TECHNICAL
REPORT

The Global Technology Revolution China, In-Depth Analyses

Emerging Technology Opportunities for the Tianjin Binhai New Area (TBNA) and the Tianjin Economic-Technological Development Area (TEDA)

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Summary

Running along 150 kilometers (km) of coastline in the sprawling municipality of Tianjin in northeast China,[1] Tianjin Binhai New Area (TBNA) has taken on a pivotal role in China's national economic strategy. Tianjin municipal authorities first established this locality of approximately 2,200 square km (sq km) in 1994. At that time an arid, undeveloped area, TBNA was given the ambitious task of spurring industrial growth in Tianjin. In little more than a decade, it has become home to 1.4 million people, northern China's largest container port, and a broad base of industry and manufacturing.

In 2006, China's State Council named this industrial center in the municipality of Tianjin as a "special pilot zone" with a mandate to become the country's next regional engine for economic growth. In this capacity, it is to serve as a model of regional development and economic reform for other parts of China. Now reporting directly to the State Council, TBNA benefits from a host of favorable national-government policies and tax incentives designed to attract foreign and domestic investment and stimulate trade. It is expected to emerge as China's next economic powerhouse, invigorating the economy of the northeastern Bohai Rim region in the same manner as Shanghai and Suzhou did in the Yangtze River delta area and Guangzhou and Shenzhen in the Pearl River delta area before it.

The Tianjin Economic-Technological Development Area (TEDA) is one of three administrative zones in TBNA. It is also TBNA's industrial and manufacturing base and the center of TBNA's financial and commercial activities. TEDA is to play a key part in the economic growth envisioned for TBNA. Established in 1984, TEDA is today a bustling industrial-park complex. It possesses a robust manufacturing base, with pillar industries in electronics, automobiles and parts, food processing, and biopharmaceuticals. Many of the world's Fortune 500 companies, top Chinese firms, and other leading multinationals have strong presences in TEDA.

A Vision of the Future for TBNA and TEDA

In its directive, the State Council specified that TBNA focus its development efforts in three domains, eventually becoming a center in north China for the following three spheres:

- leading-edge research and development (R&D) and technology incubation

[1] A *municipality* in China is not a city in the Western sense of the term but rather an expansive administrative unit that extends from a populous urban core to cover a very large surrounding region. There are only four such municipalities in China, each of which holds the status of province and reports directly to the Chinese central government.

- first-class, modern manufacturing
- international shipping and logistics.

At the same time, along with economic development, the State Council intends for TBNA to lead efforts to address many of China's most urgent national problems. Steadily rising energy demands, a growing scarcity of usable water supplies, and gravely escalating urban pollution are among China's greatest concerns. With these needs in mind, TBNA, as a *pilot zone*, is to present an alternative to the traditional industrial economy, shaping a model of sustainable development and ecofriendly industry that will contribute to tackling all of these challenges.

Innovation in science and technology (S&T) stands at the core of this vision of economic and environmental development, particularly of cutting-edge R&D. TBNA will need to take definitive steps to pursue this goal, and TEDA will be at the forefront of this effort. Building on its existing manufacturing base, TEDA aims to transition from a successful industrial-park complex into a state-of-the-art science and engineering (S&E) center for high-impact emerging technologies. Other enterprises with relevant capacity located elsewhere in TBNA will follow suit. The desired end result is innovative R&D that meets international standards and positions TBNA as a global technology leader.

Achieving the Vision for TBNA and TEDA Through Foresight Analysis

Early in the process of developing a strategic plan for this ambitious transformation, senior managers from TBNA and TEDA found a 2006 report by the RAND Corporation, *The Global Technology Revolution 2020*, Executive Summary: *Bio/Nano/Materials/Information Trends, Drivers, Barriers, and Social Implications* (GTR 2020 Executive Summary) and *The Global Technology Revolution 2020*, In-Depth Analyses: *Bio/Nano/Materials/Information Trends, Drivers, Barriers, and Social Implications* (GTR 2020 In-Depth Analyses) (together, GTR 2020). This pair of reports is a comprehensive foresight analysis that identifies *technology applications* (TAs) most plausible by 2020, those countries capable of acquiring them, and their likely effects on society. The study focused on the applications made possible by emerging technology trends rather than on the technologies themselves because technologies on their own rarely deliver solutions to real-world problems. Instead, solutions derive from the ways in which technologies are put to beneficial use. Accordingly, GTR 2020 highlights TAs, such as cheap solar energy, instead of technologies, such as photovoltaic (PV) materials.

Having reviewed GTR 2020, TBNA and TEDA managers approached RAND to conduct a series of foresight studies designed specifically for their purposes. They commissioned RAND to do the following:

- Identify promising emerging TAs for TEDA and other high-tech centers in TBNA to implement as a pivotal part of TBNA's overall strategic plan for economic growth.
- Identify the capacity needs to implement these TAs, as well as the critical drivers and barriers that might facilitate or hinder implementation.
- Develop a strategy and action plan for each TA.[2]

[2] In this summary, we describe the strategy for each TA. The detailed action plans can be found in the chapters on the individual TAs in Part Two of this report.

- Provide guidance on how these TAs might fit into an overarching strategic plan for TBNA's economic development.

An Overview of the Most-Promising Technology Applications for TBNA and How We Selected Them

Seven innovative TAs emerged from our analysis as particularly promising for TBNA to pursue as it endeavors to fulfill the State Council's mandate:

- *Cheap solar energy:* Solar-energy systems inexpensive enough to be widely available to developing and undeveloped countries, as well as disadvantaged populations[3]
- *Advanced mobile communications and radio-frequency identification (RFID):* Multifunctional platforms for sensing, processing, storing, and communicating multiple types of data. RFID involves technologies that can store and wirelessly transmit information over short distances
- *Rapid bioassays:* Tests to quickly detect the presence or absence of specific biological substances with simultaneous multiple tests possible
- *Membranes, fabrics, and catalysts for water purification:* Novel materials to desalinate, disinfect, decontaminate, and help ensure the quality of water with high reliability
- *Molecular-scale drug design, development, and delivery:* The abilities to design, develop, and deliver drug therapies at the nanoscale to attack specific tumors or pathogens without harming healthy tissues and cells and to enhance diagnostics
- *Electric and hybrid vehicles:* Automobiles available to the mass market with power systems that combine internal combustion and other power sources
- *Green manufacturing:* The development and use of manufacturing processes that minimize waste and environmental pollution and optimize the use and reuse of resources.

To arrive at this selection, we began with the 12 TAs identified in GTR 2020 as those that China could acquire by 2020. We then combined this with a rigorous study of realities, circumstances, and issues in TBNA and in China more broadly, drawing on a diverse array of Chinese- and English-language sources:

- Chinese- and English-language documents describing the mission, history, and current status of TBNA and TEDA
- Chinese- and English-language literature on China's social, environmental, and economic needs and measures that the Chinese government has taken to date to address them
- on-site interviews that we conducted in TBNA, TEDA, the Tianjin Port, the municipality of Tianjin more broadly, and the city of Beijing
- visits to S&T institutions that could provide capacity outside TBNA and TEDA, such as Tsinghua University and the Chinese Academy of Sciences
- a two-day workshop that we held in TEDA with key figures from TEDA scientific institutions, firms, and management.

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[3] This and the following definitions are based on those used in GTR 2020.

On the basis of that analysis, we narrowed down the top 12 TAs for China to the final selection of seven. These either come directly from GTR 2020 or are hybrids combining one or more of the top 12.

The Foundation for TBNA's Future Development in Science and Technology

The analysis on which we based our selection of TAs and, eventually, the strategies and action plans that we suggested for them, took into account four principal factors:

- TBNA and TEDA's missions, as mandated by China's State Council
- China's pressing national needs
- drivers and barriers to technological innovation in China as a whole and for TBNA more specifically
- relevant capacity currently available to TBNA and TEDA both locally and more broadly in R&D, manufacturing, and S&T commercialization.

TBNA and TEDA's Mission as a Special Pilot Zone for Economic and Environmental Development

In a relatively short time, TBNA and TEDA have successfully established a strong manufacturing base. With its three-pronged mandate for TBNA, the State Council is now calling for TBNA and TEDA to build on this base to develop a modern, high-tech manufacturing capacity that emphasizes R&D to produce goods that add value and create better-paying jobs. This type of manufacturing is knowledge-based; consequently, S&T will be a crucial part of this transformation. The capacity for S&T commercialization will also be vital so that the products that TBNA and TEDA design in their R&D efforts are highly marketable and can be manufactured using innovative production processes.

The part of the State Council's mandate that directs TBNA to become a center for international shipping and logistics is closely integrated with R&D and manufacturing objectives. Achieving this goal will require TBNA to operationalize cutting-edge supply-chain and logistics technologies emerging from current R&D.

A companion mandate for TBNA to experiment with reforms to the financial sector has helped identify preferred business areas for S&T development. In December 2007, TBNA signed an agreement with the China Development Bank to co-finance a RMB 2 billion (US$293 million) venture-capital fund to boost high-tech start-ups in TBNA.[4] This specifies favored areas for investment: electronics, bioengineering, new materials, new energy, environmental protection, and automated manufacturing.

The State Council's directive to TBNA to implement innovative environmental initiatives alongside economic development stems from the recognition that three decades of rapid economic growth have taken a grave toll on the environment in China. While economic development must continue, it must be sustainable. TBNA has already taken definitive first steps to meet the environmental directive with such initiatives as its circular economy and the Sino-

[4] As of November 5, 2008, the exchange rate was 0.146445 U.S. dollars per Yuan. RMB is Renminbi, the official Chinese currency, which is also frequently referred to as *Yuan*.

Singapore Tianjin Eco-City.[5] The first involves using and regenerating resources in sustained cycles that minimize industrial waste and pollution. The ecocity, with a planned population of 350,000, will be constructed and operate using advanced green technologies, guided by Singapore's experience with renewable energy, green manufacturing, low-pollution public transportation, and recycling of water and waste. These efforts are only the beginning of a push from TBNA to create a showcase of sustainable development and environmentally friendly manufacturing approaches. What TBNA successfully prototypes could eventually be put into use throughout China.

China's Pressing National Needs

Even as China's economy continues to grow and its rising middle class enjoys the higher standard of living that accompanies that growth, the country faces serious challenges:

- *Reduce rural poverty:* China's meteoric economic growth has dramatically decreased poverty in busy urban commercial areas. But poverty remains entrenched in much of rural China. The country needs TAs that can help create opportunities for rural dwellers, improve their standards of living, and reduce the pressure to migrate to urban centers for work.
- *Provide for a large and rapidly aging population:* Despite having curbed its population growth, China still has more than 1 billion residents, many of whom are elderly. At the same time, China is transitioning to a new social-welfare system that calls on working-age people to shoulder much of the cost of providing previously state-funded services. Consequently, TAs that help provide well-paying jobs are essential, as are medical innovations to help meet the special health requirements of senior citizens.
- *Meet the population's health and sanitation needs:* A population as large as China's presents daunting health-care needs. Noncommunicable diseases are now the primary concern, although certain communicable diseases remain a problem. The health-care burden is disproportionately high in rural areas. China needs TAs that can improve private and public health care and cost-effectively enhance the quality of water and sanitation, particularly in rural areas.
- *Meet growing energy demands:* China is one of the world's top energy consumers, and its needs are on a steady upward curve. Oil and gas for automobiles are in particularly high demand as ever-larger numbers of China's expanding middle class purchase cars. The country needs TAs that can tap alternative energy sources, reduce demand for oil, boost energy efficiency, and decrease industrial energy requirements.
- *Reverse water shortages:* Clean water is scarce in China overall. Shortages are especially severe in the north of the country, which suffers from very low rainfall and dwindling groundwater sources. Yet, residential and industrial demand shows no signs of abating, and supplies cannot keep pace. TAs that can provide access to clean water from a variety of sources are vital.
- *Reduce pollution:* China's economic boom has left it facing critical pollution levels. Acid rain, air pollution, urban sprawl, loss of arable land, and red tides are among the gravest problems. The country needs TAs that can help balance economic development with

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[5] A *circular economy* uses energy, water, and raw materials in sustained cycles to minimize waste and pollution.

environmental protection by reducing toxins in automotive and industrial emissions, recycling resources, and increasing energy efficiency.
- *Sustain high economic growth:* China must continue to build and expand its economy to be able to solve national problems, create jobs, and enhance quality of life for its residents. The country is now at a crossroads at which knowledge-driven economic growth is critical to its future. At the core of this growth will be TAs that help China reduce its reliance on foreign technology sources, join the ranks of the world's leading S&T nations, and repair a national brand image damaged by a series of high-profile incidents indicating poor quality assurance.

Drivers and Barriers to Technological Innovation in China and TBNA

Widespread, sustainable implementation of any TA depends on the balance between the drivers that facilitate implementation and the barriers that hinder it. A single factor can be a driver or a barrier. Consider cost and financing: The availability of ample venture capital can make money a driver, but lack of funds can turn it into a barrier.

In our view, the factors that will most influence China's ability to successfully pursue cutting-edge R&D and technology innovation are as follows:

- the country's needs
- its national R&D policies
- other national policies that could generate demand (or, as appropriate, reduce demand) for certain TAs
- intellectual property rights (IPR) protection
- finance and banking laws and regulations
- local policies, laws, and regulations that could directly affect individuals' and organizations' ability to conduct cutting-edge R&D and commercialize innovative technologies
- human capital
- culture of R&D and innovation.

These same eight factors will most affect TBNA's ability to develop and implement the selected TAs. Some of these are clearly either a driver or a barrier throughout most of China. But occasionally, local circumstances make them stronger or weaker drivers or barriers in a particular organization or region (or for a specific TA) than they are elsewhere in the country.

Several of these factors are unmistakable barriers in TBNA and hold for all seven TAs. IPR protection, for example, remains a barrier in TBNA, as in China as a whole, to both homegrown innovation and the involvement of foreign capital and talent in new R&D and technology ventures. Finance and banking laws and regulations are also a barrier in TBNA, as they are in China generally, because they discourage investment of venture capital. But, for certain of the seven TAs, sources of venture capital available to TBNA for specific technologies mitigate this barrier to some degree. Lack of a culture of R&D and innovation is a third barrier in TBNA, as it is in China as a whole. It discourages the risk-taking in new ventures that is essential to pursuing and commercializing groundbreaking R&D.

TBNA has one driver that all seven TAs share: human capital. This stems from the strength of TBNA's current manufacturing base, the corresponding workforce, and the concentration of academic institutions in the municipality of Tianjin. However, young Chinese people are tending to shy away from technical and vocational training, and domestic competition for S&E talent is heated. Both of these could be mitigating factors.

Capacity Currently Available to TBNA and TEDA

To fulfill the State Council's mandate, TBNA and TEDA will need capacity in three areas: (1) R&D, (2) manufacturing, and (3) S&T commercialization. Both local capacity—in TBNA, TEDA, and the municipality of Tianjin more broadly—and that from elsewhere in China and internationally will play a part.

In terms of R&D capacity, TBNA and TEDA have a growing number of institutions that provide cutting-edge research facilities and a professional cadre of highly trained scientists and engineers. But they face intense competition, both within China and abroad, for human capital of this caliber.

With regard to manufacturing capacity, TBNA and TEDA have a substantial industrial base that has been growing for the nearly 25 years since TEDA's inception. Investment by an array of Fortune 500 companies, a track record of increasing industrial output, and a rising gross domestic product (GDP) indicate the strength of this base. TBNA is also steadily improving the physical infrastructure—utilities, cargo facilities, and waste-management processes—that are vital to manufacturing capacity. But a potential shortage of the skilled laborers and technicians needed to work in manufacturing and, again, heightened competition for those on the job market are real challenges.

As for S&T commercialization, TBNA and TEDA operate a well-established network of research parks and technology incubators aimed at supporting emerging high-tech enterprises. Ample financial incentives help spur development and attract human capital. Yet, these enterprises face considerable challenges due to China's need to better protect IPR and reform finance and banking laws and policies. They also lack strong linkages between R&D institutions and commercial industry to facilitate the transfer of high-tech products to market.

A Close Look at the Seven Most-Promising Technology Applications

The seven TAs that appear to be most potentially fruitful for TBNA build on two highly influential emerging global trends in technology and industry. The first is micro- and nanoscale technology. The vast majority of the TAs identified in GTR 2020 involve micro- or nanoscale advances and the integration of bio-, nano-, information, and materials technology. Similarly, six of the TAs recommended for TBNA involve technologies in this domain. Second, both industry and consumers today are moving clearly in the direction of green processes and technologies. Four of the TAs recommended for TBNA are focused on using energy, water, and other resources much more efficiently than has occurred in the past.

Cheap Solar Energy

Cheap solar energy has strong potential worldwide market demand. Driven by government incentives and renewable-energy subsidies—especially in Germany and Japan—the solar-electricity industry has grown at an average annual rate of 44 percent over the past five years. In 2007, it grew by 55 percent to nearly $13 billion. To sustain such growth, companies are now competing to make solar-energy systems less expensive and more efficient.

China needs to promote energy growth but, concurrently, to develop renewable-energy sources, improve air quality, and reduce pollution. Pursuing cheap solar energy is consistent with these needs because it would replace energy currently being generated mostly by coal-fired power plants.

There are three generations of solar electric technologies. The first generation, based primarily on polycrystalline silicon, currently accounts for more than 90 percent of global sales. The emerging second- and third-generation systems are based on thin-film materials and novel nanoscale technologies. They have the potential to transform the industry, offering lower costs and potentially greater efficiency. The growth of the global market demand depends on them.

Available Capacity. The Tianjin area offers substantial capacity for TBNA to implement cheap solar-energy applications. The thin-film silicon research group at Nankai University, working in collaboration with the Beijing Solar Energy Institute, is one notable example. Another is the China National Academy of Nanotechnology and Engineering (CNANE) in TEDA. CNANE has the technical and instrumentation capacity on the nanoscale level required to conduct R&D on third-generation solar materials.

Drivers and Barriers. China's need to ensure energy growth while reducing harm to the environment and improving air quality is a driver for this TA. China's national R&D policies, including support for solar-energy demonstrations, and other national policies are also drivers.

Local policies and laws—in particular, building codes and regulations governing electric-utility connections to buildings—have often been barriers where solar-electricity systems have been implemented. This is because *balance-of-system* equipment, such as batteries and electrical inverters, as well as other safety and metering equipment that building inspectors and the local electric utility might require have presented a considerable ongoing expense. TBNA has the opportunity to mitigate these problems and perhaps even turn local policy and law into a driver by reviewing building codes and utility-interconnection regulations to ensure that the balance-of-system requirements for solar electricity provide needed safety without increasing costs.

Finance and banking laws and regulations do constitute a barrier as well. But this is to a somewhat lesser degree with cheap solar energy than with other TAs because TEDA's nanotechnology venture fund and the green venture-capital fund of Tsinghua University, Tsing Capital, are potential sources of investment funds for TBNA to pursue this TA.

Recommended Strategy. China already has a well-developed first-generation solar-electricity industry. Consequently, we believe that the best opportunity for TBNA and TEDA lies not in entering the first-generation market but rather in becoming an R&D and manufacturing center for second- and third-generation systems. The initial focus should be the global export market and, in the longer term, the domestic Chinese market, as it develops.

Advanced Mobile Communications and RFID

Mobile-communication devices increasingly do much more than exchange voice data. They also serve as platforms that can sense, process, store, and communicate data in multiple forms. At the same time, RFID devices have become increasingly inexpensive and sophisticated. Already in widespread use in supply chains and a variety of commercial transactions, they are now poised for integration into mobile-communication devices.

The demand for multifunctional wireless communications in both rural and urban markets is growing rapidly worldwide. This is particularly true in the Asia-Pacific region and China.

In addition, with its mandate to become an international shipping and logistics center with the Tianjin port as its hub, TBNA has a pressing need for advanced mobile-communication and RFID technologies that promise to streamline cargo logistics, reduce the cost of port operations, and increase shipping security.

Advanced mobile-communication and RFID systems are composed of many individual component technologies—for example, displays, memory, batteries and power storage, and sensors and antennas. Each of these constitutes an industry itself and will determine the future direction of wireless computing platforms. As global demand for this TA grows, the market for these component technologies will strengthen in kind.

Available Capacity. TEDA produced more than 105 million cell-phone handsets in 2006—approximately 10 percent of the mobile phones sold worldwide. Its extensive manufacturing base in this area includes Samsung's largest facility for manufacturing mobile phones. TBNA also has available capacity in component technologies. Two groups at Tianjin University (TU) are doing leading edge R&D on display technologies. In addition, a TEDA firm manufactures the smallest hydrogen canister in the world (just the size of a AA battery), which can provide the hydrogen storage for fuel cells and mobile-phone chargers.

Drivers and Barriers. China's need to spur economic development and increase productivity is a driver for this TA. Advanced mobile communications will help supply the country's growing mobile-phone market and, accordingly, boost consumption. RFID applications for supply chains and logistics have the potential to enhance manufacturing and shipping considerably. China's national R&D policies supporting integrated circuit, software, and network development are another driver.

Other national policies—especially China's resolve to date to not adopt international standards for mobile communication—may constitute a barrier.

Recommended Strategy. TBNA should aim to become an R&D and manufacturing center for mobile-communication devices and RFID systems. It should focus initially on the domestic Chinese market and then broaden to the global market. In addition, it should build state-of-the-art R&D programs in two component technologies: displays and power sources. It should not, however, attempt to shape R&D trends in integrated circuits.

Rapid Bioassays

Global markets for better means of testing personal and public health and monitoring the environment are emerging rapidly. China has a particular need for state-of-the-art technology to help meet public-health and environmental challenges. Novel biochips to detect and analyze genes and proteins are enabling very fast tests for diseases and pathogens. The specificity and sophistication of these advanced bioassays has increased to the extent that some lab-on-a-chip systems can even perform as small-scale laboratories using miniaturized devices. These types of bioassays could identify or eliminate threats to public health, significantly improve patient outcomes, and accurately detect pathogens in the environment and the food supply.

Available Capacity. TEDA is home to one of China's five national biochip R&D centers, the Tianjin Biochip Corporation. This institute produces its own biochips, as well as reagents and other disposables used in bioassays. It also provides diagnostic bioassays to detect *E. coli*, *Shigella*, and *Salmonella*. It has partnered with a global leader in the field, the U.S. company Affymetrix.

Drivers and Barriers. This TA has several drivers. One is China's need to improve public health, reduce environmental damage, and, especially, to improve the quality of the water supply. Another is China's national R&D policy, in which health, medicine, and biotechnology are focus areas. Other national policies (particularly those designed to regulate food and drugs more effectively) are a third.

Recommended Strategy. The long-term strategy is for TBNA to become a leading player in the global marketplace for state-of-the-art rapid bioassays. But its initial focus should be on using licensing and partnership agreements to attract leading companies to TBNA and TEDA. During this period, TBNA should build capabilities as a reseller of bioassay disposables and equipment. Eventually, TBNA companies should start manufacturing these products themselves. The Chinese domestic market should be the first target, followed by the global market.

Membranes, Filters, and Catalysts for Water Purification

Ensuring affordable access to clean water is a major global challenge. This challenge is acute in China, one of the world's top five growth markets for water and wastewater technologies. It is especially weighty in the Bohai Rim region and TBNA, where usable water supplies are exceedingly scarce.

Technologies for purifying water are an important emerging area of S&T. Four applications are being developed:

- *desalination*: removing salt from sea water
- *disinfection*: removing microorganisms
- *decontamination*: removing toxic compounds
- *quality assurance*: detecting potentially harmful matter.

Novel nanomaterials can enhance current purification systems and may make them much more cost-effective. Examples include nanocomposite and biomimetic membranes,[6] filters made of fibrous media, filters with nanoscale porosity, nanoscale catalysts, and DNA-nanoparticle composites. The principal challenge will be to scale up materials from labs to commercial applications.

Available Capacity. TBNA is the home of Tianjin Motian Membrane Engineering and Technology Company. Motian has a 20-year track record of manufacturing water-filtration membranes for industrial, personal, water-utility, and medical uses, including desalination. CNANE has the capacity to conduct research on nanoscale filters and catalysts. TU's School of Chemical Engineering and Technology has a strong R&D program in desalination, including a desalination demonstration project, and is designing, fabricating, and testing nanoscale filters. TEDA's nanotechnology transfer and commercialization organizations, the Nanotechnology Industrial Base Company (NIBC) and the Nanotechnology Venture Capital Company (NVCC), have named nanoscale water-purification filters as key targets for commercialization.

Drivers and Barriers. China's need to improve public and individual health and meet the demand for clean water is a driver for this TA. China's national R&D policies, which have earmarked R&D funding for water purification, and other national policies aimed at providing clean water for China's residents are two others.

6 Those that mimic mechanisms found in nature.

Chinese government subsidies have kept the price of water lower than what it would cost to provide it by desalination or purification. These subsidies fall into the category of other national policies, making this a barrier as well as a driver.

Recommended Strategy. We suggest two long-term goals for TBNA: (1) to become a center for R&D in nanoscale membranes, filters, and catalysts and (2) to become a leader in manufacturing state-of-the-art membranes for purifying water. It is vital for TBNA to foster close relationships between research labs and private companies to facilitate commercialization.

Molecular-Scale Drug Design, Development, and Delivery

The demand for new, more-effective medical treatments, with lower needed doses and fewer adverse side effects, is growing both in China and globally. Molecular-scale drug therapies and diagnostics are based on recent developments at the intersection of nanotechnology and biotechnology. This young, very promising field of nanomedicine could serve this market. Four innovative applications are of particular interest:

- targeted carriers for drug delivery and imaging
- controlled-release platforms and materials
- novel methods of drug administration
- means of increasing solubility.

Available Capacity. In terms of R&D capacity, TEDA's nanotechnology center, CNANE, runs a pharmaceutical R&D program. TU and Nankai University have world-class research groups working together on an exciting new platform for drug delivery: carbon nanohorns. TEDA is also home to Tianjin SinoBiotech, a company developing biotechnology and gene therapies at the preclinical stage. There is a strong industrial base for pharmaceuticals in the municipality of Tianjin that includes several of the world's top pharmaceutical companies. Biopharma and bionanomaterials for drug delivery have been named as thrust areas for technology transfer and commercialization in TBNA.

Drivers and Barriers. One driver for this TA is China's need to improve public and individual health. China's national R&D policies are also a driver. They have thrusts in demonstration projects for commercially producing vaccines and gene-modified medicines, improving modern traditional Chinese medicine, and enhancing capabilities for inventing and producing new drugs.

Other national policies are a barrier—specifically, regulations that make development more expensive and impede clinical testing and marketing of new drugs.[7]

Recommended Strategy. TBNA should aim to become a center for R&D and manufacturing of drugs developed through bionanotechnology. It should focus initially on attracting investment from foreign enterprises and, in tandem, aggressively building homegrown R&D capacity. Eventually, it should direct R&D activities toward commercializing novel medical treatments and techniques.

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[7] Despite these problems, a recent article in *Nature Biotechnology* assesses the market for biotechnology-derived pharmaceuticals in China as "beginning to take off" (see Frew et al., 2008). Detailed data for the article were derived from interviews of 22 homegrown Chinese health biotechnology firms, including Tianjin SinoBiotech. The authors note that this constitutes only a small fraction of the "thousands of companies in this sector."

Electric and Hybrid Vehicles

Current trends in the global marketplace, including concerns about the price of oil and global warming, suggest that vehicles using electric and hybrid technologies will assume an increasing market share. At the same time, China faces a severe problem with urban pollution. Among its national priorities are reducing automobile pollution and lowering demand for oil.

Hybrid vehicles are already a leading worldwide automotive market. The emergence of plug-in hybrids, which allow the batteries that power the electric motor to be recharged independently of the motor itself, has blurred the distinction between hybrid and electric vehicles. With this in mind, we created this combined TA. It encompasses four types of automobiles:

- purely electric vehicles
- traditional hybrids, in which an internal combustion engine recharges the batteries
- plug-in hybrids
- serial hybrids, in which an on-board power source charges the batteries.

Many of the components needed for this class of vehicle also have a growing market demand and strong potential for development. These include batteries, power electronics and electrical machines, power trains, internal combustion engines, and emission controls. Advances in battery technology, for example, are extending the range and improving the performance of electric and hybrid vehicles.

Available Capacity. To our knowledge, hybrid vehicles are not currently being manufactured in TBNA. But TBNA does have extensive capacity to conduct R&D on electric vehicles as well as to manufacture them. The Tianjin Qingyuan Electric Vehicle Company in TEDA builds electric cars, buses, and vans and has sold them globally.

TBNA also has capacity in electric-vehicle components. Qingyuan has an ongoing research collaboration with the U.S. Argonne National Laboratory in power-train technology and other component areas. One of the stakeholder companies in Qingyuan, EV Battery, is conducting battery research. CNANE, TEDA's nanotechnology center, has an active research program on nanoscale capacitors for electric vehicles. And in terms of S&T commercialization, the China Automotive Technology and Research Center (CATARC) conducts standards and certification testing, which will be essential in developing a market for electric and hybrid vehicles. CATARC is headquartered in the municipality of Tianjin.

Drivers and Barriers. China's need to raise energy efficiency and reduce environmental damage is one driver for this TA. China's national policies that promote both the manufacture and purchase of fuel-efficient vehicles are another.

But other national laws and policies are barriers. Examples include tariffs on vehicles or auto parts coming into China, hybrid-component patents held by foreign firms, controls that keep fuel prices low in China, and restrictions on electric vehicles in large Chinese cities.

Recommended Strategy. Given the strong market potential of electric- and hybrid-vehicle components, we recommend that TBNA develop and expand collaborative R&D on subsystems and component technologies. At the same time, it should develop the capacity to manufacture hybrid vehicles and components for hybrid and electric vehicles. It should target the growing global market first and the Chinese market later.

Green Manufacturing

Both multinational corporations and consumers worldwide are increasingly embracing green manufacturing. In many developed economies, for example, governments have established national green chemistry awards for industry. China is no exception: Green manufacturing plants are appearing in the country, and clean-technology venture capital has started to flow in. Mandates, such as the State Council's directive to TBNA to establish a circular economy, are other signs of this trend.

Four approaches are commonly employed in green manufacturing:

- *Green chemistry:* environmentally benign chemical processes and products
- *Green engineering:* feasible processes and products that minimize pollution and risks to health and the environment
- *Inherently safe process design:* smaller quantities of hazardous material, less hazardous material, and alternative reaction routes or process conditions
- *Good manufacturing practices (GMPs):* methods, facilities, and controls to make high-quality reproducible products that meet appropriate regulations and standards.

Available Capacity. Several companies located in TBNA already have programs in green chemistry and experience with green manufacturing. Several firms that have won the U.S. Environmental Protection Agency (EPA) Presidential Green Chemistry Challenge Awards, such as PPG Industries and Novozymes, operate facilities in TEDA. Otis Elevator has built the world's first green elevator-manufacturing plant in TEDA.

Drivers and Barriers. China's need to boost energy efficiency and reduce pollution and other environmental impacts is one driver for green manufacturing. Another is national policy designed to conserve resources and reduce pollution. In some cases, these policies explicitly support green manufacturing.

Cost can be a barrier, especially when an existing plant needs to be renovated or replaced to become green. But the competitive advantage that green manufacturing provides in many cases can mitigate this barrier.

Recommended Strategy. TEDA should become a center for green manufacturing in China. The initial focus should be on attracting to TBNA those companies at the leading edge of green chemistry and engineering. Over time, TBNA itself should start conducting R&D on new green manufacturing processes and, eventually, implement them in TBNA and TEDA. When designing green manufacturing initiatives, TBNA should emphasize new plants and focus on processes that offer cost savings.

Building for TBNA's Future: Integrating the Seven Action Plans into an Overarching Strategic Plan

We believe that the seven TAs should form a pivotal part of TBNA's strategic plan for transitioning into a state-of-the-art S&E center. All of the TAs are in line with promising global trends; are well suited to current capacities in TBNA, TEDA, and the municipality of Tianjin and build on existing pillar industries; and support Chinese government priorities.

Part of the overarching strategic plan should be geared toward addressing broad general challenges that currently stand as barriers to all seven TAs. One of these is protecting IPR. The plan should include measures to help TBNA and TEDA enforce existing laws in this domain. A second is getting people at different stages of technology development working together. Here, we recommend that TBNA and TEDA incorporate into the plan ample opportunities for cross-fertilization between research facilities and industry. Finally, it is vital that TBNA build a culture of R&D and innovation. The plan should contain elements that promote flexibility and risk-taking in TBNA and TEDA's funded ventures.

Beyond this, TBNA could use a three-pronged framework to integrate the specific action plans for the seven TAs into an umbrella strategic plan:

- Develop state-of-the-art R&D capacity in relevant areas.
- Update and expand the existing manufacturing base.
- Build capacity for S&T commercialization.

These three activities would need to be carried out in parallel. Each requires using and expanding existing local capacity and introducing new capacity. Novel advances should stem from and extend the existing capacity base while fresh R&D programs are started and new companies with state-of-the-art capabilities come in to bring overall capacity up to world-class standards. Each will also support the others.

Develop State-of-the-Art R&D Capacity in Relevant Areas

The strategic plan should lay out an agenda for each TA for (1) making optimal use of current local R&D capabilities, (2) expanding the outreach of existing R&D programs, and (3) beginning entirely new ones. Efforts in all three of these areas would need to go on in tandem. Existing local R&D programs include those of TEDA's nanotechnology center (CNANE) and of Tianjin and Nankai universities. TBNA could provide resources to expand these programs in areas that underpin the seven TAs—for example, bionanotechnology, nanofiltration, and microfluidics. A good model for expanding the outreach of existing research programs is the collaboration between the Qingyuan Electric Vehicle Company and the U.S. Argonne National Laboratory. This is an excellent example of a public-private partnership, as well as a cross-cultural one.

A first step in building entirely new R&D programs could be to cement relationships with leading global companies developing second- and third-generation solar collectors, nanoscale filters and membranes, and nanoscale-formulated drugs. These companies could partner with appropriate research institutions in TBNA, TEDA, or the municipality of Tianjin more broadly. Building new programs could also involve attracting companies that already have cutting-edge R&D capabilities to establish a presence in TBNA.

Update and Expand the Existing Manufacturing Base

TBNA's strategic plan should include measures to ensure that manufacturing companies currently operating in TBNA and TEDA are using processes that take advantage of the most recent advances in both design and technology. For example, TBNA could provide a package of subsidies and awards to firms that apply green manufacturing principles. It should also establish the infrastructure that would make it easier for them to do so. At the same time, it should make provisions in the plan to institutionalize the training that TBNA's manufacturing workers need for these advanced processes.

Bringing in new companies with state-of-the-art manufacturing capabilities should be a vital part of this effort as well. TBNA could approach and provide a portfolio of incentives to global companies manufacturing second- and third-generation solar collectors, system components for advanced mobile communications, or lab-on-a-chip bioassays to establish plants in TBNA or TEDA.

Build Capacity for S&T Commercialization

The strategic plan should include initiatives aimed at ensuring that TBNA and TEDA's manufacturing plants and processes meet global standards. It might make mandatory, for instance, such certifications as the International Standards Organization standard 14001, a globally recognized environmental management standard.

The plan should also lay out steps to position TBNA to serve the global marketplace. It should make a standard practice of using the local Tianjin market as a testing ground for products that could eventually be marketed elsewhere in China and worldwide. Provisions should be included to ensure that products tested and approved in TBNA are on par with accepted practices and standards in target global markets. Electric and hybrid vehicles, for example, would have to meet the most restrictive U.S. and European Union (EU) standards for emissions and mileage performance. Bioassays to monitor food and water developed in TBNA would need to satisfy U.S. and EU standards for demonstrated levels of pathogen detection.