Heartland Science
Ohio's Legacy of Discovery & Innovation

Future Horizons
From Here to There

Ohio Science and Technology in the Future

STEPHEN M. MILLETT, Ph.D.
Battelle

An excerpt from the Heartland Science Website

http://www.heartlandscience.org/future/future.htm

Heartland Science portrays how Ohioans have changed the world through discovery and innovation in science, engineering, technology, medicine and health care.

Introduction

According to legend, over 200 years ago Thomas Worthington from his Adena estate watched the sun rise over the hills of Chillicothe and visualized a bright future for the infant State of Ohio. The scene was incorporated into the state's Great Seal. Worthington believed that he had seen a providential sign, which over time came true.

Positioned between the Ohio River and the Great Lakes and on the well-traveled road to the beckoning West, Ohio attracted hard-working, ambitious, and entrepreneurial folks. Forests and prairies became farms, cabins became cities, and shops became factories. By the beginning of the 20th century, Ohio had become one of the five leading states in the country in terms of population, economic size, and political power.

Despite changes in its status, with several states surpassing it in population and wealth during the second half of the 20th century, Ohio is well positioned to be great again as it enters its third century as a state. Even more so than in the past, the future will require innovations in science, technology, and business and the development of a culture of success to revitalize the fortunes of Ohio.

A Foundation of Innovation

Ohio has been a great state for innovation, both in technology and in business. Ohio spawned the development of numerous technologies and cradled the creation of corporate models needed to develop and sustain them in the world marketplace. Ohioans invented, to use an old metaphor, both new mouse traps and new mouse trap companies. A few examples follow.

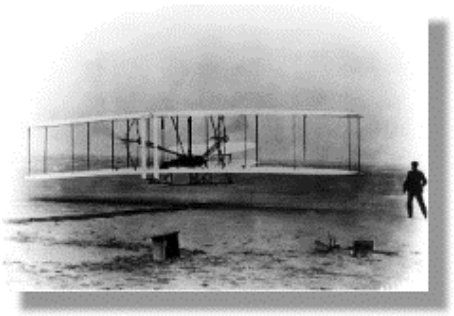
In Cincinnati, William Procter and James Gamble entered into a partnership in 1837 to make superior soaps and candles. Their partnership became The Procter & Gamble Company (P&G), which invented and commercialized such innovations as floating bars of soap, laundry detergents, cavity-preventing fluorinated toothpastes, and treatments for heartburn and osteoporosis. P&G remains today a global leader in consumer products because of technological research and development (R&D), product innovation and quality, and strong marketing.

In 1870, Dr. Benjamin Franklin Goodrich, a Union army surgeon in the Civil War, founded a company to manufacture innovations in rubber products. The B. F. Goodrich Company of Akron successfully produced rubber fire hoses and other products that

replaced leather. In 1896 the company began production of the first rubber tires for the first generation of automobiles.

In 1879 James S. Ritty of Dayton invented the "Incorruptible Cashier," popularly known as the cash register. He sold his patent to John H. Patterson, who created the National Cash Register Company (NCR). Ritty's invention and Patterson's savvy for organizing a business presaged the development of mechanical parts manufacturing in Ohio and laid the groundwork for automotive manufacturing. For decades NCR dominated the manufacturing of cash registers and other retail and banking equipment. Nearly a century later, NCR became a global pioneer in automated teller machines (ATMs), business computing, and digital data analysis.

Charles Kettering, a former employee of NCR in Dayton, invented an electric starter for automobiles, and with Edward Deeds, founded Delco in 1909. The company was later sold to General Motors, where Kettering became the champion of technical innovations for cars and trucks. Production of automobiles and automotive components remains a significant portion of Ohio's industrial output.



Also in Dayton, at about the same time that Kettering was creating a breakthrough innovation in the automobile industry, the Wright Brothers, whose bicycle shop was practically in the morning shadow of NCR factories, created the first airplane capable of controlled, powered flight. After they successfully tested it in the high winds of North Carolina's Outer Banks, the Wrights continued their experimental flying at Huffman Prairie north of Dayton. They attracted the attention of the Army, which eventually established its own aviation R&D facility at the site that became Wright-Patterson Air Force Base.

Gordon Battelle, the son of a steel company president, provided in his Will for the creation of a private, non-profit R&D organization in Columbus. The Battelle Memorial Institute opened its doors in October 1929, and despite the Great Depression provided research services to both industrial and government clients. In 1944, Battelle began its collaboration in the development of a dry, electrical copying machine. The process of xerography, or "dry copying" resulted in a device that was given the name of Xerox®, as was the name of the company set up to manufacture machines in Rochester, NY. Through Battelle, Ohio participated in the development and commercialization of one of the great technical innovations of the 20th century.

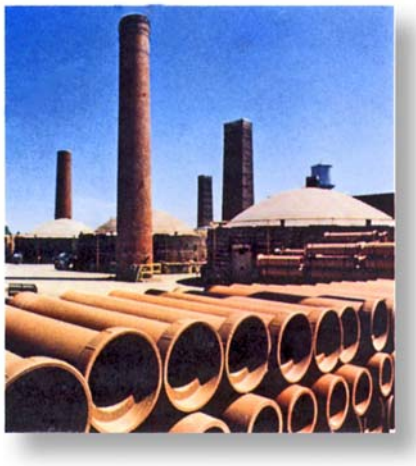
In addition to these famous historical examples, there are thousands of innovations associated with Ohio that have contributed to economic growth and the quality of life worldwide. These examples reflect a strong foundation of innovation in the history of Ohio due to individual creativity, an entrepreneurial spirit, investment, business leadership and hard work.

By 2004, Ohio's gross state product amounted to $429 billion, ranking it seventh in the nation for all sectors and third in manufacturing. In R&D, Ohio's core strengths in manufacturing, instruments and controls, power and propulsion systems, biomedical sciences, and information technologies help it rank 11th nationally with $8.1 billion annually in R&D. Ohio ranks 9th in the country with over 3,500 patents granted annually. These facts illustrate that Ohio is still a major economic and R&D player in the U.S. and global economies.

Innovations in the 21st Century

With a strong foundation of innovation, Ohio enters the 21st century with exciting possibilities in science, technology, and business. Among many potential scientific and technological opportunities, the leading candidates for successful applications and commercialization include innovative materials; biomedical technologies, especially genetic engineering; energy products and services; automated and flexible manufacturing systems; and information technologies. Ohio's governmental, educational, and corporate infrastructures provide the foundation for the development of the following technologies.

Innovative Materials



Historically Ohio has been a state with rich natural resources, especially in materials. They have been one of the foundations of Ohio's economy from the earliest days. Wood from great forests provided the fuels for kilns and furnaces. Coal was burned in the great steel mills of northeastern Ohio. Clay provided the basis of a vigorous ceramics and pottery industry that extended from Pittsburgh to Cincinnati. Sand (silicon dioxide) supplied the material base for the extensive glass industries of central, eastern, and northern Ohio, especially Toledo. Fats from farm-raised pigs generated numerous soap and candle companies, the most famous of which became P&G in Cincinnati. Both the American Ceramic Society, the world's leading organization dedicated to the advancement of ceramics, and ASM International, a worldwide network of materials scientists and engineers, are headquartered in Ohio.

In addition, vulcanized rubber made Akron the rubber products capital of the world. In this instance, the raw material was imported into Ohio, which had the knowledge, labor skills, and factories to turn raw rubber into value-added commercial products including tires for bicycles, trucks, tractors and automobiles, and other products like gaskets, oil seals and rubber hoses.

In the future, Ohio will shift from the exploitation of natural resources to laboratory-engineered materials. The shift has been occurring for at least 50 years, and the rate of change will likely accelerate within the next 10-20 years. By 2050, the creation and use of materials will likely look very different than they do today.

Polymers, for example, have been made and used in Ohio to substitute for traditional rubber and metal materials. The chemistry of polymers will extend into applications unknown today. The University of Akron, Case Western Reserve University, and Kent State University are leaders in polymer research and liquid crystal technologies.

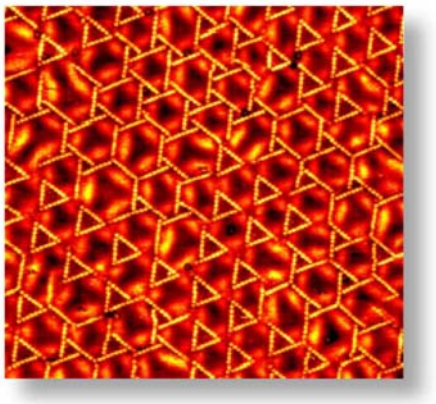
A very exciting possibility for the future is the development of new materials for the Polymer

Electrolyte Membrane (PEM) fuel cell. Extensive research into PEM materials is currently underway in Cleveland, Akron, Columbus, Dayton, Cincinnati and elsewhere in Ohio. The challenge is to develop new membranes and methods of assembly that are substantially less expensive and more reliable than today's products.

The State of Ohio made fuel cells the center of the state government's Third Frontier program. The Ohio Fuel Cell Coalition is an exceptional example of technology cooperation throughout Ohio. PEM fuel cells offer the possibility of manufactured energy devices, which, unlike batteries, can produce a continuous stream of electricity based on hydrogen fuels. They have the potential of first augmenting and eventually replacing internal combustion engines for both stationary and automotive power generation.

In addition to polymers, ceramics are an important material for future fuel cells. The Solid Oxide Fuel Cell (SOFC) uses ceramics for electrolytes and operates at very high temperatures with more reliability and fuel efficiency than PEM fuel cells. Ohio, with its historical foundation in ceramic products, and its strong institutional R&D base, is an ideal site for the R&D and production of SOFCs. Several companies in northern and central Ohio are developing SOFCs for commercialization in the future.

As with the example of P&G, agricultural materials can be developed for many applications. With the breakthroughs in DNA research that are occurring today, crops and animals can be engineered to produce advanced materials. For example, soybeans can be raised to supply chemicals for printing inks, lubricants, soaps and other cleaning products. Such bioengineered materials are farm-raised and environmentally friendly. Corn husks and other crop fibers can be developed to make exceptionally strong construction materials to replace traditional wood. With further advances in genetic engineering, Ohio could become a powerhouse of agriculturally produced materials for any number of potential applications in personal products, construction, energy, and health care.



Exceptionally powerful microscopes and new computer technologies have been used for the first time to actually see atoms. Such R&D tools provide the means to not only better understand but to manipulate atoms. This is giving rise to computational chemistry, which is a new approach to designing and making innovative micro- and nano-materials. Potentially these techniques and materials are as important to the future of materials production as tools and dies are for manufacturing. Micro- and nano-technologies for materials of the future might include highly protective but comfortable clothes; new sources of semi-conductive materials for computers and electronics; strong but light weight materials, perhaps used in composites of varying types of materials; for construction and transportation; and highly precise medical tools for diagnostics and surgery.

Another new area of development includes smart materials. They are "smart" in the sense that they react in prescribed ways to external conditions. They can change color, and even shape, according to temperature and pressure changes. The change in color, for example, may provide a signal that will warn of potential failure. Smart materials

will have many applications, including construction (especially bridges and weight-bearing supports), automotives, and consumer products.

Exciting materials innovations are occurring today and will likely explode in commercial opportunities within the next 10 to 20 years. Polymer Ohio Inc., the Edison Materials Technology Center and the Edison Welding Institute foster R&D in materials. Ohio has the potential to remain a leading state in materials and material-based products because of its R&D, agricultural, and manufacturing assets. Within the next 50 years, Ohio is likely to emerge as a leader in genetically modified and laboratory-engineered fibers, fabrics, membranes, and composites.

Agriculture

Genetic engineering, resulting in genetically modified organisms (GMOs), is the next revolutionary change in hybrid crops. In terms of practicality and impact on the economy, the rate of innovation in agricultural genetic applications exceeds that of the rate of genetic innovation in human health care.

As mentioned above, one application of genetic engineering of crops is to produce bio-materials. This includes fibers for wallboards, paneling, molding, and other construction materials. It might also provide organic (and environmentally friendly) alternatives to plastics in consumer products.

A second application, also mentioned above, is bio-energy. R&D suggests that bio-energy supplements blended with diesel fuel or gasoline may improve engine efficiency and produce less pollution. The use of ethanol as a blend with gasoline is already well known, but not widely used. Yet another possibility for the future is methanol derived from plant matter rather than from natural gas. Bio-produced methanol might emerge as a commercially viable source of hydrogen for fuel cells.

With genetic engineering, crops can be raised specifically for their energy content. They may be designed to require less processing to the end product.

One day Ohio farmers may be tending "fuel farms," where their crops go into energy sources that will contribute to national energy self-sufficiency and relieve, if not eliminate, American economic dependence on foreign sources of oil and natural gas. This may, however, require decades to achieve.

Finally, genetic engineering will lead to designer foods. Varieties of vegetables, fruits, and grains will be engineered for their nutritional as well as their taste and

appearance qualities. Just as hybridization in the past created a green revolution that gave us more hardy and productive crops, genetic engineering can be the driver for innovative foods for a growing world population. Virtually any crop in the future could be engineered to reinforce its nutritional contents, leading to more balanced diets. In the near future, for example, a tomato may be genetically engineered with high vitamins and minerals but with low acidity.

One concept that has gained interest is nutraceuticals, or food products genetically engineered to deliver a pharmaceutical substance to the consumer in place of pills and injections. The R&D being performed today in the laboratories of Ohio's universities and companies will lead to natural foodstuffs with pharmaceutical and nutritional benefits. This could happen within the next 10 years and certainly within the next 20 years.

In addition to genetically modifying the nutritional and health properties of foods, new crops can be designed to withstand weeds, pests, and drought, leading to more organic quality foodstuffs. Genetically engineered crops could be grown with little or no added weed-killing chemicals and fertilizers. The ability of plants to withstand drought would relieve the heavy burden on water systems created by agricultural irrigation and reduce the risk of plant growth under the annual, regional variations of Ohio's weather.

When genetically engineered corn and soybeans were first introduced in Ohio, there was public concern about the unknown but potentially negative environmental and human health impacts. The public concern over genetically altered corn, in particular, has required farmers to progress slowly with further DNA-engineered crops. On the other hand, the lack of public protest and the great appeal to farmers of genetically engineered soybeans and corn has further increased its planting in Ohio as well as in other states.

Ohio is a great farming state, but its size in comparison with larger states will put Ohio at an agricultural disadvantage if Ohio has to compete only on quantities and market prices of commodity foodstuffs. To be successful in the future, Ohio farms must produce value-added products that compete on value rather than cost. Biotechnology as applied to agriculture, for both crops and farm animals, is the best candidate to give Ohio its opportunity to re-emerge as a national leader at the supermarket and chemical plant.

Energy

Fuels for internal combustion engines are recognized as the hallmarks of the modern age. Not so well known are their birth and sustenance in the state of Ohio. In 1891, John Lambert of Ohio City, Ohio, invented an automobile and internal combustion engine that ran on gasoline, a refined product of oil. Thomas Midgley of Dayton developed leaded "antiknock" gasoline, and William M. Burton of Cleveland developed the first commercially successful catalytic cracking technology to refine crude oil into gasoline. Perhaps the principal beneficiary of these discoveries was another Ohioan, John D. Rockefeller of Shaker Heights, Ohio. The Standard Oil Company had been founded by John and William Rockefeller in 1867, but their business suffered when electricity shifted consumers away from the use of

oil burning lamps for lighting. Whereas one technology discovery hurt Standard Oil, another, the internal combustion engine using gasoline for automobiles, propelled it to new levels of success in a new business.

Ohio is rarely thought of as a great energy state. It has been overshadowed by Texas, Louisiana, California, and Alaska. In the early 20th century, however, Ohio was an energy leader. It was a major producer of coal, natural gas, and oil. More importantly, Ohio was the home of great energy companies. For example, Standard Oil and later Sohio originated in Cleveland. Sohio, before it merged with BP, was the leading oil exploration company in Alaska. Marathon Oil dates back to the Ohio Oil Company, which was founded in 1887 in Lima, Ohio. It participated in the shift of oil drilling to Texas, Louisiana, Oklahoma, and abroad. Although its corporate headquarters moved to Houston, Marathon still maintains extensive operations in Findlay, Ohio.

Economically the oil and natural gas supplies of northwestern Ohio are now largely depleted. The great coal deposits of eastern and southern Ohio (also producing some natural gas) supplied the fuel for the steel mills of Ohio. The state still contains large deposits of coal, which is now principally used to generate electricity in large power plants. Coal, however, raises environmental concerns, including smoke, particulates, and sulfur emissions. Today there is a growing concern about mercury released from burning coal. In the future, the great environmental regulatory challenge of coal will be carbon dioxide emissions that may contribute to global climate change. Within 20 years, if not sooner, the U.S. may have to resort to a carbon (dioxide) management plan in order to prevent further damage to the Earth's atmosphere. Ohio is currently a leader in examining the best options for carbon management. A regional consortium of companies and universities that includes AEP, FirstEnergy, Cinergy, Battelle, The Ohio State University, and Ohio University is working with the U.S. Department of Energy and state agencies to identify and evaluate alternative methods of carbon management, including sequestration. "Carbon sequestration" captures and permanently isolates gases that otherwise could contribute to global climate change.

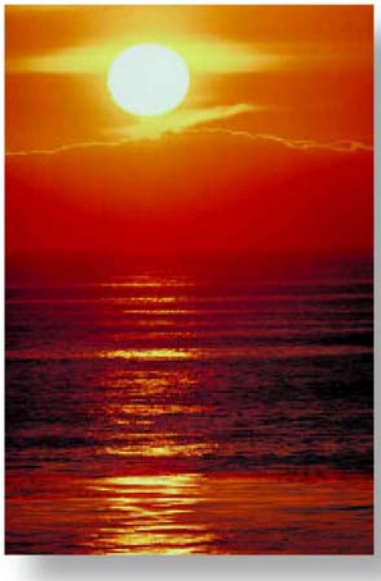
One great innovation of the future may be a new technology for coal gasification. The process today is too expensive compared with current commodity fuel prices. The goal is to remove sulfur, mercury, and other constituents of coal leaving only high-energy hydrogen and carbon. Gas derived from coal could be used as a fuel for fuel cells as well as burned in internal combustion engines for transportation and power plants for electricity.

In addition to the possible gasification of coal, two other exciting technologies may drive Ohio back to its position as a national leader in energy. One is bio-fuels, discussed above in the section on agriculture. This includes ethanol and methanol for use as blends with gasoline and diesel (thereby reducing quantities of foreign oil and pollutants), as a fuel for modified internal combustion engines, and methanol as a fuel for fuel cells.

The other exciting possibility is "manufactured" energy, which relies on the state's industrial foundation. The principal product would be PEM and Solid Oxide Fuel Cells.

Ohio is currently a leading generator of power, with AEP in Columbus being the largest producer of electricity in the U.S. There will be a need for the huge amounts of electricity that can be generated in a central power plant. Innovations in power generation, such as the integrated gas combined cycle (IGCC) generators, will appear over the next 20 years. In addition, there will be more distributed generation of smaller generators to augment

the electric power grid. These generators might be fueled by synthetic diesel, bio-fuel blends of diesel, natural gas, and fuel cells.



The ultimate source of energy is the sun, yet solar power remains a tough technical challenge, especially for Ohio. Today solar power technologies operate in the visible light part of the electromagnetic spectrum. A great innovation would be the discovery of materials reactive to different ranges of the spectrum, such as ultraviolet, which Ohio receives even on cloudy days. There are possibilities of hybrid energy systems using solar power, batteries, engines or turbines, and fuel cells. Large scale solar power is not likely within the next 20 years, but perhaps within the next 50 years.

Another energy option for the future is a new generation of nuclear power. Innovative pebble bed nuclear reactors are being tested now. Also emerging is a new technology called pyrometallurgical processing that will process spent fuels at the reactor, thereby eliminating a major nuclear waste disposal challenge. Because it releases little or no carbon dioxide, nuclear power could be the most effective response to the emerging challenges of carbon management. Large amounts of very inexpensive electricity generated by nuclear power plants off-peak could be used for the affordable electrolysis of water to produce hydrogen for fuel cells.

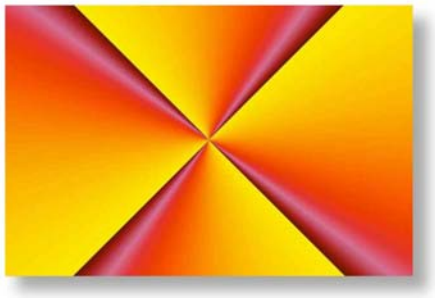
Manufacturing

A hundred years ago, huge foundries and vertically integrated manufacturing dominated the landscape of Ohio. Often vertically integrated factories owned or controlled all aspects of production from raw material through design and development, processing, packaging and distribution. The leading industries were steel, glass, automotive, and consumer products. In addition, virtually every little town contained numerous small factories. Today, many of the large factories are empty. Many of the small town manufacturers are gone, although a surprising number remain. New focused factories are being built, despite stiff competition from Asian manufacturers, but with lower profiles and much lower employment numbers. Focused factories produce only a few, perhaps world-class products, at competitive prices. A focused factory does not try to do all things for all customers. It strives instead for a narrow range of products, customers and processes. The result is a factory that is smaller, simpler and totally focused on one or two key manufacturing tasks.

Will manufacturing go the same way as agriculture? In 1803, perhaps 90% of all Ohioans worked on farms. Today, that number is less than 5% (and maybe closer to 1%). Today's farms are much larger and more productive than they were 200 years ago. The long-term trends of manufacturing may somewhat parallel the long-term trends in agriculture, but they will not be exactly the same. Because of the use of electricity, computers, networking and extensive automation, factories are becoming smaller and more distributed rather than aggregating like agribusiness. Manufacturing, like agriculture, is capital and energy intensive, but the variations in manufacturing exceed those of agriculture. Like agriculture, the number of employees will likely decline greatly while productivity greatly increases in manufacturing.

The long-term trend is that large scale production of lower value commodity products sensitive to labor costs will increasingly shift to other countries with large working populations and lower wages. These same areas represent some of the fastest growing consumer markets in the world. There are, however, two very important exceptions to this general trend.

One is the case in which transportation costs, market relationships, or political and legal considerations give an advantage to local manufacturing in the U.S. Sometimes, there is a competitive advantage to being close to consumers, especially for highly differentiated, high value products (the opposite of commodities). Ohio will continue to have an advantage to produce goods with intellectual property rights where the manufacturing processes rely on new, innovative, and proprietary technologies that can be better guarded at home than abroad. New factories are being built in Ohio and the rest of the U.S. in which new technologies compete very favorably with foreign low labor rates. At the same time, Ohio has greatly benefited by the location of factories by foreign corporations in Ohio. Primary examples are Honda Manufacturing Co. near Marysville and Anna, along with numerous small factories that supply Honda like American Showa. It will be interesting to see whether Chinese companies follow the Japanese example and locate factories in Ohio.



The future of manufacturing is flexibility and automation. As consumers become more demanding, there will be a growing need for relatively low volume production of highly differentiated products for highly targeted markets. The challenges of flexible manufacturing and mass customization will be met through Ohio companies' successful implementation of the next generation of computer aided design (CAD), computer aided manufacturing (CAM), and strict quality control.

These factories will employ fewer people but the productivity will increase greatly. American workers will work as long and hard as any in the world, but they will have more responsibilities and they will add more value. They will be highly knowledgeable, and skilled relative to their production processes. And they will likely be paid well in the future.

What will likely be the products manufactured in Ohio by the year 2020? They will most likely include hybrid and electric automobiles and automotive sub-systems, fuel cells and other energy products, food and beverage products, construction materials, health care products, and consumer products.

Health Care

Ohio boasts a world-class medical facility, the Cleveland Clinic, which attracts patients from around the world. There are other hospitals with great capabilities, too. Major medical schools are found in Cleveland, Toledo, Columbus, and Cincinnati, all of which support excellent hospitals and clinics in addition to teaching and research facilities.

Health care is one of the largest sectors of the U.S. economy, and its growth will follow population demographics. Annual expenditures on health care of all types approximate 18% of the annual American GDP of some $11 trillion, and are growing. Rising costs are being driven by the increasing numbers of the elderly, the advancing middle-aged Baby Boomers, new technologies for diagnosis and treatments, and by an expanding knowledge of both preventive and curative treatments and regimens.

Ohio could claim a much larger piece of the national health care pie than it has today. Cleveland Clinic could generate many medical product companies just as the Mayo Clinic has done for the greater Minneapolis-St. Paul vicinity. There could also be larger medical equipment and supply industries in Toledo, Columbus, Dayton, and Cincinnati. A major challenge of the future is to leverage the medical and heath care assets of Ohio for much more economic growth.

One idea for the future is to combine health care with entertainment, recreation, and relaxation. In other words, one could adapt the 19th century concept of the health spa to 21st century conditions. Medical treatments could be delivered in the atmosphere of a vacation hotel rather than a sterile institution. Treatments could be combined with physical therapies and exercise in the style of a vacation resort. Diets could be enforced for best nutrition. Such types of facilities were very popular a hundred years ago and they may be found in limited numbers today. Even more attractive than curative spas would be preventative spas, where people go to relax and learn new, more wholesome lifestyles.

Science and technology have greatly changed health care in the last 50 years and they will change it radically again in the next 50 years. Perhaps the biggest breakthrough in health care will come from human genome mapping and genetic-based medicine. Within the next 10 years, each individual will be able to get his or her own genetic map. People will know for sure whether or not they carry genes associated with many illnesses and disorders. Knowing will likely (hopefully) lead to healthier lifestyles, the avoidance of risky foods and behavior, and preventative medical regimens. As medical science progresses, treatments and possibly cures will be developed to address disease-associated genes.

Genetic engineering may create the means of cloning human organs and tissues for transplants. While genetic engineering has created numerous ethical and social questions, it may offer new hope to people in desperate need of new organs and radical approaches to the treatment of cancer and potentially fatal diseases.

Advances in materials and nano-technologies will also benefit health care. New materials for health care might emerge from genetically engineered agricultural products. The development of nano-technologies will open up possibilities for

treatments and surgery that will be highly targeted, such as super-precise removals and treatments of malignant growths.

Infotainment

A convergence of technologies is occurring today in telecommunications, entertainment, information, and education. The personal computer and the Internet have given people instruments for both computing and communications. The Internet supplements both telephone communications and TV. Likewise, the TV can be used for traditional entertainment, video conference calls, and access to the Internet. Cell phones supplement traditional telephone networks and also provide access to the Internet. The consumer has so many more options today of giving and receiving messages than just 10 years ago.

In 1950 a home might have had one black and white picture TV and one telephone. Before World War II, a home might have had at most one radio. To see a movie, people went to the theatre where they also saw newsreels before the feature film. To get information, they went to the library. To send messages, they wrote letters. Today most homes have multiple radios, TVs, telephones, and computers. From home, people can access information from libraries (real and virtual), communicate in writing, attach files and photos, make telephone calls anywhere they choose, and watch TV shows and movies from around the world.

The long-term trend shows the convergence of functionality and the proliferation of hardware platforms. Communications and entertainment will converge in the product platforms of TV, video and voice communications, and computers. Information will also converge with entertainment (hence the word "infotainment") through TV and the Internet. Information sources will become more entertaining, especially through computer graphics and sound. Entertainment will carry the responsibility of providing more accurate and timely information. People will expect information to be entertaining and entertainment to be informative.

The trend in infotainment has spread to education, which will radically change over the next 20 years. The age of computer-based learning has just begun. Like the trend in manufacturing, some processes will become automated. The use of people will be in critically important and high value applications. Teachers will still be required, but they will be used when they are most important to the educational process. Computer programs can be used for individual learning through explanations, sources of data, reference sources, and problem solving. The principles of computer games will migrate to modeling, simulation, and forecasting. This makes understanding and most importantly, the application of even the most advanced concepts accessible to all. This will contribute to the continued creativity of Ohio's entrepreneurs, workforce, and citizens. Learning and experimental computer programs will be exciting with visuals, graphics, and sounds.

Ohio has been a player in all of the trends mentioned above, although it does not enjoy the "high tech" image associated with California, Washington, and Texas. Ohio remains well situated to participate in such an electronic renaissance. In addition to widely deployed broadband and wireless networks Ohio counts a number of companies as part of its critical mass of information convergence networking base. Ohio researchers have contributed significantly to develop the whole industry of liquid crystal displays (LCDs) that are ubiquitous on cell phones, computers, PDAs and other infotainment devices.

NCR in Dayton has been a major manufacturer and supplier of computer hardware and computer-based services for banks and retailers. Lexis-Nexis®, a pioneer in digital information services, is also based in Dayton. Columbus was the home of CompuServe®, one of the earliest network service providers in the U.S. Columbus is currently the home of a large concentration of information and Internet service providers including Chemical Abstracts, Online Computer Library (OCLC), Battelle, as well as numerous companies created since the 1990s.

Ohio has a powerful network of public and private universities. The Ohio State University, the University of Cincinnati, and Case Western Reserve, to name just three, claim international reputations in engineering. Ohio's higher education system, if integrated in their R&D programs, could be as productive as any in the country.

Elements of Success

The future of Ohio is not guaranteed. As in the past, the future of Ohio will be what Ohioans make it. Wishing for a bright future is not enough. We need to anticipate the future and identify the key elements of success to get to a bright future.

Based on the past and current trends, at least five elements of success emerge:

1. Leadership. As illustrated in the examples above, men and women with exceptional vision will have to emerge to provide leadership in innovation, business, academia, government and other endeavors. Ohio must provide an environment for the cultivation and encouragement of leaders, both those native to Ohio and those who come to Ohio from all over the world. This can be achieved through education in general and leadership preparation programs in particular. It can also be achieved by creating an environment conductive to pursuing leadership opportunities. The entrepreneurial spirit must be as strong, if not stronger, in the future than it was in the past. Both universities and corporations will have to offer the highest quality educational programs and incentives to attract, develop, and retain leaders of the future.

2. Education. Education is an investment in the intellectual capital of tomorrow. Ohio must have a world-class education system as the infrastructure of ideas and knowledge for innovation in technology and in business. Ohio has parts of this equation today, but the quality of basic education has to improve continuously. In addition, Ohio would benefit from a comprehensive and fully integrated life-long education system. Pre-school children have to be better prepared for success in the early grades. Middle-school students should have a seamless transition to high school work. Substantial reforms are required for high schools, and they need to be closely connected with post-secondary education. Colleges and universities need to generate R&D for industry and prepare their students for successful careers in many different walks of life. Regardless of what level of education may be achieved by the individual, there will be educational needs throughout one's adult life. Science and technology do not stand still for anyone and will continue to drive the needs for improved educational attainment in Ohio.

3. World class R&D. Technological developments were key to the success of Ohio in the past. They will be absolutely vital for success in the future. Ohio has excellent research programs and facilities across the state. A major challenge is keeping them up to date and competitive in a rapidly changing world of intense competition. Ohio will not only have to cultivate its own students to grow into top scientists and engineers, but it will also have to attract talent from around the world. The funding of world class talent and R&D will be a difficult challenge, but the right opportunities, a talented workforce and compelling programs can continue to spawn innovation and draw investments into Ohio. Innovation in business models and building companies, and consortia is just as important to future success as innovation in science, technology, and new products.

4. Investment. Innovations and start-up companies require financing. Ohio has often been criticized for having insufficient venture capital. Whether or not this is true, Ohio has to attract more venture capital and corporate investment funds from around the world. Attractive opportunities will attract direct investment, and Ohio needs to be pro-active to attract more attention in the future.

5. A Pro-Business Environment. Through tax incentives and other forms of public support, Ohio will have to provide a business environment that will encourage R&D,

entrepreneurialism, start-up companies, and new businesses. In the 19th century, a pro-business policy often took the shape of trade protection, monopolies, and subsidies for private companies. Today, a pro-business policy may include tax deferments, credits, and public support of R&D and demonstration projects. Flexible policies and leadership that recognizes the need to nurture investment will be the foundation for Ohio's future entrepreneurs, start up companies, and new businesses.

Summary

In summary, Ohio has enjoyed great success in science, technology, innovation, and business in the past and it is well positioned to be successful again in the future. Ohio has university research and development centers, world class medical institutions, and a number of leading companies developing and implementing the latest technologies to provide the vehicles to drive Ohio into an innovative, sustainable future. However, a bright future, unlike the sun that rose for millennia over the hills of Chillicothe, will not happen naturally without focused human effort. Ohioans have to want a bright future, invest in it, and make it happen. Perhaps the most important element is a culture of success that needs to be restored to Ohio.

*About the Author

STEPHEN M. MILLETT is an internationally recognized authority on emerging technology management and futuring methods. He joined the staff of the Battelle Memorial Institute in 1979 as a national security analyst. He currently serves as a thought leader for Battelle, focusing on technologies and products of the future.

Millett holds a bachelor's degree from Miami University and a master's and Ph.D. in history from The Ohio State University. He was an officer in the U.S. Air Force and served as a faculty member at the Air Force Institute of Technology's School of Engineering. He has authored or co-authored four books as well as numerous professional articles. He is a professional member of the World Future Society and a founding member of the Association of Professional Futurists.

In 2003 Ohio Governor Bob Taft appointed Millett as a member-at-large of the Ohio Board of Education

An excerpt from the Heartland Science Website

http://www.heartlandscience.org/future/future.htm

Heartland Science portrays how Ohioans have changed the world through discovery and innovation in science, engineering, technology, medicine and health care.