the full spectrum of performance benefits of concrete. Currently, the industry operates in a prescriptive rather than performance-based environment. Thus, the full potential of concrete is often not realized. Accordingly, the procurement process for concrete construction and products typically favors the low-cost bidder because no incentives are provided for improved performance. This forces concrete companies to keep costs down and creates a disincentive to investing in research and development. Improved technology can reduce service life costs, prevent premature repairs, and also use less energy.

Within the concrete industry, it is well-known that concrete has a formidable advantage over other materials in terms of sustainability. However, this is not fully grasped by consumers, in part because it is not stressed enough by the industry. The concrete industry's inability to demonstrate its considerable contribution to sustainable construction has been symptomatic. The industry is challenged to develop easy-to-communicate definitions of sustainability and cost-effectiveness.

Computer-integrated knowledge systems can provide a practical basis for optimizing concrete for specific applications by taking technical, economic, and environmental factors into account. Advanced systems models must be developed to show the prediction of performance for any mix design under a range of environmental conditions lasting over decades and even centuries. Aggregates, cement, repair and maintenance, materials transportation, life-cycle analysis, and other areas can all be readily addressed under this concept. It can also take into account global perspectives on environments, opportunities to reduce heat sinks, materials used in concrete, construction needs of increasing populations, and energy wasted due to construction delays. These kinds of analyses would provide very useful tools to demonstrate the benefits of concrete.

The concrete industry is challenged to move beyond the status quo and to start working toward a vision for 2030. The industry has identified specific goals that will guide it in realizing that vision.

A UNIFIED INDUSTRY VISION

The diverse concrete industry recognizes the importance of a unified and forward-looking vision. In developing *Vision 2030*, leaders throughout the industry have described the desired state of the industry in 2030. They have identified potential breakthroughs in materials and ingredients, product performance, supplier-designer interaction, concrete construction, and public perception. They realize that the process of exploring uncharted waters will involve unforeseeable challenges as well as those that can be projected in *Vision 2030*, and eagerly look forward to meeting them.

Specifically, industry leaders have categorized *Vision 2030* into eight key areas. These are presented without order of preference.

Process Improvements

The industry will make processing improvements throughout the life cycle of concrete including design, manufacturing, transportation, construction, maintenance, and repair. By 2030, concrete will become the most efficient and cost-effective material of construction.

Important opportunities to improve process efficiencies exist throughout the life cycle of concrete. Breakthrough technologies and innovative methods can lead to significant energy and environmental benefits. The most energy-intensive phases of concrete production are cement manufacturing and materials transfer, and both offer significant opportunities for improvement.

The concrete industry is unique in that process improvements can crosscut many other industries. Foundry sand, fly ash, silica fume, slag, and other byproducts from industries such as aluminum, metal casting, steel and power generation can be and are used as ingredients in the manufacture of cement and concrete. Opportunities exist for more utilization of these materials. The concrete industry will commit to changes in practices in the materials, design, and construction arenas through the use of materials and systems that improve function, durability and sustainability. Conservation will move beyond the present focus on efficient use of limited resources to one of achieving similar benefits from alternate/advanced materials and systems. With this futuristic-materials mindset comes the challenge of overcoming technical, educational, and institutional barriers. Accelerated adoption of innovative materials and applications pulls along supporting technologies needed for their understanding and utilization. A major challenge is the lack of understanding among designers and construction firms as to what the industry can offer.

The concrete industry envisions significant strides in process improvements over the next thirty years. In the industry's vision for 2030:

- A variety of byproducts from other industries as well as recycled concrete are used as constituent materials for concrete production.

- Synthetic or bio-based materials are commonly used in concrete production.

- Biomimetic processes, or processes which mimic natural mechanisms, are used to create concrete.

- A geomimetic approach is used to tailor mix design to specific structural environments.

- Optimal particle size distribution of the constituent2 materials is achieved.

- Cement is manufactured with less energy and fewer emissions such as nitrous oxide and carbon dioxide, and decreased production of byproduct cement kiln dust.

- The industry uses accepted techniques and processes to produce lighter-weight, higher-strength products, thereby reducing volumetric requirements and making transportation easier and less expensive.

- The industry uses advanced systems modeling to predict the performance of concrete for customers.

- The delivery system for concrete is enhanced.

- Automation is standard practice in concrete placement.

Product Performance

The industry will make improvements in concrete strength and performance in order to improve both the demand for and quality of concrete. By 2030, concrete will be the prime construction material selected based on life-cycle cost and performance.

Concrete is one of the most durable and cost-effective construction materials in use in civil engineering. However, opportunities to improve its performance, reliability, and life-cycle cost-effectiveness are present. The diverse applications for concrete have a wide variety of performance requirements. The industry needs critical research to produce high-performance, cost-effective concrete. This will come through advanced materials, improved data, and advanced technologies in concrete manufacturing. Fully integrated engineering design methods, shared information networks, computer-aided in-field construction management, shared life-cycle data, uniform field-testing technologies, and pooled resources and technologies will take the historically fragmented construction industry to a new level.

Through a unified vision guiding future research, the industry will be able to offer better products, including durable constructed facilities with low maintenance needs and the reserve capacity and flexibility to meet future demands. It will be able to offer construction that adapts the principle of agile manufacturing to enable rapid cast-in-place or precast construction, and also offers open and easy substitution of construction systems and processes. It will enable lighter structures that are flexible and highly energy-absorbing with the ability to withstand seismic events. Research will provide longer life to pavements, bridges, and underground structures, thereby reducing costly repairs and replacements as well as downtime costs to the public using these facilities. These efforts will result in breakthroughs in infrastructure repair, retrofit, and renovation as well as enable further advances in waste utilization.

Over the next thirty years, the product performance benefits of concrete will be strongly communicated to users. By 2030:

- Effective, consistent quality assurance/quality control standards are used throughout the industry.
- Self-compacting and self-leveling concrete is routinely used in suitable applications.
- The industry makes full use of nondestructive measurements, sensors, intelligent curing techniques, and other technology advances to continuously monitor property performance and to maintain durability.
- The strengths of concrete products are up to ten times that of current levels leading to a reduction in the overall volume of concrete required.
- More concrete material options exist for direct consumers, including designer colors and textures.
- Issues regarding product performance are reduced such that demand is quadrupled.
- The industry has a system of shared, consolidated data such as materials, structures, design, and performance databases and uses them with computer-integrated knowledge systems to demonstrate product quality to customers.
- Concrete reinforcement is more durable through the use of advanced fibers and composites, enhancing the life-cycle benefit of concrete.

Energy Efficiency

The concrete industry will continue to identify methods of improving energy efficiency in all stages of the concrete life cycle. By 2030, the concrete industry will have reduced energy consumption from current levels by 50 percent per unit of output.

In addition to the need to remain competitive, increasing energy costs ensure that energy efficiency will be a key technological issue in the concrete industry for years to come. More than any other factor, energy efficiency can be quantified, both on a short-term and life-cycle cost basis, as a tangible component of marketplace costs. Accordingly, the concrete industry's success in managing energy use has a direct correlation to market share. There are opportunities to reduce energy costs throughout the life-cycle of concrete products. Some of these areas include cement manufacturing, transportation, emplacement, maintenance and repair, demolition, and disposal. In most cases, concrete provides a superior energy-based, life-cycle advantage over other competing construction materials.

To improve energy efficiency, the industry identified a vision for 2030 that challenges current standards. In the industry's vision for 2030:

- The industry is using bio-based raw materials as fuel sources in cement making.
- The industry is using biomimetic materials in concrete manufacturing.
- The industry is using aggregates that are less energy-intensive to produce.
- The industry is using advanced technology to improve process heating for cement making.
- The industry is utilizing cementitious materials that require less process heating and produce fewer emissions.
- The industry is saving energy by making increased use of industrial and post-consumer waste byproducts.
- The industry has optimized its rolling stock in order to reduce the total miles traveled in moving and delivering concrete.
- The industry transports less water for shorter distances.

Environmental Performance

The concrete industry will continue to make strides to use recycled waste and byproducts, from within the concrete industry and from other industries, in concrete manufacturing. By 2030, the concrete industry will achieve zero net waste from concrete and its constituent materials.

Environmental stewardship, responsiveness to environmental regulations, and waste management are part of daily operations in the concrete industry. The industry continually seeks to identify how it can increase its use of environmentally friendly practices and processes. Moreover, the concrete industry is consuming a wider range of byproducts from other industries to evolve novel concretes for tailored waste isolation. Concrete technologists are faced with the challenge of leading future development in a way that protects environmental quality while projecting concrete as the construction material of choice. Public concern will be responsibly addressed regarding climate change resulting from the increased concentration of global warming gases.

In its vision for 2030, the concrete industry seeks to eliminate emissions from concrete production in general and cement manufacturing specifically. As it progresses to 2030 the industry envisions that:

- The industry has removed prior obstacles to recycling wastewater and thereby has removed wastewater from cement and concrete manufacturing.
- Technology has eliminated particulate and gaseous emissions and alleviated local neighborhood concerns regarding cement making and concrete manufacturing.
- The cement industry has developed beneficial reuse technologies for fully-recovered cement kiln dust.
- Closed-loop concrete plants and cement manufacturing sites are located closer to demand centers, thereby reducing transportation requirements.
- No net environmental waste is associated with cement and concrete production and use.
- Concrete from demolition is routinely recycled in new products.

Technology Transfer

Currently, it takes more than 15 years for new concrete technology to penetrate the marketplace. By 2030, the industry will reduce the time required for new technology acceptance to two years.

Effective technology transfer is critical to the success of any industry and to the application, testing, and learning from technology research. Currently, technology transfer in the industry is too slow. Technology transfer in U.S. commerce must become more efficient and the rule rather than the exception. Reasonable means and incentives must be created to motivate private corporations to share technologies they have invested heavily to develop.

The U.S. concrete industry's vision for 2030 foresees aggressive improvements in technology transfer. The industry envisions that by 2030:

- Performance codes, along with improved technology and product testing, allow new technologies and products to penetrate the marketplace three times faster than the current pace.
- Increased industry outreach, a centralized body to provide leadership on research, and new technology standards facilitate technology transfer.
- Design/build replaces design/bid/build as the standard.
- Technology transfer is greatly facilitated by pooled resources, interoperable databases, and knowledge systems.

Institutional Improvements

The concrete industry will address the need to reduce fragmentation and to work together towards common goals. By 2030, the industry will be cohesive and will demonstrate strong leadership pursuing a fully-integrated, well-defined strategic vision.

Due to its diversity and fragmentation, it is difficult for the concrete industry to address institutional barriers that prevent concrete from achieving its full potential as the preferred material of construction. Some examples of institutional barriers include difficulty in changing imperfect standards and codes, particularly in the absence of research to support needed changes and increased costs resulting from unnecessarily restrictive governmental regulations. Also, there is a lack of comprehensive course offerings in concrete technology in university civil engineering departments. Other institutional barriers include the slow pace at which technical societies exploit advances in information technology and the tendency of trade associations to sustain the commodity nature of the industry. There is a need for greater cooperation among industry to work with regulatory agencies, standard and code bodies, academics, technical societies, and others to address these institutional barriers. Many of the barriers can only be addressed effectively if the industry has a unified voice.

In order to achieve the Vision 2030 goals, a number of fundamental institutional changes are needed. In the industry's vision for 2030:

- The industry is more consolidated and vertically integrated, having more large companies and strategic partnerships.
- Significant cooperation exists between the industry and all levels of government.
- An effective standards development process produces materials science based standards that facilitate reliable predictions of performance.
- One accountable body is providing leadership for the industry and serves as the industry's voice.
- Industry leaders are committing forty hours per year, throughout the year, to promote concrete to government, the construction community, and the public.
- Maintenance, repair, and restoration are integral to an expanded design and build, construction bidding, and contracting process.
- All concrete products are designed to meet quality and sustainability criteria.
- The concrete industry is viewed as a provider of services as well as products.

Education and Employment

In order to attract more skilled workers from laborers to engineers to executives, the industry will place increased emphasis on education. By 2030, the concrete industry will be seen as a source of safe, well paying, and challenging careers resulting in the creation of a committed, diverse, and skilled workforce.

The successful future of the U.S. concrete industry depends greatly upon the industry's ability to attract high-quality, well-trained personnel. To attract high-quality personnel, the industry must continue to grow and effectively communicate the diverse, rewarding, and challenging career opportunities it offers.

In its vision for 2030, the industry will be a recognized source of challenging and well-paying careers. The industry envisions that by 2030:

- The concrete industry attracts "the best and brightest" by being more innovative and by using the latest technologies.
- The concrete industry is a source of safe, well-paying careers.
- Scientists and engineers are rewarded on a timely basis for developing practical innovations. Designers and owners are rewarded for adopting these innovations.
- Specialized education tracks for the concrete industry exist, such as web-based education options for students.
- The concrete industry uses virtual reality and other environments to which youth are accustomed and attracted.
- User-friendly design tools are available to students, suppliers, and owners.
- An established certification program exists to identify good performers.
- All concrete installers are required to meet established industry criteria.
- The concrete industry embraces "digital technology."

Industry Image

Through process and product improvements, as well as greater education and outreach, the concrete industry will have made significant strides in improving its image with consumers and the public. By 2030, concrete will be recognized as an environmentally friendly material that is durable and versatile.

The industry seeks to improve its image by more effectively communicating that it is a good neighbor and publicizing the many benefits of concrete, both as a material of choice and an environmentally sound product of a technologically advanced industry. Improvements in the image of the industry will bring crosscutting benefits in many of the above *Vision 2030* goal areas, including the ability to attract students and new employees, to site manufacturing facilities, and to increase customer awareness of the benefits of concrete as a material of choice.

The improved industry image also will emphasize the quality of its operations and of its products. As increasing attention is paid to conservation of resources and protection of the environment, improved quality systems will be needed to ensure that quality goals are met. The systems will meet or exceed those established by internationally accepted quality standards.

In its vision for 2030, the industry seeks to improve its image to that of a durable, reliable, and sustainable product that is environmentally sound. The industry envisions that by 2030:

- Consumers demand concrete as the material of choice in all facets of construction, from public works to residential.
- Concrete has the reliable image of a manufactured product.
- Concrete industry producers interact directly with consumers to learn from them as well as to educate them about purchasing decisions.
- Consumers have access to evaluation and rating systems for concrete products.
- Aggregate quarries are viewed as assets to the neighboring community.
- Cement manufacturing is viewed as an asset to the neighboring community.
- Ready mixed concrete and concrete product plants are viewed as assets to the neighboring community.
- Concrete industry stakeholders develop self-policing, quality certification procedures.
- The concrete industry provides incentives such as loans, grants, and applied energy credits for developers of new concrete technologies.

ACHIEVING OUR GOALS

The U.S. concrete industry is committed to developing and implementing a unified vision. It is committed to successfully implementing the government-industry research partnerships necessary to achieve the goals set forth in *Vision 2030*.

The creation of *Vision 2030* is a seminal event in the U.S. concrete industry. It has brought together diverse and disparate members of industry to identify common needs and create a unified vision for the future. It has enabled the industry to look back at the progress it has made and to look forward to the potential it can achieve.

The industry enthusiastically anticipates a bright, productive, and energy-efficient future using *Vision 2030* as its basis. *Vision 2030* is a living document. It is a document to be revisited and reinvigorated so that it reflects the ongoing progress of the concrete industry as well as the dynamics of competitive, regulatory, institutional, and societal changes.

REFERENCES

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3. National Ready Mixed Concrete Association, *Concrete Basics*, <http://www.nrmca.org/concrete_basics/>.

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APPENDIX A
CONCRETE BASICS

This section provides a brief overview of the current concrete manufacturing process and the materials used in concrete.

In its simplest form, concrete is a mixture of cement paste and aggregates (sand and rock). The paste, composed of cement and water, coats the surface of the fine (sand) and coarse aggregates (rocks) and binds them together into a rock-like mass known as concrete.

A key feature of concrete is that it is plastic and can be molded or formed into any shape when newly mixed, and it is strong and durable when hardened. These qualities explain why concrete can be used to build skyscrapers, bridges, sidewalks, superhighways, houses, and dams.[1]

The key to achieving a strong, durable concrete rests on the careful proportioning and mixing of its basic and process components. A description of these ingredients[2] follows:

- **Cement** - Portland cement, the most widely used cementitious ingredient in concrete, is a calcium silicate cement containing phases consisting of atoms of calcium, silicon, aluminum, iron, and oxygen. Producing a cement that meets specific chemical and physical specifications requires careful control of the manufacturing process. Generally, raw materials consisting of combinations of calcium carbonate (limestone, shells or chalk), silicates (shale, clay, sand), and iron ore, are mined from quarries near the plant. At the quarry, primary and secondary crushers reduce sizes of the raw materials. Typically, stone is first reduced to 5-inch size (125-mm), then to 3/4-inch (19 mm). Once the raw materials arrive at the cement plant, the materials are proportioned to create the desired chemical composition. Two different methods, dry and wet, are used in preparing the raw materials for the manufacture of portland cement. In the dry process, dry raw materials are proportioned, ground to a powder, blended together and fed to the kiln in a dry state. In the wet process, grinding the properly proportioned raw materials in water forms a slurry. The grinding and blending operations are then completed with the materials in slurry form. After blending, the mixture of raw materials is fed into the upper end of a tilted rotating, cylindrical kiln. The mixture passes through the kiln at a rate controlled by the slope and rotational speed of the kiln. Fuel consisting of powdered coal or natural gas is blown into and burned in the lower end of the kiln. Inside the kiln, raw materials reach temperatures of 2,600°F to 3,000°F (1,430°C to 1,650°C). At about 2,700°F (1,480°C), a series of chemical reactions causes the materials to fuse and create cement clinker — grayish-black pellets, often the size of marbles. Clinker is discharged red-hot from the lower end of the kiln and transferred to various types of coolers to lower the clinker to

[1] Source: National Ready Mixed Concrete Association, *Concrete Basics*
[2] Source: Portland Cement Association, *Concrete Basics*

handling temperatures. Cooled clinker is combined with gypsum and ground into a fine gray powder. The clinker is ground so fine that nearly all of it passes through a No. 200 mesh (75 micrometer) sieve. This fine gray powder is portland cement.

- **Aggregate** - Aggregates are inert granular materials such as sand, gravel, crushed stone, recycled crushed concrete or manufactured aggregates that, along with water and portland cement, are an essential ingredient in concrete. For a good concrete mixture, aggregates need to be clean, hard, strong particles free of absorbed chemicals or coatings of clay and other fine materials that could cause the deterioration of concrete. Aggregates, which account for 60 to 75 percent of the total volume of concrete, are divided into two distinct categories-fine and coarse. Fine aggregates generally consist of natural sand or crushed stone with most particles passing through a 3/8-inch (9.5-mm) sieve. Coarse aggregates are any particles greater than 0.19 inch (4.75 mm), but generally range between 3/8 and 1.5 inches (9.5 mm to 37.5 mm) in diameter. Gravels constitute the majority of coarse aggregate used in concrete with crushed stone making up most of the remainder. Natural gravel and sand are usually dug or dredged from a pit, river, lake, or seabed. Crushed aggregate is produced by crushing quarry rock, boulders, cobbles, or large-size gravel. Recycled concrete is a viable source of aggregate and has been satisfactorily used in granular sub-base, soil-cement, and in new concrete. Lightweight aggregates are produced by expanding clay or shale to provide a lower density material. Manufactured aggregates, e.g., fly ash and recycled glass (Europe), are also used to produce lightweight concrete.

- **Chemical Admixtures** - Chemical admixtures are the ingredients in concrete other than portland cement, water, and aggregate that are added to the mix immediately before or during mixing. Producers use admixtures primarily to reduce the cost of concrete construction; to modify the properties of hardened concrete; to ensure the quality of concrete during mixing, transporting, placing, and curing; to overcome certain emergencies during concrete operations; and to improve durability of the concrete in use. Admixtures are classed according to function. Currently, there are seven distinct classes of commercially-available chemical admixtures: air-entraining, water-reducing, retarding, accelerating, plasticizers (superplasticizers), corrosion inhibitors, and shrinkage reducers accelerating admixtures increase the rate of early strength development, reduce the time required for proper curing and protection, and speed up the start of finishing operations. Accelerating admixtures are especially useful for modifying the properties of concrete in cold weather. Whereas retarding admixtures modify concrete properties in hot weather, superplasticizers, also known as plasticizers or high-range water reducers, reduce water content by 12 to 30 percent and can be added to concrete with a low-to-normal slump and water-cement ratio to make high-slump flowing concrete or high-performance, low water/cement ratio concrete. Specialty admixtures, such as corrosion inhibitors and alkali-silica resistivity suppressants, are used to improve durability in environments that are harsh to reinforcing steel. Volume change of concrete under drying conditions is reduced by the use of shrinkage-reducing admixtures.

- **Supplementary Cementitious Materials** - Supplementary cementitious materials, which are often referred to as mineral admixtures, contribute to the properties of hardened concrete through hydraulic or pozzolanic activity. Typical examples are natural pozzolans, fly ash, ground granulated blast-furnace slag, and silica fume, which can be used individually with portland or blended cement or in different combinations. Pozzolons react chemically with calcium hydroxide released from the hydration of portland cement to form cement compounds. These materials are often added to concrete to make concrete mixtures more economical, reduce permeability, increase strength, or influence other concrete properties. Fly ash, the most commonly used pozzolan in concrete, is a finely divided residue that results from the combustion of pulverized coal and is carried from the combustion chamber of the furnace by exhaust gases. Commercially available fly ash is a byproduct of thermal power generating stations. Blast-furnace slag, or iron blast-furnace slag, is a nonmetallic product consisting essentially of silicates, aluminosilicates of calcium, and other compounds that are developed in a molten condition simultaneously with the iron in the blast-furnace. Silica fume, also called condensed silica fume and microsilica, is a finely divided residue resulting from the production of elemental silicon or ferro-silicon alloys that are carried from the furnace by the exhaust gases. Silica fume, with or without fly ash or slag, is often used to make high-strength, high-performance concrete.

- **Curing -** After concrete is placed, satisfactory moisture content and temperature (between 50^{o} and 75^{o}F) must be maintained typically for three to seven days. This process is called curing. The object of curing is to keep the concrete as saturated with water as possible until the original water-filled spaces in fresh cement paste have been filled to the desired extent by the hydration products of portland cement. Adequate curing is vital to quality concrete. To ensure that hydration will not stop at an early stage and that the concrete strength will continue to be developed, the relative humidity inside the concrete has to be maintained at a minimum of 80 percent. Besides strength, curing has a strong influence on other properties of hardened concrete, including durability, water resistance, abrasion resistance, volumetric stability, and resistance to damage from freeze/thaw cycles and de-icing salts. Exposed slab surfaces are especially sensitive to curing. Surface strength development can be reduced significantly when curing is defective.

- **Reinforcement** - Concrete is a relatively brittle material, with a tensile strength significantly less than its compressive strength. Steel reinforcing bars are commonly used to resist those tensile stresses, and the resulting combination of steel and concrete is known as reinforced concrete. Reinforced concrete can be used in a broader array of more demanding construction applications; however, lack of proper reinforcement is a major cause of deterioration in concrete structures. More durable reinforcing systems, incorporating existing and emerging technologies from fiber and composite systems, are being developed. While more costly than steel, fiber-reinforced plastic product is now being used to successfully reinforce and strengthen concrete structures, and the fiber-reinforced concrete does not suffer durability problems, such as the corrosion associated with steel reinforcement. The incorporation in concrete of discrete fibers of different types, such as steel, glass, polymer, and carbon, has led to the development of fiber-reinforced concrete, a product with even greater tensile strength and ductility.