INFORM
SPECIAL REPORT

China at the Crossroads

Energy, Transportation, and the 21st Century

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Preface

This new INFORM report looks at a drama unfolding halfway around the globe, as a vast and complex country seeks to build its economy and take its place among the world's industrialized nations. How China charts its course will in many ways determine the well being not only of its 1.2 billion citizens but of people throughout the world.

China's production and export of goods are soaring. So is its use of energy. And while China has extensive mass transit, it now aspires to the same vehicle systems that have given Americans such great mobility and convenience over the last century. Because its choice of technologies and fuels is relatively unencumbered by significant vehicle-related investments, China has the remarkable potential of building its vehicle and fuel infrastructure systems virtually from scratch. It can take advantage of transportation fuels that are much cleaner than the gasoline and diesel fuels that have powered vehicle growth in the United States and across the industrialized world. But the die is being cast by investments that China is making today.

In just the last decade, as INFORM's senior consultant James Cannon spells out in the pages of this report, China's push for modern transportation has led to a tripling of its vehicle population and, since l980, to a 700 percent increase in its use of energy—mostly oil—for transportation. Were China to achieve a per capita vehicle population the same as that of the United States, over 900 million vehicles—40 percent more than the world's total today—would be traveling its roads. Its oil demand would be 18 percent greater than world production of oil today. To continue in this direction would, without question, have dire consequences for China and the world:

- Coal has served as the backbone of China's energy system for decades, and extensive coal use, now supplemented by increasing use of oil, has placed the country's ecosystems and its people's health at extreme risk. In a country where coal burning already causes 250,000 premature deaths a year, and where one in four people dies of respiratory disease, millions upon millions of added gasoline- and diesel-fueled vehicles would aggravate these health impacts greatly.

- Soaring use of oil for transportation, and related investments in pipeline and trucking systems to transport it, would commit China to reliance on the world's most rapidly dwindling fossil fuel, and political tensions around the world because of competition for this resource would assuredly grow.

- A gasoline- and diesel fuel-based transportation system in China would dramatically increase the threat of global climate change that has been affirmed by thousands of scientists and that was the subject of the 1997 Kyoto Agreement. The effects of global climate disruptions would wreak havoc on the lives of people and ecosystems worldwide.

The internal combustion engine and gasoline and diesel fuels have provided a high level of convenience, ease, and mobility to Americans and people across the industrialized world for the better part of a century. However, it has become clear that moving into the twenty-first century with vehicle systems reliant on these polluting fuels and on inefficient 100-year-old internal combustion technology makes no more sense than it would have made to move into this century with a transportation system based on the horse.

In the United States, emissions from almost 200 million gasoline- and diesel-fueled vehicles on our roads have damaged the health of millions of people. More than 85 million residents of our country breathe air that does not meet public health standards. Rates of asthma, especially among children in urban areas, are steadily rising, largely from vehicle emissions. A growing number of scientific organizations have determined that diesel fumes are carcinogenic. The United States faces growing political jeopardy from dependence on foreign sources for more than 50 percent of its oil—a dependence that was a major factor in the l990 Gulf War that cost more than $50 billion and involved 400,000 Americans. Vehicle emissions, further, contribute 25 percent of the greenhouse gases believed to cause global climate change.

While massive US investments in oil production, in transportation infrastructure, and in conventional vehicle technologies have made a shift from gasoline- and diesel-fueled transportation difficult, a revolution to vehicles powered by more efficient engines and cleaner fuels is under way. Across the industrialized world, countries are moving to take advantage of them. Today, 750,000 vehicles fueled by much cleaner natural gas are traveling the world's roads—70,000 of them in the United States. Battery-powered electric vehicles—two to three times more efficient than the internal combustion engine—are in production.

Beyond these attractive commercially available options, demonstrations have begun of electric hybrids and fuel cell vehicles powered by nonpolluting and renewable hydrogen. Hydrogen today is obtained largely from natural gas, but when it can be extracted from water, using solar electricity, the hydrogen fuel cell vehicle may well stand as the ultimate sustainable driving machine.

China's choice of vehicle transportation systems is ultimately its own to make, but its unique moment of opportunity is now. At this crossroads, with financial and technological commitments just beginning to be made, China can commit itself to using much cleaner natural gas and other alternative fuels and to increasing its use of electric engine technology: for its vehicles, for its hundreds of thousands of buses, and even for rail systems in industrial areas and for boats used to transport goods along the nation's waterways. Moving in these directions would mean not only efficient transportation but two bonuses: cleaner and healthier air and oil supplies freed up for other uses or for export.

As the United States takes steps forward in its transition to cleaner alternative fuels and vehicle technologies, it is also in our urgent interest to make available the technology and financing that will facilitate China's progress in building a modern transportation system. In an increasingly global economy, the options of any nation—even one as large as China—are influenced by an array of investors, corporate technology and fuel providers, international financial institutions, and other governments. *China at the Crossroads* shows why development of a transportation infrastructure in China that is clean and powered by nonpetroleum fuels is so crucial to China's and to our world's future.

Joanna D. Underwood
President
INFORM, Inc.

Introduction: A Moment of Choice for China

Nearly 200 years ago, Napoleon Bonaparte summed up his impressions of the world's most populated nation with these words: "China? There lies a sleeping giant. Let him sleep! For when he wakes, he will move the world." The awakening of the People's Republic of China is undoubtedly now at hand.

As a result of mushrooming ties with the West that began with the dramatic economic reforms of President Deng Xiaoping in 1978, growth in China's gross domestic product (GDP) over the past decade has exceeded 10 percent annually, one of the fastest rates in the world and more than four times the rate of growth of the US economy. The Ninth Five-Year Plan projects annual increases in GDP of 8 percent through the year 2000.

This explosion in economic growth has also made China the world's second largest energy-consuming nation and its third largest energy producer. Since 1980, overall energy use in China has grown at an annual rate of about 5 percent, approximately three times the rate of growth worldwide and nearly four times the country's own rate of population growth. Reliance primarily on coal and oil for this energy has created pollution of staggering proportions. Already some cities are so dense with smog that their lights are "invisible" to satellite sensors. Already about 250,000 premature deaths per year are attributed to air pollution. And already China ranks second only to the United States in total emissions of carbon dioxide, believed to be the major cause of global climate change.

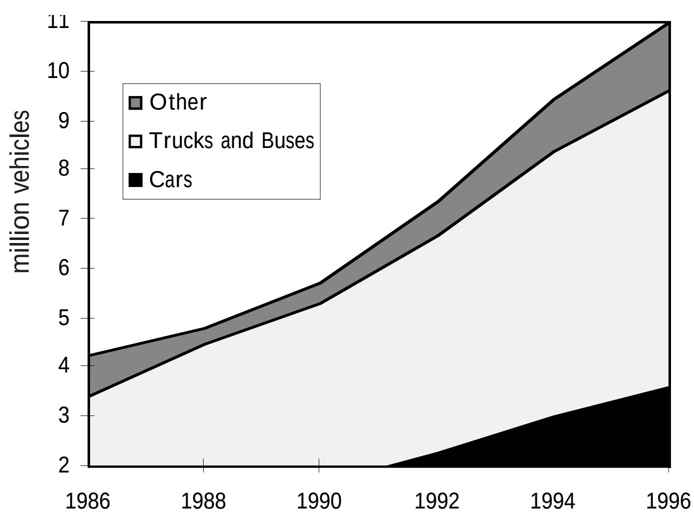

Figure 1

Vehicle Growth in China

China's population of motor vehicles—nearly all of them dependent on the internal combustion engine powered by gasoline or diesel fuel—has tripled since 1986.

China's fastest-growing energy sector is transportation. There are approximately 11 million motor vehicles in China, including 3.6 million passenger cars, 6 million trucks and buses, and 1.4 million other vehicles, primarily motorcycles (see Table 1). Since 1986, while the number of motor vehicles has grown a mere 13 percent in the United States and 28 percent worldwide, the motor vehicle population of China has tripled (see Figure 1). By the year 2010, that number could triple again.

How will China address the needs of its 1.2 billion citizens for transportation and for the motor vehicles and infrastructure it entails? Hinging on the answer are the health of millions of Chinese, the health of China's ecosystems, and, potentially, the stability of the world's climate. With relatively little existing economic investment in particular fuels or technologies, China has the opportunity to build a transportation system from the ground up. To what extent will it develop mass transportation to move its millions of people? Will it attempt to follow the model of the industrializing nations, producing oil-dependent internal combustion vehicles? Or will it instead promote the production and use of cleaner fuels such as natural gas (and ultimately hydrogen), which can be burned in traditional internal combustion engines, in the much more efficient electric hybrid vehicle, and in the fuel cell vehicles of the future?

China's decisions will also have important repercussions for the United States, in terms of both energy security and economic competitiveness. Already since 1980, China's use of transportation energy—mostly oil—has leapt a phenomenal 700 percent. Should China emerge as a major new market for oil, a huge drain on already shrinking supplies will result, setting off a worldwide resource grab on a scale unparalleled in history.

In this report, INFORM presents the results of an investigation of energy issues in China—with particular emphasis on trends in transportation—and their implications for energy policy in China, the United States, and the rest of the world. The project involved a two-week trip to China in September 1997 that included visits to leading energy research and planning institutions in four major cities (Beijing, Xi'an, Shanghai, and Guilin) and extensive follow-up research.

Table 1 **China's Vehicle Population**

China's vehicle fleet is dominated by trucks and buses used by government and industry.

Year	Cars	Trucks and Buses	Other	Total
1986	966,000	2,465,000	799,000	4,230,000
1988	1,303,000	33,178,000	318,000	4,799,000
1990	1,621,000	3,684,000	410,000	5,715,000
1992	2,261,000	4,414,000	687,000	73,620
1994	3,000,000	5,400,000	1,050,000	9,450,000
1996	3,600,000	6,000,000	1,400,000	11,000,000

Motor Vehicles in China: Oil and Other Options

Although China's fleet of motor vehicles is dwarfed by the estimated 600 million bicycles that ply its roads, the use of motor vehicles is growing much faster than any other ground-based transportation alternative. While the last twofold increase in the world's motor vehicle population took 20 years to occur, in China it took just three years.

Motor Vehicle Manufacturing

Despite this recent explosive growth, China's automotive market has barely been touched. There is still only one motor vehicle per 115 people in China, compared to one vehicle for every 1.3 people in the United States. China's motor vehicle population is only 6 percent that of the United States. If its vehicles per capita were the same as ours, there would be 920 million vehicles in China alone—47 percent more than the entire motor vehicle population of the world today.

Motor vehicle manufacturing in China has nearly tripled this decade, to about 1.5 million vehicles per year, the great majority of which are trucks. (The United States manufactures 10 million vehicles annually.) An additional 100,000 vehicles are imported annually. Most automotive manufacturing in China is performed by joint ventures involving foreign companies. The first, and for a long time only, foreign automobile company licensed to build passenger sedans in China was Volkswagen. Working through a joint venture with the Chinese-owned Shanghai Automotive Industries Corporation, Volkswagen is by far the largest car manufacturer in China, producing 122,000 cars in 1994 (including the popular Santana, which is widely used as a taxicab). Daihatsu is the second largest automotive manufacturer in China, producing 58,000 cars per year. As of 1994, other automakers operating in China included Citroen and Peugeot, with total car production by all companies totaling 239,000 annually.

During the past few years, new joint ventures with foreign partners have led to a major expansion in automotive manufacturing in China. Arrangements for the first joint venture with an American company to produce a passenger sedan were completed in March 1997. This $1 billion deal between General Motors and Shanghai Automotive Industries will result in the manufacture of up to 100,000 Buick Regal and Century automobiles at a new assembly plant to be built in China around the end of the decade. These full-size cars, which have very low fuel efficiency (under 25 miles/gallon), will burn both leaded and unleaded gasoline and will not be equipped with catalytic converters.

In contrast to the US vehicle fleet, which is vastly dominated by passenger cars, China's fleet is mainly composed of trucks, buses, and other heavy vehicles used by government and industry. These include over 500,000 buses, compared to only 65,000 in the United States. Most of China's commercial trucks and buses are manufactured by companies that are wholly Chinese-owned. One US company, Chrysler, has been manufacturing the light-duty Cherokee truck for years in China, first for the military and more recently for purchase by private citizens. Unlike commercial vehicles, nearly all automobile production involves joint ventures with foreign partners. Joint-venture manufacturing agreements exist with Peugeot, Daihatsu, and Suzuki.

China's large motorcycle population accounts for about 10 percent of the motor vehicle fleet. Motorcycle manufacturing, like car production, occurs largely through joint ventures. It, too, is growing rapidly, despite steep registration fees and safety-related restrictions on the use of motorcycles in some cities, including Beijing and Shanghai.

Taken together, there were 123 motor vehicle manufacturing plants operating in China in 1997, the 13 largest of which are responsible for over 90 percent of the industry's output. Most motor vehicle manufacturing occurs near Shanghai and in the northeastern province of Liaoning, where Dalian, China's version of Detroit, is located.

Because the number of motor vehicles in China has only recently begun to expand, transportation accounts for less than 7 percent of the country's total energy use (compared to 27 percent in the United States). As in the United States, however, virtually every motor vehicle in China depends on an internal combustion engine powered by either gasoline (leaded and unleaded) or diesel fuel. Since most Chinese automobiles and trucks are small vehicles, their fuel economy tends to be good. Large trucks and buses, however, are equipped with older, more inefficient engines. Vehicles in China are equipped with virtually no pollution controls.

Oil: Supply and Demand

Oil in China is almost exclusively used as a transportation fuel or as a feedstock for the petrochemical industry. It is the largest energy resource used after coal, supplying about 20 percent of the nation's energy needs, or about 7 quads annually (a quad equals a quadrillion Btus—British thermal units—of energy). In 1995, about 3.4 million barrels of oil were consumed daily in China, compared to 17.7 million barrels per day in the United States. Currently, oil consumption in China accounts for about 5 percent of the world's total.

Oil use in China is growing faster than any other energy resource. Between 1986 and 1995, oil consumption increased by 66 percent, compared to 9 percent in the United States. During the same period, oil production grew only modestly, from 2.9 to 3.1 million barrels per day (see Figure 2). In 1993, with consumption exceeding production for the first time in its history, China joined the ranks of the world's oil-importing nations. A mere three years later, oil imports had grown from under 100,000 barrels/day to about 300,000 barrels/day, nearly 10 percent of the country's total oil use.

The degree to which China relies on oil imports in the future will depend primarily on how well efforts to increase domestic oil production keep pace with demand, which in turn will depend on decisions China makes about the nation's transportation system. Three regions of China have been the main targets of attention:

- The extreme northeastern province of Heilongjiang is the major petroleum-producing region. It accounts for about 90 percent of China's total production. The province's largest oil reservoir, the Daqing field, accounts for about one third of total production. Although

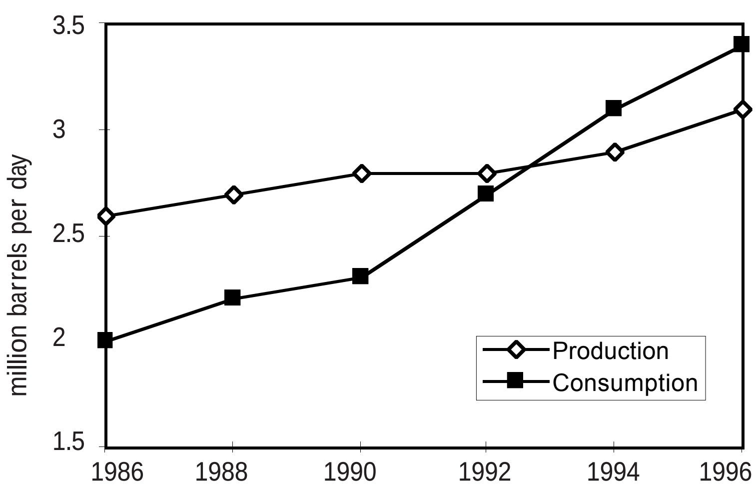

Figure 2
Oil Production and Consumption in China

Oil production in China has lagged behind consumption since 1993. With a growing motor vehicle population hungry for oil, the situation has disturbing implications for China's own energy security and that of the United States.

it is one of the largest oil fields in the world, Daqing has been producing oil for more than 30 years and its ability to greatly increase oil production over the long term is doubtful.

- The offshore waters of the East and South China Seas and the northern Bohai Sea, where most oil exploration in recent years has occurred, have19 oil fields currently contributing about 10 percent of the country's oil. Several new offshore oil fields are under development, which should lead to an additional 100,000 barrels/day of domestic oil production before the end of the decade. However, prospects for future development are clouded by a number of territorial disputes, especially with Vietnam, over rights to offshore oil in the China seas.

- The Tarim Basin in the western province of Xinjiang produces 2 percent of China's total oil. China has invested tens of billions of dollars in exploration here over the past decade. However, the results do not appear to have paid off. The small amount of oil found to date is transported by truck or train to local markets. New discoveries have not warranted construction of a long-distance pipeline to carry the oil over 1000 miles to the country's major markets.

In China, the road map for economic development is spelled out in national plans developed by the State Planning Commission in Beijing. It is through these plans that the state exercises its centralized control of China's industrial and economic development, including its energy policy. Recently, implementation of China's Ninth Five-Year Plan passed the halfway point. In the area of oil development, the plan calls for an additional $10 billion investment in oil exploration in Xinjiang by the end of the decade. The goal is to expand oil production tenfold by the year 2000, to about 15 percent of the country's total oil production. However, recent experience suggests that attaining this goal could prove difficult.

The political face of China's oil industry is in transition. Before the most recent economic reforms enacted first under President Deng Xiaoping and then by his successor, Jiang Zemin, oil exploration and development were nationalized under the Ministry of Petroleum. Now the industry has been partially privatized, with the formation of the China National Offshore Oil Company (formed in 1982), the China National Petroleum Corporation (formed in 1986), and the China National Star Petroleum Corporation (formed in mid-1997). Although these companies are state-owned, they are free to enter into joint ventures with foreign oil companies and must compete with each other to obtain exploration licenses.

China's lagging production and growing appetite for oil create risks for its own energy security and that of the United States. China and the United States each holds only about 2 percent of the world's known oil reserves (some 25 billion barrels). In contrast, approximately 60 percent of global oil reserves are located in the Middle East. Like the United States, China is overproducing relative to its known reserves, while the Middle East is holding back on production. The Middle

East accounts for 28 percent of world oil production, while China and the United States account for 4 percent and 14 percent, respectively.

Unless oil consumption drops or major new discoveries are made, the United States and China will have no choice but to turn increasingly to the Middle East to meet demand. This has been the trend in the United States for more than a decade, with oil imports first declining from 35 percent (during the 1974 oil embargo) to 28 percent in 1982, then climbing back to today's rate of over 50 percent of supply and apparently headed for the 60 percent mark by early next decade. The State Planning Commission projects that oil imports in China will more than triple, to one million barrels per day, by early next decade, at which time imports could account for 20 to 25 percent of the country's total oil supply.

To meet its demand for oil imports, China is looking first to the oil-producing countries of the former USSR, specifically Kazakhstan and Russia. In September 1997, China announced an agreement to help Kazakhstan develop a new field near the Caspian Sea and to construct a 1900-mile pipeline capable of carrying this oil to northwestern China. Moreover, in October 1997, China announced "intense negotiations" with Russia to construct oil, natural gas, and electricity links between China and the Krasnoyarsk region of eastern Siberia. The leading Sino-Russian oil project involves construction of a 1600-mile pipeline from Siberia's Urudchan oil field to northeastern China. Uzbekistan and Azerbaijan are other former Soviet republics being studied as potential suppliers.

Until these pipeline projects and oil field developments are completed, however, China is likely to increase its imports by tanker from the Middle Eastern OPEC producers and from other traditional oil-exporting regions. Whatever import scenario ultimately unfolds, China has clearly become a global competitor for oil in a big, and probably lasting, way.

Alternative Vehicles and Fuels

The dependence of China's motor vehicles on oil-derived fuels and conventional internal combustion engine technology appears certain to continue into the foreseeable future, unless current trends are modified. Development of alternative transportation fuels and advanced propulsion systems that do not rely on oil has barely begun in China. Only a few encouraging signs of change have emerged. There is significant commercial use of natural gas, as well as considerable interest in developing electric-battery vehicle technology, especially for motorcycles. There are also several small-scale demonstrations under way involving other alternative fuels and propulsion systems.

Natural Gas Vehicles

The use of natural gas as a transportation fuel in China dates to the 1950s. According to the Institute of Natural Gas Vehicles in Beijing, there are approximately 2500 natural gas vehicles in China today, nearly all of which are buses, which must rely on only 35 refueling stations. In the United States, by contrast, there are over 60,000 natural gas vehicles in operation, including nearly 2000 buses, and 1200 refueling stations.

Most natural gas vehicles in China are found in the natural gas-rich Sichuan province. Fleets of hundreds of natural gas buses are operating in the provincial capital city of Chengdu and in Zigong. Smaller fleets are operating in other Sichuan cities as well. The design of these natural gas buses is not at all like that of natural gas buses in the United States and other countries. In conventional designs used elsewhere, natural gas is stored either in a highly compressed form in metal storage cylinders or in a super-cooled, cryogenic liquid state. In Chinese buses, on the other hand, the gas is typically stored in large rubber bags that sit atop the vehicles like bal-

Natural gas vehicles

Natural gas (also called methane) powers about 750,000 vehicles worldwide and can be burned directly in conventional internal combustion engines. When used as a transportation fuel, it releases up to 95 percent less carbon monoxide and toxic air pollutants, 80 percent fewer hydrocarbon emissions, and 30 percent fewer nitrogen oxides than gasoline. Natural gas vehicles also emit significantly less carbon dioxide than oil-burning vehicles.

In refueling, natural gas systems provide a leakproof connection between the fuel dispenser and the automobile intake port, thereby helping to eliminate the evaporative emissions that account for up to half the hydrocarbon pollution from gasoline vehicles. Additionally, production of natural gas avoids the pollution problems associated with producing oil-derived fuels: spills, releases of toxic pollutants from refineries, and leaks from underground storage tanks into groundwater.

Natural gas vehicles are up to 5 to 10 percent more fuel efficient than gasoline- or diesel-powered vehicles, and their operating costs are significantly lower. In the United States, only two or three of the heavy cylinders required to store the fuel can be installed on a vehicle at a time, limiting driving range to less than 300 miles between refuelings. China, however, has the loons. The pressure in these bags is only 6 to 7 atmospheres, compared to 200 to 300 atmospheres of pressure in the storage cylinders. Because of the low pressure, the bags must be huge—typically the size of the bus frames on which they sit—in order to accommodate sufficient quantities of fuel. Even so, the range of these buses before refueling is typically less than 100 miles. As the gas is consumed, the bags gradually deflate, providing an obvious indicator of the need to refuel.

Although this fuel storage technology is primitive, it has been used successfully for decades. The bags are cheaper than tanks and the refueling equipment is simpler. One problem, however, is that the bags can snag and rip if they catch on overhead branches or power lines. They can also restrict access to tunnels and underpasses.

In addition to the bus fleets of Sichuan, a few vehicles in other regions are using natural gas produced as a by-product of oil production and traditionally vented or flared. One conventional high-pressure natural gas refueling station has been built near the Daqing oil fields in northeastern China to service a fleet of 200 natural gas trucks. In Beijing, the city's first fleet of 10 natural gas vehicles is planned as soon as a refueling station is connected to a recently completed natural gas pipeline. Entex Fuels, Inc., of Houston, Texas, is a leading US participant in this project. In Xi'an, 150 conversion packages that will allow conventional cars to burn natural gas have been sold by Clean Vehicle Systems, a New York-based company. The packages are to be installed by a joint-venture company in China. A small fleet of natural gas vehicles is also operating in Xinjiang province.

In September 1997, China's first commercial buses powered by liquefied natural gas (LNG) took to the streets of Haikou, capital of China's island province of Hainan in the South China Sea. The buses are the first stage of a much larger effort, valued at over $4 million, to convert 5300 cars and buses in Haikou to LNG. In early 1997, LNG storage and fuel handling equipment made by Denver, Colorado-based Cryenco Sciences, Inc., was licensed for sale in China for the first time, further signaling the country's growing interest. An earlier LNG demonstra-

opportunity to increase driving range by creating new vehicle designs able to accommodate larger fuel tanks.

Conventional gasoline-powered vehicles are easily converted to burn natural gas: the engine remains largely the same, with most of the changes involving only the fuel storage and delivery systems. In the United States, where natural gas is cheap and plentiful, conversion costs—especially for the operators of large commercial fleets—can usually be recouped fairly quickly. The Chinese, however, do not yet manufacture the conversion equipment themselves (it is often obtained free of charge from foreign manufacturers). Moreover, there is no established pricing structure for natural gas as a transportation fuel.

The major safety issue raised by natural gas vehicles involves the high-pressure tanks needed for storage. But the overall safety record of natural gas, including production, delivery, and end use, is superior to that of any other automotive fuel. In accidents involving natural gas vehicles, fewer injuries (and deaths) occur because leaks are less likely to cause fires: the gas disperses quickly into the atmosphere (unlike liquid fuels) and burns only when its concentration in air is between 5 and 15 percent. In the 25 billion miles that natural gas vehicles have been driven worldwide, no recorded deaths have resulted from the rupture of a storage cylinder.

tion project took place in 1990, when Kaifeng Cryogenic Devices Manufacturing Company converted a bus to LNG in the eastern interior province of Henan.

Numerous other natural gas initiatives have been reported over the past six months. In May of 1998, Volvo displayed various natural gas-powered vehicles to Beijing city officials seeking solutions to the city's traffic and pollution problems. Also in May, Beijing officials and automotive experts completed a six-month technical training program conducted by General Motors and IMPCO Technologies, Inc., in cooperation with the Beijing Science and Technology Commission. The officials are developing standards and infrastructure to facilitate conversion of Beijing's buses and taxis to natural gas. As part of the program at IMPCO's technology center in Irvine, California, Chinese engineers converted a five-passenger taxi designed by Beijing Automotive Industrial Corp. Group to natural gas.

Liquefied Petroleum Gas

Liquefied petroleum gas (commonly called LPG or propane, after its chief chemical constituent) is available in limited quantities as a by-product of natural gas production and oil refining in some regions of China. Like natural gas, LPG burns more cleanly and completely compared to gasoline or diesel fuel, and the air-tight storage system required to contain the gas eliminates emissions from evaporation.

In September 1997, a major project was announced by the Chinese news agency Xinhua that, if implemented, will result in the nation's largest LPG-powered transportation fleet: all 15,000 public transit vehicles in Shenzhen, near Hong Kong, are to be converted to run on LPG by the year 2000, beginning with 1000 taxis. This project, whose projected cost is over $19 million, is being undertaken as part of an effort to combat air pollution, to which motor vehicles contribute some 65 percent in Shenzhen.

Liquefied natural and liquefied petroleum gas

Liquefied natural gas (LNG) offers greater energy density than compressed natural gas, reducing the space requirements for fuel storage by half. Tanks of LNG are still bulkier and heavier than gasoline systems, but they are a considerable improvement over compressed-gas storage cylinders. Refueling with LNG is also faster than with compressed natural gas. The main drawback is the energy, and the associated costs, required to reach and maintain the very low temperature (-258° F) at which natural gas liquefies.

Liquefied petroleum gas (LPG) is produced only as a by-product of oil or natural gas production. Its low-pressure storage system costs less than the system for storing compressed natural gas, and the costs of converting a vehicle to LPG are also lower. However, because supplies of LPG are limited, it can serve only a relatively small transportation market, even in a country with substantial natural gas production.

Electric Battery Vehicles

In the past few years, the first serious research and development effort to build and test electric battery-powered vehicles was initiated in China. Only a few electric vehicles have been built to date. Most electric-battery vehicle development to date has been located at Tsinghua University in Beijing, which is directing a program with more than 10 other research agencies and industrial partners. So far since 1992, four electric-battery minivans and one electric bus have been built. The vehicles are equipped with lead-acid batteries.

A second electric-vehicle project began in late 1996 at the Beijing Institute of Technology. The first vehicle produced was a compact passenger car equipped with a nickel–metal-hydride battery developed by the General Research Institute for Nonferrous Metals, also in Beijing. The institute, one of the world's leading research centers for hydride material development, currently manufactures about 50 tons of the materials per year for use in hydrogen storage systems and nickel–metal-hydride batteries. The Beijing Institute's car has a range of approximately 75 miles and a top speed of 70 miles per hour. A second vehicle using nickel–metal-hydride batteries has also been built—a tricycle with a top speed of 14 miles per hour.

In late 1996, the State Science and Technology Commission announced the formation of a panel of experts to coordinate the nation's electric-battery vehicle R&D efforts. A total of $12 million has been approved by the commission to fund these programs over the next couple of years. The commission has also announced a goal of between 3000 and 5000 electric-battery vehicles for China by the year 2000.

Battery-powered electric vehicles

Electric propulsion systems are far more efficient than vehicles powered by the internal combustion engine. A vehicle fueled by electricity stored in batteries, currently the most widely used storage technology, is about four times as efficient as an internal combustion engine.

But batteries are heavy, bulky, and sometimes filled with toxic chemicals. Replenishing depleted batteries can take up to 10 hours, and the number of times recharging can occur is limited by chemical decomposition. Moreover, the flow of energy from a recharged battery to the electric motor is often too slow or too weak to provide enough power to match the performance of a gasoline-burning engine.

While electric vehicles generate virtually no pollution themselves, their environmental impact depends on how the electricity used to recharge the batteries is generated and on how the batteries are disposed of.

Most prototype electric cars on the road today have a driving range of less than 100 miles. However, nickel–metal-hydride batteries, considered the next generation of batteries for electric vehicles, are expected to double that range.

Since then, the French auto company Peugeot has formed a joint venture with Dong Feng Motors in Hubei province to develop electric cars and vans, and American Electric Automobile Company of Bonita, California, has signed an agreement with the Guangdong Science and Technology Commission to convert several gasoline-powered cars to run on electricity. Accordingly, American Electric formed a joint venture with China Electric Automobile Company of Hong Kong in May 1997. Also, in August 1997, Wilmington, Massachusetts-based Solectria Corporation announced an agreement whereby GPE Industries Ltd. will be licensed to manufacture electric-vehicle components developed by Solectria. GPE is part of Gold Peak Industries Ltd., China's largest manufacturer of car radio and electrical wiring systems.

In the meantime, a major effort has been under way to sell electric bicycles in China. In February 1997, ZAP Power Systems of Sebastopol, California, which sells electric bicycles in the United States, established a joint venture between its ZAP China division and Shanghai Forever Company Ltd., which manufactures three million bicycles in China per year. The partners will manufacture bicycles in China and sell them at the 1500 sales outlets currently operated by Shanghai Forever. ZAP will provide the first 50,000 motors from its manufacturing plant in the United States. Future plans call for the production of a variety of small electric vehicles, including three-wheel bicycles, scooters, and motorcycles. In March 1997, the project received a $20,000 grant from the US Environmental Protection Agency.

Hydrogen Vehicles

INFORM's visit to China in September 1997 was part of a "hydrogen energy delegation" (organized by the Spokane, Washington-based People to People Ambassador Program) to institutions specifically involved in hydrogen projects. The welcoming meeting provided the first hint of what the delegation would learn about the state of hydrogen development in China.

The agenda called for the group to be greeted by the chairman of the "China Hydrogen Association," but no such official was present.

Fuel cells

In a fuel cell, hydrogen and oxygen merge, releasing energy as electricity and forming water as the only by-product. Because there is no combustion to generate the high temperatures that lead to the formation of nitrogen oxides, fuel cell-powered electric vehicles offer the cleanest way of using hydrogen: they are zero-emission vehicles.

Fuel cells are two to three times as energy efficient as combustion engines. An internal combustion engine loses more than 80 percent of the energy it generates, mainly as waste heat. When a hydrogen fuel cell is used, the energy loss is 40 to 60 percent, so the energy percentage delivered as movement is much greater. Compared to batteries, fuel cells are lighter, more durable, and less bulky. Fuel cell vehicles also have a greater driving range than vehicles equipped with batteries, and their refueling time is faster (minutes rather than hours).

The five major fuel cell technologies under development are the proton-exchange membrane and molten carbonate fuel cell, mentioned in this report, and the phosphoric acid, alkaline, and solid oxide fuel cell.

Repeated calls to the China Energy Association and other organizations found no evidence that a specific organization dedicated to hydrogen energy issues even exists in China. Instead of a focused discussion, the opening meeting served as a forum for officials from the Energy Research Institute to provide a broad overview of energy in China. When asked specifically about hydrogen, Deputy Director Zhou Da Di responded, “There is no practical plan to develop hydrogen over the next 20 years.”

Two weeks of meetings confirmed that hydrogen energy development in China is only now beginning. The delegation did uncover several recently initiated hydrogen vehicle projects involving fuel cells, an important early step toward a more comprehensive national effort. Additional hydrogen R&D projects were also found to be under way at several research and academic institutions.

A joint hydrogen fuel cell bus project was inaugurated in 1995 between the Institute of Nuclear Energy Research at Tsinghua University in Beijing and the Karlsruhe Research Center (formerly the Karlsruhe Nuclear Research Center) in Germany. The project is an outgrowth of previous collaboration on nuclear energy development and exemplifies a broadening of energy research activities at both institutions. The goal of the project is to develop a fuel cell-powered bus similar to Tsinghua University’s electric-battery bus. Although the collaboration is three years old, it only began to receive serious attention late in 1997. Decisions about what fuel cell technology and hydrogen storage system the bus will employ are likely to be made in 1998.

The Shanghai Institute of Organic Chemistry is the lead agency in a second fuel cell vehicle project. According to Deputy Director Dr. Jiang Biao, this is a “big project” that aims to incorporate a membrane developed over the past 10 years at the institute into a commercial fuel cell. So far, a 1.2 kilowatt proton-exchange membrane fuel cell has been built and the institute is working with four other partners (including Shanghai Automotive Industries Corporation and the Chemical Physical Sciences Institute in Dalian) to design a fuel cell-powered automobile using the technology. The national government is investing $2 million per year in this project, which may produce a prototype as early as the end of 1998.

The protein-exchange membrane (PEM) fuel cell is considered the most promising for use in vehicles. Because the membrane is extremely sturdy and remains chemically stable for long periods under harsh operating conditions, the estimated lifetime of the best PEMs is 150,000 to 200,000 miles—a slight improvement over the average internal combustion engine and vastly better than the 10,000- to 30,000-mile life span of most automotive batteries now under development. PEM fuel cells operate at moderate temperatures (150° F) and can be started very quickly, in part because they do not need to heat up for the flow of electricity to be initiated. Proton-exchange membrane fuel cells can also operate on ambient air rather than pure oxygen, and they are relatively light and compact. Finally, they can be operated over a wide and rapidly changing range of power outputs.

Molten carbonate fuel cells are at a much earlier stage of development. These cells are very efficient, but they operate at higher temperatures and pressures than proton-exchange membranes. Though they are not practical for use in vehicles, they are being developed to supply electricity to “stationary sources” such as homes and businesses.

In October 1997, the W. Alton Jones Foundation announced a grant of $127,000 to support the development of hydrogen fuel cell bus projects in three Chinese cities: Changchun, in the northeastern province of Jilin; Shanghai; and Ningbao, in the province of Zhejiang south of Shanghai. The first phase of this project, in the first half of 1998, includes workshops for preliminary discussion and data collection. Phase II will involve site visits to fuel cell manufacturers, followed in August 1998 by the development of specific fuel cell bus designs. The project is coordinated by the Unirule Institute of Economics in Beijing.

Fuel Cells and Batteries

Fuel cells and batteries offer alternative ways of delivering electricity to an electric vehicle. Batteries store electricity, previously generated by an outside source, in the form of chemical energy. Fuel cells actually generate electricity on board the vehicle.

The electric motor, controller, and many of the other components of electric battery-powered vehicles are identical to the systems used in hydrogen fuel cell vehicles. However, hydrogen offers certain advantages over batteries. For example, refueling with hydrogen is quicker than recharging batteries, and most hydrogen storage systems are much lighter and smaller than batteries.

Several other hydrogen research projects are being conducted at Shanghai Jiao Tong University's Department of Electrochemistry. One of these involves collaboration with the Japan Central Institute for Electricity to develop a molten carbonate fuel cell for stationary-source electrical generation. A second effort involves development of a proton-exchange membrane fuel cell. These two projects are supported by $625,000 in funding from the national government.

A hydrogen research project at the China Petroleum University near Beijing has as its goal a process for removing hydrogen from the large quantities of waste hydrogen-sulfide gas generated during oil production and refining. A two-step, indirect electrolysis process is under development that would convert this highly poisonous and corrosive gas into pure hydrogen and sulfur. (The sulfur, extracted as a solid, could then be sold or disposed of as a solid waste.) Finally, the General Research Institute for Nonferrous Metals is developing hydride materials for hydrogen storage (see the section on electric-battery vehicles).

While hydrogen R&D in China is only beginning, there are signs that hydrogen is capturing the attention of energy policymakers and that its role in future energy development may increase. In May 1997, the United Nations Development Program sponsored a two-week trip by seven leading Chinese hydrogen experts to the United States, Germany, and Canada. The leading government agency involved in setting energy research and development policies—the Science and Technology Commission—is currently preparing a national hydrogen energy development plan. Finally, having won a competition held in 1996, China will host the 13th World Hydrogen Energy Conference in Beijing in 2000. By then, it is possible that hydrogen vehicle programs in China will have increased far beyond the level of today's activities.

Energy in China: A Look at the Big Picture

Expanding our view beyond oil to all types of fuel, China (as shown in Tables 2 and 3) consumes about 36 quads of energy yearly, compared to about 89 quads in the United States—about 60 percent less per year for a country whose population is five times greater. On a per capita basis, the average American consumes three times more coal, 25 times more oil, and 100 times more natural gas than the average person in China (see Table 4). But this situation is likely to change radically.

Table 2

China and the United States: Overall Energy Use, 1995

	CHINA		USA	
Primary Energy Source	**Quads of Energy**	**Percent of Energy**	**Quads of Energy**	**Percent of Energy**
Coal	26	73%	20	26%
Oil	7	20%	35	39%
Natural Gas	0.7	2%	22	22%
Hydropower	2	6%	3	3%
Nuclear	0.1	<0.1%	6	7%
Other Renewables	<0.1	<0.1%	3	3%
TOTAL	36	100%	89	100%

Since 1980, overall energy use in China—primarily coal and oil—has grown at an annual rate of about 5 percent, approximately three times the rate of growth worldwide and nearly four times the country's own rate of population growth.

Table 3

China and the US: Comparative Fuel Consumption, 1995

Primary Energy Source	Consumption in China	Consumption in the USA	China as % of USA
Coal	1.46 billion tons/y	0.95 billion tons/y	154%
Oil	3.4 million barrels/d	17.7 million barrels/d	19%
Natural Gas	0.7 trillion cubic ft/y	21.6 trillion cubic ft/y	3%
Hydropower	175 billion kwh/y	337 billion kwh/y	52%
Nuclear	12 billion kwh/y	2,202 billion kwh/y	1%
Other Renewables	Very small	3 quads/y	NA
TOTAL	36 quads/y	89 quads/y	40%

China's reliance on coal is the highest in the world. Production has increased 40 percent in the past decade, and China has the resources to burn increasing amounts of coal for many decades to come.

Table 4 **China and the United States: Per Capita Energy Consumption, 1995**

Primary Energy Source	Per Capita Energy Use in China	Per Capita Energy Use in the USA	China as % of USA
Coal	1.2 tons/y	3.6 tons/y	33%
Oil	1.0 barrels/y	25 barrels/y	4%
Natural Gas	495 cubic ft/y	71,293 cubic ft/y	1%
Hydropower	145 kwh/y	1,281 kwh/y	11%
Nuclear	10 kwh/y	2,559 kwh/y	<1%
Other Renewables	Very small	11 million Btu/y	NA
TOTAL	29 million Btu/y	338 million Btu/y	9%

Although China consumes 29 percent of the world's coal output annually, the average American uses three times more coal than the average person in China.

Coal

Everywhere you turn in China, there are signs pointing to coal as the country's basic energy commodity. Coal powers most electrical generating stations, it is almost exclusively used in China's industrial factories, it heats homes and office buildings, it is even commonly used for cooking. Long coal trains carry the fuel from massive mines in the north-central provinces of Shanxi and Hebei and from Liaoning province in the northeast to urban distribution centers throughout China. From there the coal is carried to local markets mostly by short-haul trains or trucks, but it is also common to see bicycles and handcarts laden with coal destined for delivery to homes and office buildings.

China is the world's largest producer of coal. With more than 125 billion tons of recoverable reserves already known and much more likely to be found in the future, China has the resources to burn increasing amounts of coal for a long time to come. This is clearly the energy path that the nation is now following. Coal production in China has increased by over 400 million tons per year in the past decade, a 40 percent jump. This increase alone is more than the current total production of any country save the United States. The Ninth Five-Year Plan projects coal production to exceed 1.6 billion tons by 2000. The US Energy Information Administration forecasts that coal production in China will double by 2020.

China's reliance on coal—about 73 percent of total primary energy consumed—is the highest in the world. (Primary energy is the original source from which energy is derived; it includes all the fossil fuels as well as solar, biomass, wind, and hydropower.) In the United States, coal burning accounts for only 26 percent of total primary energy use. China consumes about 1.46 billion tons of coal annually, about 29 percent of the world's total output.

About 25 percent of China's coal production is used to generate 74 percent of the country's electrical generating capacity. In the United States, by contrast, 90 percent of coal production is used to generate 63 percent of electrical generating capacity (see Table 5). Electrical generation from coal has doubled in China over the past decade, compared to the US growth rate of 21 percent. New electrical generation capacity in China is currently growing at an average rate of 15,000 megawatts (MW) per year, mostly from coal burning.

Despite the depth of its commitment to coal burning for electrical generation, about three quarters of the coal burned in China is used in other energy sectors—a reliance unique in the world today. The industrial market burns about 750 million tons per year, an extraordinarily high level of coal use for an energy sector that in most other countries has converted to electricity or diversified through the use of natural gas. Coal burning also provides heat in most office buildings and homes, another use that electricity and natural gas have largely displaced in the rest of the world. In many urban areas, coal destined for commercial buildings and residences is first gasified into a mixture of hydrogen and carbon monoxide called "town gas," which is distributed locally by pipeline. About 25 million people in China today are served by town gas produced from coal. Once commonly used in Europe and the United States, town gas was largely replaced after World War II by cheaper and more energy-rich natural gas.

Table 5

China and the United States: Electrical Generation Capacity, 1996

	CHINA		USA	
Primary Energy Source	**Generation Capacity (kw)**	**Percentage of Capacity**	**Generation Capacity (kw)**	**Percentage of Capacity**
Coal	137,100	74%	446,200	63%
Hydropower	44,600	24%	96,600	14%
Nuclear	1,200	1%	99,000	14%
Natural Gas	2,400	1%	56,900	8%
Oil	Near zero	Near 0%	4,700	1%
Other Renewables	Near zero	Near 0%	1,800	<1%
TOTAL	185,300	100%	705,300	100%

Electrical generation from coal has doubled in China over the past decade, but most coal-fueled power plants are equipped with only the most rudimentary pollution control devices.

Natural Gas

China's production and use of natural gas are minuscule compared to that of the United States, mostly because the effort devoted to prospecting and developing known reserves has been minimal. In 1995, 700 billion cubic feet of natural gas production accounted for just 2 percent of China's energy use. In the United States, 21.6 trillion feet are consumed annually, accounting for about 22 percent of the country's primary energy consumption. Per capita natural gas consumption in China is less than 1 percent that of the United States.

Nearly all of China's natural gas is used as a fuel in industrial factories and as a feedstock in the chemical industry. A small but growing use is as a residential cooking and heating fuel and a very limited use is in transportation. The Ninth Five-Year Plan calls for natural gas production to approach a modest 900 billion cubic feet by 2000. During the first eight months of 1997, natural gas production rose by 13 percent compared to the same period the previous year. The US Energy Information Administration projects that natural gas production will quadruple in China by 2020, at which time it will supply about 4 percent of the country's total primary energy.

Natural gas production is concentrated in three areas:

- The south-central province of Sichuan accounts for most of China's production and use. Local distribution pipelines serve the province's major cities, including the capital of Chengdu, but there is no long-distance pipeline system to carry the gas to other provinces.

- The second major natural gas-producing area is Shanxi province, which has been supplying the fuel to Beijing and to Xi'an since the completion in September 1997 of China's first long-distance natural gas pipeline.

- The Yacheng field in the South China Sea provides natural gas to Hainan Island and to a new 2400 MW electrical generation station near Hong Kong, the only one in China to be fired by natural gas.

Although natural gas use in China is small, the large quantity of known supplies within its borders or in close reach could enable the fuel to play a significant role. The country has 55 trillion feet of proven natural gas reserves (about 1 percent of the world's total). But it has recently begun to expand its traditionally underfunded exploration activities. Untapped natural gas deposits in all the nation's oil-producing regions await commercial development. In addition, natural gas produced during oil extraction, and now commonly wasted through venting or flaring, awaits construction of long-distance pipelines to bring it to market.

Deposits of natural gas not associated with oil production are also being explored. The search for natural gas, like the search for oil, is particularly robust in the Tarim Basin of Xinjiang province. The Ninth Five-Year Plan calls for natural gas production from this region to exceed 100 billion cubic feet by the end of the decade. Opportunities to import natural gas from neighboring Russia also exist. Russia holds 40 percent of the world's natural gas reserves, but there is presently no pipeline across the vast expanse from the Russian natural gas fields to China. One project under development would bring natural gas from eastern Siberia.

Coal mines are another potentially large source of natural gas for China. As coal is mined, small quantities of natural gas trapped within seams can leak into the air, causing explosions and unhealthy working conditions. To avoid this, the mines are frequently "degassed" with strong ventilation before and during mining. Throughout China, this process involves venting the natural gas to the atmosphere, but the technology exists to capture and clean it instead. According to the China United Coalbed Methane Corporation Ltd., established in March 1997 by the Ministry of Coal, this technique of "coal-bed methane" extraction could supply 30 billion cubic feet of natural gas by 2000 and up to 300 billion cubic feet by 2010. Several coal-bed methane projects are currently being developed by the Central Institute of Coal Mining Research in Xi'an.

Nuclear Energy

A small nuclear power industry has existed in China since the completion of the country's first commercial nuclear generating station in 1992. According to the Institute of Nuclear Energy Research at Tsinghua University in Beijing, there are currently two nuclear facilities in China—the 300 MW Qinshan nuclear power station in Zhejiang province, along the coastline south of Shanghai, and the 900 MW Dayawan station in Guangdong province near Hong Kong. Together these plants contribute about 1200 MW, or 1 percent, of China's electrical generating capacity and far less than 1 percent of its primary energy.

However, the Ninth Five-Year Plan calls for a major expansion in nuclear power. By the year 2003, the capacity of nuclear generating stations is projected to reach 9000 MW, a sevenfold jump. In the interests of reaching that goal, two new 600 MW units are now under construction at the existing Qinshan plant, and two other 700 MW units are planned. Two 1000 MW units are under construction at a new site, called the Ling-ao nuclear power station, and another two 1000 MW units are planned for a site in Lian-yun-gang in Jiangsu province, also along the coast. When these four projects are completed, nuclear energy will provide about 3 percent of China's electricity.

*Renewable Energy Resources**

Of all renewable energy resources, only hydropower plays a major role in China today. Commercialization of advanced renewable energy technologies—biomass, wind, solar, geothermal, and tidal power—remains in its infancy, although the resource base is huge. Resources other than hydropower supply far less than 1 percent of the nation's primary energy, compared to 3 percent in the United States.

Hydropower currently accounts for 6 percent of China's primary energy, or 2 quads per year (compared to 3 percent, or 3 quads annually, in the United States). It accounts for 24 percent of China's electrical generation capacity, or nearly all the electricity not generated by coal. In the United States, hydropower accounts for just 14 percent of electrical generation capacity.

Untapped hydropower resources in China are vast, and unlike the United States, the country is moving aggressively to increase their use. Like coal, the use of hydropower in China has doubled over the past decade, to about 44,600 MW of capacity. The country's untapped hydropower resources are estimated to equal 290,000 MW.

Hydropower capacity will increase by an additional 18,200 kilowatts with the completion of the Three Gorges Dam on the Yangtze River. The largest construction project in the world since the building of China's Great Wall centuries ago, the Three Gorges Dam will force the relocation of more than 1.9 million people and the inundation of dozens of cities. When the project is completed 12 years from now, the result will be a 370-mile-long artificial lake and the world's largest hydropower plant. Even so, the dam will increase China's electrical generation capacity by only about 5 percent.

A number of other hydropower projects are also under way, further ensuring that hydropower will continue to be China's main source of electrical generation after coal.

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* *For purposes of this report, the burning of wood for heating and cooking is not considered a renewable energy resource, because it is inefficient and polluting and because consumption often exceeds the rate of regeneration.*

Biomass crops are one of China's largest renewable energy resources. They include straw and tree farms and crop by-products such as rice husks, wood shavings, and sugarcane bagasse. An estimated 15 million acres in China currently supply biomass products for energy uses. The State Planning Commission estimates that development of this resource for use in high-efficiency combustion technology for electrical generation could replace 120 million tons of coal annually. However, the Ninth Five-Year plan projects that biomass combustion will supply just 50 MW of generation capacity by the year 2000.

Another biomass application is in anaerobic digesters, which produce a clean, gaseous fuel similar to natural gas from decomposing animal and crop wastes. There are an estimated six million biomass digesters in China today, most of which supply gas to the farms on which they are located. One of these is a pig farm visited by INFORM in the southern province of Guangxi. Pig manure and crop wastes fed continuously into an underground digester generate fuel that passes through plastic tubing to the farmhouse, where it is used in gas lamps and cooking stoves. Like over 50 million rural homes in China, the farmhouse has no electricity, so the gas provides a vast improvement in lighting and cooking compared to wood or coal burning.

Wind resources are abundant in China's north-central and northwestern plains and along the southeastern coast. Moreover, many remote rural areas, especially in the mountains, can tap wind for local use. Large-scale commercial wind development is at present very limited, but the Ninth Five-Year Plan projects wind resources to reach 300 to 400 MW by 2000; projections for 2010 are between 1000 and 1500 MW. This is still only a tiny fraction of China's total exploitable wind resources, which are estimated to be 253,000 MW.

Solar resources are also enormous in China, particularly in the western regions. Two-thirds of the country receive over 2000 hours of sunlight a year. Most solar development to date has focused on incorporating passive solar design into new housing construction. Solar hot-water heating is rapidly expanding in residential, commercial, and industrial applications. According to State Planning Commission projections, the capacity of solar hot-water heating systems will reach 250 million cubic feet by the year 2000. There is currently no large-scale use of solar thermal or photovoltaic technology for electrical generation in China.

High-temperature geothermal resources are significant in northern Tibet and in the western portion of the adjacent province of Yunnan. This resource base is large enough to displace over 300 million tons of coal burning, but currently only 50 MW of geothermal electrical generation capacity is in place. In addition, direct use of geothermal energy for central heating in isolated areas throughout China currently displaces less than one million tons of coal.

Tidal power in China is potentially available on a vast scale, thanks to the nation's 1150-mile coastline. This resource is especially promising in Zhejiang and Fujian provinces between Shanghai and Hong Kong. Currently only about 6 MW of tidal energy capacity is in operation, mostly in small systems. Use of tidal power is projected by the State Planning Commission to grow to 50 MW by 2000 and to reach 300 MW by 2010.

China Today: Economic Miracle or Environmental Catastrophe?

The current era of Chinese participation in global affairs began in earnest in 1971, when China joined the United Nations, and it took another leap forward a year later when President Nixon's visit inaugurated diplomatic relations with the United States. China's economic system has subsequently been reshaped through the dramatic reforms begun by President Deng Xiaoping in 1978 and continued by Jiang Zemin following Deng's death in February 1997.

Modernity, Wealth, and Poverty

China has quickly become the fourth largest exporter of goods to the United States. During the first half of 1997, Chinese exports to the United States jumped by 26 percent compared to the previous year, while total exports grew by only 13 percent. Imports, on the other hand, remained constant, thereby augmenting the already healthy trade surplus that China has enjoyed throughout the 1990s.

This growth has brought great wealth to a small portion of the Chinese population and has transformed the urban landscape in many leading cities, providing work for millions of laborers in the process. The neon lights of Shanghai already rival those of New York City. Shenzhen, which was a small fishing village little more than a decade ago, is now home to three million people, with a skyline mimicking that of nearby (and recently incorporated) Hong Kong. Stocks on China's several exchanges are traded in pace with such bastions of capitalism as the Nikkei, New York, and London exchanges, and new multimillion-dollar ventures between Chinese companies and their counterparts in Europe and the United States are reported daily in the Western press. Over 14,000 such joint ventures have been established in the past 10 years alone.

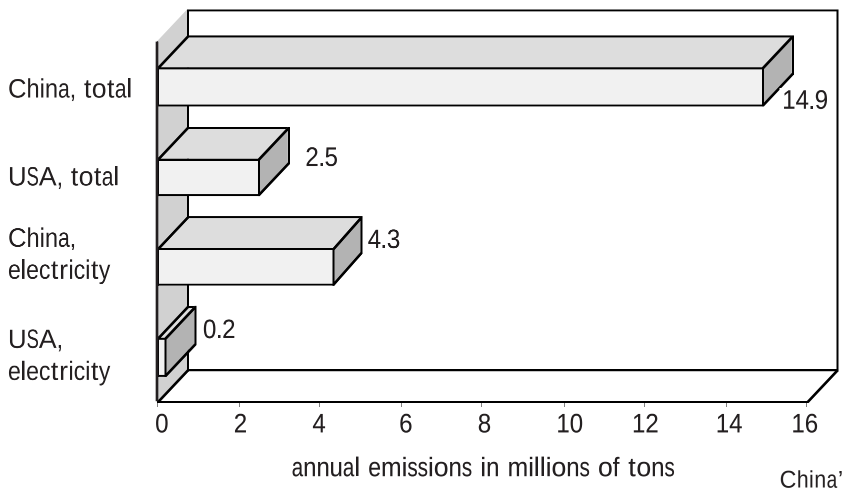
A walk into the sidestreets of China's showcase cities or a visit to the cities and towns of its vast interior reveals a different picture, however. The reality is that most of the country's vast population remains crippled by poverty, eking out a living in unsanitary conditions within a larger polluted environment. Despite 133 percent growth in economic output between 1986 and 1995, per capita income in China, measured as GDP per citizen, is still a paltry $440 per year, compared to over $20,700/year in the United States. With the typical Chinese worker's annual earnings equivalent to a US worker's average weekly income, China is still a very poor nation.

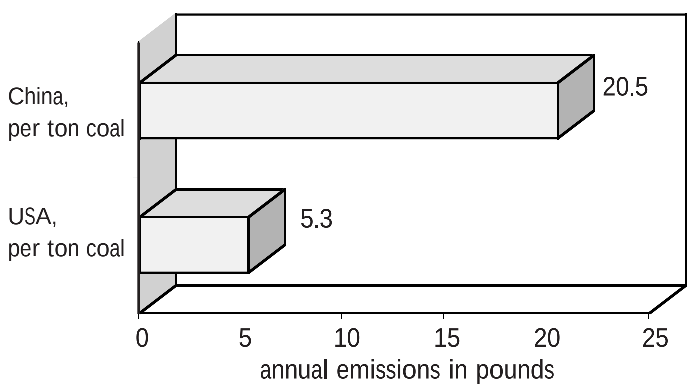
In many ways, China today is reminiscent of England in the 1830s. Britain's meteoric rise as a global economic leader was powered by an industrial revolution fueled almost solely by coal. The price of England's rapid economic growth 150 years ago included skies fouled with coal smoke and deplorable working and living conditions for the majority of its people.

An analogous situation exists in present-day China, where the effects of rapid development are clearly two-edged.

Figure 3

China and the United States: Particulate Emissions





China's coal-burning electrical generating stations burn half as much fuel but emit 17 times more particulates than those in the United States. About 250,000 premature deaths per year in China are attributed to air pollution.

Coal Burning, Health, and the Environment

Millions of smoking vehicles travel China's roads and hundreds of thousands of belching smokestacks dot the landscape, most emitting clouds of soot and high concentrations of other, invisible air pollutants. Emissions of particulate matter (soot and smoke) total nearly 15 million tons each year in China, about six times the US rate of 2.5 million tons annually (see Figure 3, opposite). In addition, emissions of sulfur dioxide equal nearly 13 million tons per year (see Table 6).

Table 6 **China and the US: Annual Particulate and Sulfur Dioxide Emissions**

	Particulates	Sulfur Dioxide
USA, total (tons/y)	2,547,000	18,319,000
China, total (tons/y)	14,970,000	12,950,000
USA, electricity sector (tons/y)	248,000	11,561,000
China, electricity sector (tons/y)	4,341,000	6,476,000
USA (lbs/ton of coal)	5.36	38.57
China (lbs/ton of coal)*	20.51	17.74

* Based on best available data.

Some Chinese cities are so thickly blanketed with particulate and sulfur dioxide emissions that their lights are "invisible" to satellite sensors. Coal burning is the major culprit.

The chief source of both particulate and sulfur dioxide emissions in China is coal burning. According to a recent World Bank analysis, concentrations of these pollutants in most Chinese cities are between two and five times in excess of public health standards established by the World Health Organization. The impact of these emissions on public health and the environment is devastating. About 250,000 premature deaths are attributed to air pollution each year in China. Overall, respiratory disease is the cause of about one quarter of all deaths, an astoundingly high percentage.

Over a quarter of China's land is contaminated by acid rain, the principal source of which is sulfur dioxide emissions from coal burning. The World Bank estimates that the country incurs $54 billion in property damage and public health costs annually as a result of air pollution.

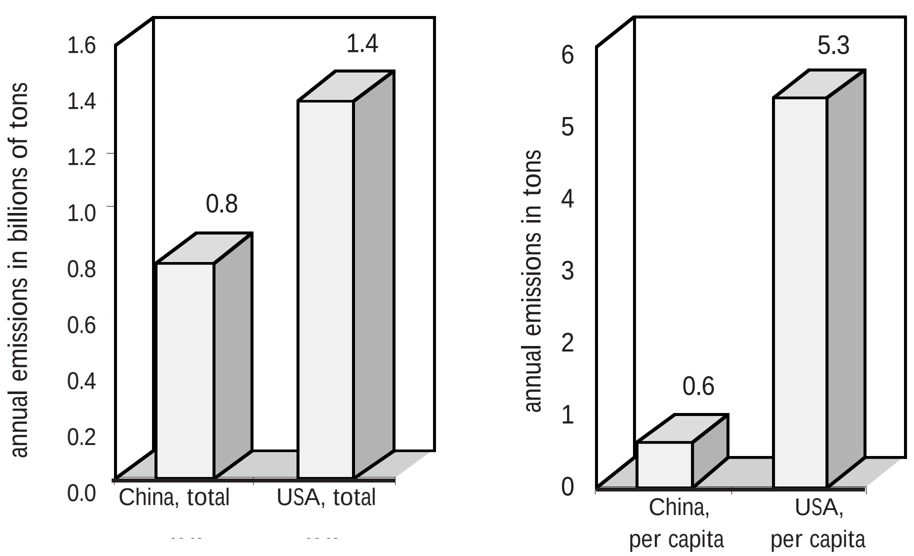
China is doing little to protect its population and environment from the effects of this pollution. Most coal-fueled power plants are equipped with only the most rudimentary pollution control devices, and pollution controls in other coal-burning processes, such as industrial boilers and home heating and cooking, are virtually nonexistent. Although coal-burning electrical generating stations in the United States burn twice as much fuel as those in China, the latter emit 17 times more particulates. Moreover, factoring in the lower efficiency of electrical generation in China, INFORM estimates that over 40 times more particulate matter is emitted per kilowatt-hour of electricity generated at coal-burning power plants in China than at comparable plants in the United States.

Coal burning is also the major source of China's emissions of carbon dioxide, now believed to be the major cause of global climate change. Carbon dioxide emissions from coal combustion now exceed half a billion tons per year (measured as carbon) and account for more than half of the country's 830 million tons of annual carbon emissions. Although China ranks second only to the United States in total emissions of carbon dioxide, its per capita rate is only about one ninth the US rate of emissions (see Figure 4).

Continued energy development in China based on coal burning and inadequate controls will only make a bad situation worse. Nonetheless, the State Planning Commission is counting on this nineteenth-century technology to form the backbone of China's electricity generation for the foreseeable future. Given this scenario, the US Energy Information Administration predicts that emissions of carbon dioxide in China will exceed 1.5 billion tons by 2010. And the nation's modest plans for diversification include only nuclear power, arguably the most dangerous of alternative options, and hydropower.

Figure 4

China and the United States: Annual Carbon Dioxide Emissions



China ranks second only to the United States in total emissions of carbon dioxide, believed to be the major cause of global climate change.

China's Transportation System: The Opportunities Ahead

China's reliance on fossil fuels to meet its energy needs has already created terrible risks for its environment, its security, and its people's health. Yet the opportunity exists for China to make a transition in one area of energy use that could be a model for the world: a transportation system based on cleaner alternative fuels and vehicle technologies. China can also take advantage of the lessons learned from the United States and other industrialized nations by planning mass transit and rail systems that will move its people rapidly, comfortably, and conveniently across and between cities.

Time to Change Course

Up until now, China's transportation sector has relied increasingly on oil and on the technology of the internal combustion engine to build the nation's growing motor vehicle fleet. This pattern of energy development raises troubling issues for both China and the United States.

World oil consumption in 1994 stood at 66.8 million barrels per day. Assuming a modest 2 percent annual growth rate, more oil will be consumed globally just during the next 20 years than throughout all of previous history. Were current trends to continue and China's per capita oil consumption to ultimately equal the current US rate, Chinese demand alone would exceed total oil production in the world today by 18 percent. Clearly, the emergence of a major new market for oil in China would greatly accelerate the existing drain on this already dwindling resource.

Reliance on oil-fueled vehicles in the twenty-first century makes no more sense for China (or for any other country) than continued reliance on the horse would have been for the United States 100 years ago. A significant motor vehicle transportation system in China will require huge capital investments, and it will be decades before that system even begins to match its counterpart in the United

States. If oil and the internal combustion engine are China's chosen fuel and propulsion technology, global oil supplies will likely be constrained by the time the nation's transportation infrastructure is established.

Although China is not completely ignoring transportation strategies based on alternative fuels and technologies, its overall approach to date has been to increase deployment of conventional technologies and expand its use of oil. When faced with lagging domestic oil production, China, like the United States, has chosen to increase oil imports rather than seek diversification to other fuels. With oil imports inching steadily upward toward 60 percent of total demand in the United States and 20 percent of total demand in China by 2010, the stage is set for competition of an intensity that could threaten the security of both countries.

Similarly, the fate of China's environment is inexorably linked to the transportation system it provides for its people. Automotive emissions are the most rapidly growing source of urban air pollution in most Chinese cities. Programs requiring the installation of catalytic converters and the use of cleaner-burning reformulated gasoline would be costly and difficult to implement, and even if successful, would do nothing to reduce emissions of carbon dioxide. In the United States, oil burning—mainly in vehicles—is already the largest source of carbon dioxide emissions, accounting for more than 40 percent of the total. If China continues on its current energy path, its own environment will undoubtedly meet with the same fate.

Clean Fuels and Other Options

China has only limited time to analyze its options and set the nation's course—one that hopefully will serve its people's needs while also promoting energy security and environmental well being for the rest of the world.

The good news is that China is still very near the starting point in its efforts to establish a nationwide transportation system. Unlike the United States, the choice it makes is not heavily encumbered by economic investments in a preexisting infrastructure. This means it can build a system from the ground up, using the latest propulsion technologies and fuels, rather than attempting to replicate the oil-based model of the nineteenth century. Among the most promising options are natural gas vehicles and a variety of electric and hydrogen vehicle technologies.

To get the job done, China will have to make a much greater commitment to developing these new technologies. A good first step would be a national program aimed at marketing electric-vehicle technologies and establishing the necessary fuel infrastructure. Some impressive work is already under way, but there is a risk that progressive transportation strategies will be subsumed by the proliferation of gasoline-powered vehicles.

Programs to diversify transportation fuels to include non-oil alternatives are only beginning in China. The only significant historical use of alternative fuels in motor vehicles is natural gas, long used in buses in Sichuan province. Several programs are now expanding the use of natural gas and liquefied petroleum gas in a variety of vehicle types, including passenger vehicles and trucks as well as buses. Such efforts will have to be greatly expanded if China is to combat its increasing dependence on oil through alternative fuels.

A Market for US Industry

Development of a transportation system in China based on alternative fuels and propulsion technologies would provide the United States with enormous market opportunities. Alternative fuels and vehicles have established a presence in the US market, but it is minuscule compared to the conventional automotive and oil industries. The ultimate success of the alternative fuel industry in the United States may well hinge on its ability to sell its products, technologies, and skills on the international market.

China represents by far the largest potential transportation market for this fledging industry, especially the urban bus market. There are more buses in China than in any other country in the world—at over 500,000, more than eight times the number in the United States. Shanghai alone has 6000 buses and Beijing has 5000. Buses offer China the opportunity to expand access to transportation to the largest number of people in the shortest time and at the least cost, while making most efficient use of the country's limited existing roadways.

Urban buses are also the strongest sector in the US alternative transportation fuel industry today, so there is an excellent fit between the transportation needs of China and the products and services available from US companies. More than 20 percent of all buses now under construction in the United States will be equipped to burn natural gas. A large industry of natural gas bus equipment suppliers and installers has sprung up to serve this market. Moreover, bus chassis and engine manufacturers have modified their products to accommodate natural gas fueling technology.

China's Crossroads

China's economic polarities and its enormous social, political, and cultural contrasts with the United States confound attempts to predict with any confidence the country's future direction. This is particularly true in the area of energy development. In a Shanghai shantytown, an electric light bulb burning over a coal-fired cooking stove may well be powered by a nuclear generating station. In Beijing, luxury cars weave cautiously through traffic snarled by thousands of bicycles and hand-pulled carts. Throughout China, the incessant clash of such disparate elements threatens at any moment to rip apart the already frayed social fabric of this nation in transition.

Will China commit itself to developing the fuels, vehicle technologies, and infrastructure that will define the transportation systems of the twenty-first century? The advantages of doing so are enormous, for China's population, security, and environment and those of the rest of the world.

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About the Author

James Cannon is an internationally recognized researcher, author, analyst, and speaker on energy development, environmental protection, and related public policy issues. Long associated with INFORM as a staff member and then senior consultant, he is the author of *Gearing Up for Hydrogen:America's Road to Sustainable Transportation* (1998), a summary of alternative fuels and advanced vehicle technologies now entering the market, and *Spotlight on New York: A Decade of Progress in Alternative Transportation Fuels* (1997), a summary and evaluation of New York State and New York City's progress toward sustainable transportation. His published works also include *Harnessing Hydrogen: The Key to Sustainable Transportation* (1995), a report illuminating the exciting potential of hydrogen as a clean, renewable fuel alternative for a non-polluting transportation system for the next century; *Drive for Clean Air* (1989), the highly influential study of natural gas and methanol as alternative vehicle fuels; and *Paving the Way to Natural Gas Vehicles* (1993), which identifies the actions necessary for the successful transition to natural gas. Mr. Cannon is currently continuing his research on the viability of non-polluting solar hydrogen-powered vehicles and the role natural gas can play as a clean-burning "bridge" fuel to solar hydrogen.

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Related publications from INFORM include:

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