# Spurring Innovations for Clean Energy and Water Protection in China: An Opportunity to Advance Security and Harmonious Development

By Lü Zhi, Michael Totten, and Philip Chou

*China has experienced a phenomenal economic boom over the past 26 years—with an average 9 percent annual GDP growth—bringing millions out of poverty and establishing the country as a major economic powerhouse in the world. This growth, however, has been built on a foundation of environmental degradation. The ecological problems in China are numerous, but the two most serious challenges are: (1) destruction of water ecosystems from mismanagement and hydropower construction, and (2) air pollution stemming mainly from coal burning for energy. China's State Council has recognized the lack of clean energy and water as two of the six main bottlenecks for the country's next five-year development.*[1] *How well or how poorly the Chinese government decides to deal with its energy and water management issues will determine environmental quality within and well beyond China's borders. Current policy and investment trends in China could stimulate stronger clean energy and better water conservation. Of particular note are some integrated resource planning and technology-promoting policies and pilot projects that could not only spark more domestically produced pollution control and energy efficiency products to clean up China, but also turn the country into a leading exporter of such technologies. Creating clean technologies markets could help promote a truly harmonious development cycle in China.*

## THE ENERGY AND WATER CHALLENGES IN CHINA

### The Challenge of Coal

China is the largest consumer of coal—most of it low quality—in the world. Thus it is not surprising that with the largest population and sixth largest GDP, China is the world's second largest emitter of greenhouse gas emissions behind the United States. Moreover, China's economic growth may double carbon dioxide ($CO_2$) emissions by 2020, overtaking the United States to become the largest climate polluter in the world (Lan, 2005).

China's *National Communication on Climate Change* presented at COP10 in Buenos Aires in 2004 left no doubt as to the monumental climate change threats the country and the world faces. Western China's mountain glaciers already have shrunk by one-fifth, endangering water supplies for a quarter billion Chinese. Global warming would mean one-fourth of China's single crop season area would be lost, resulting in an overall decrease of wheat, rice, and maize. Cities along China's densely populated southern coast face submersion from rising sea levels and storms (PRC, 2004).

It is easily arguable that the Chinese leadership faces too many domestic economic, social and environmental crises to take on climate pollution responsibilities as well. However, China's domestic air quality and global climate change problems are intimately linked. Each year, more than a million Chinese die from respiratory diseases due to severe air pollution, costing the equivalent annual salaries of 5 million people. China's regional haze, largely caused by coal combustion and burning agricultural wastes, is depressing 70 percent of crops by up to 30 percent (Chameides et al., 1999). Effectively addressing these more immediate air pollution problems would have a major impact on decreasing China's contribution to greenhouse gas emissions.

### Water Wastage and Mismanagement

While air quality statistics are gloomy, China also faces a water crisis of epic proportions that threatens to weaken the nation's economic engine. China has some 2,140 $m^3$ of water per capita, one-fourth the world average (Liu & Chen, 2001). These water resources are spread severely skewed, with 80 percent of the total volume located in southern China, while north China—where two-thirds of cultivated land is located—has only 226 $m^3$ of water per capita, nearly tenfold lower than the national average. Throughout northwestern and northern China, drought affects 27 million hectares (ha) of agricultural land and desertification afflicts some 300 million ha of grasslands. The decrease in cultivable land is primarily due to over-exploitation of water resources by farmers, due to both under pricing of water and wasteful irrigation techniques (Liu & He, 2001). On many farms, water flow per unit of land is 50 to 150 percent above that optimally needed for the crops, wasting water and reducing land productivity (Ma, 1999).

China's water resources per capita may decline to around 1,700 $m^3$ by 2050, which is the threshold of severe water scarcity. Water shortage already has become a critical constraint for socioeconomic development in northern China. The Chinese leadership is responding to the water crisis by simultaneously promoting aggressive water efficiency measures, a doubling or tripling of dams, and vast water transfers from the south to the north.

## China's Unique Opportunity

The Chinese leadership stands at an important crossroads in terms of the country's development. The western growth model, which China has in many ways been following, largely fails to address the country's pressing development challenges. Historically, China has spent 12 times more on expanding energy, water, resources, and land, than on efficiency. Some Chinese experts have estimated that if the country can achieve energy efficiency levels comparable to Japan, China would not have to increase its energy supplies in the next 60 years. To achieve this goal, China would have to build on some of the country's more progressive environmental policies that would support stronger pollution control and energy efficiency technologies. China is not only capable of producing cutting edge clean technologies, but also could use the sheer size of its domestic market to accelerate manufacturing experience and learning curves, which would drive down production costs. Chinese companies would thus be positioned to capture an increasing percentage of the global export market for less polluting and energy, water, and resource efficient products.

The global economy is projected to grow tenfold this century, with an extraordinary level of new low-polluting, higher performance products and goods to be purchased by developing and industrialized countries. Using the "California effect"[2] as a model, some researchers suggest countries with progressive technology-pushing environmental policies and programs can actually enhance their competitiveness in the global market (Porter & van der Linde, 1995). China's Eleventh Five-Year Plan (FYP) and other recent energy policies have been laying the foundation for such technology-pushing policies.

## The "Four Efficiencies"

In preparation for the new Eleventh FYP, President Hu and Premier Wen have made striking pronouncements on the importance of China building a great, "resource-conserving and innovating society." They are pushing conservation through some unprecedented laws that prioritize the "four efficiencies" (4Es)—efficient use of energy, water, land use, and natural resources (e.g., metals, minerals, and chemicals). The leadership is ambitiously promoting conservation and renewable energy to help continue its economic boom, as well as to address the growing concerns over pollution and energy security. If the leadership is truly committed to the 4Es they may succeed in turning the country into a major clean technology producer both domestically and globally.[3] The looming question is whether this new spirit for enhancing energy and natural resource security will be embraced by the entrenched bureaucracies and traditional resource-inefficient industries or derailed by their lack of transparency, corrupt practices, misallocation of investment capital, and stonewalling of public participation.

This article highlights some innovative energy and water policies and pilot projects that show how the government's push for a more resource-conserving society could work. Such pilots could be crucial for showing the entrenched bureaucracies the prosperity-generating advantages of being "clean and green." We also discuss some technologies and policies used internationally that could easily be adopted in China. If, as we discuss in the next section, Chinese policymakers opt to install more solar and wind energy—which the 2005 Renewable Energy Law requires—they can draw from a rich array of experiences that have been tried internationally and promise a high return on investment (De Moor, et al., 2003; Ghanahan, 2002; Margolis, 2002; Williams, 2002; Elliott, 2001; IEA & OECD, 2000).

## OPPORTUNITIES FOR PROMOTING ENERGY EFFICIENCY AND RENEWABLE ENERGY

### Energy Efficiency

China's energy intensity has fallen fourfold since the 1980 liberalization of markets. Most strikingly, this reduction in energy intensity led to three gigatons less coal emissions in the 1990s; right in the midst of an economic boom that was lifting 400 million citizens out of poverty. While a Chinese citizen consumes less than half the world average for energy, China's energy intensity per unit of GNP is 50 percent *more* than the world average—five times more than the United States and up to ten times more than Japan. The Eleventh FYP set targets that require per GDP energy consumption to decrease by 20 percent from 2005 to 2010, while per capita GDP doubles by 2010. To reach these goals, energy efficiency gains must meet or exceed a 3 percent annual energy savings rate through 2050 (Hu, 2005). Pursuing energy efficiency and renewable power could become the enabling engine for the nation to leapfrog into a robust, developed nation with a cleaner environment. For example, from 1990 to 2001, the European Union (EU) produced three times the GDP of China with a net increase in $CO_2$ of only one-eighth that of China's (Papineau, 2005).

#### *Integrated Resource Planning and Efficiency Power Plants*

When evaluating the goals of the Eleventh FYP the first question that arises is how China will be able to finance these efforts, as well as the related education, training, certification, R&D, manufacturing, and enforcement work. In China considerable more investment is going into developing coal-fired electric power systems (~$60 billion per year until 2030) than into cleaner and cheaper energy options (IEA, 2003).

A fundamental tool for securing these savings and avoiding sub-optimal investments in the energy sector is integrated resource planning (IRP). IRP is a well-established, scientifically based methodology that compares costs, benefits, and risks of all supply and demand-side management (DSM) efficiency options (RAP, 2004; Finamore, et al., 2003). China already has experience with energy efficiency programs, many of which were done in partnership with international NGOs and bilateral organizations. Government studies have concluded that more than 100 GW of new generating capacity by 2020 can be met faster, cleaner, and at least cost through DSM efficiency initiatives (Hu, Moskovitz, & Zhao, 2005). This would otherwise require 2.5 to 6.6 million railroad cars shipping 250 to 660 megatons of coal per year to power plants.

Capturing these savings will require rigorous and transparent implementation of policies and regulatory procedures that, among other things, firmly incorporates IRP as a requirement on decision-making for all grid and power company investments (Hu & Moskovitz, 2004; RAP, 2004). A well-run IRP process prioritizes allocations to projects that offer the most services per unit of investment and numerous ancillary benefits, while avoiding misallocations resulting in lost opportunities (OECD & IPCC, 2000). IRP is indispensable for identifying and resolving a myriad of technical, financial, institutional, and market barriers that threaten resource-conserving laws. For example, the Chinese government plans to invest $30 billion to add 30 GW of nuclear capacity in the next 15 years. The capital costs appear unrealistically low by a factor of two or more based on nuclear industry cumulative empirical construction experience and projected best guesses by nuclear advocates for constructing new reactors (MIT, 2003). Using more reasonable cost estimates shows nuclear energy to be uncompetitive with a portfolio of higher value energy efficient purchases. The $30 billion could instead bring online 45 GW of wind power, upwards of 100 GW of cogeneration, and more than 100 GW from DSM and end-use efficiency projects (Lovins, 2005).[4]

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In 2005, utility experts from Jiangsu Province, Shanghai, Beijing, and elsewhere, began creating an inventory of DSM opportunities—such as high-efficiency lighting, industrial motors, and appliances—that could be brought "online" more rapidly and cheaply than coal plants. Developed in collaboration with the Natural Resources Defense Council (NRDC) over a 48- to 72-month period, the study effort has resulted in opportunities for 1.7 GW of what are technically referred to as "Efficiency Power Plants" (EPPs). The EPPs have a lifetime delivered cost of $0.01 per kWh saved, five times less than coal plants (Niederberger & Finamore, 2005).[5]

China also is implementing building, appliance and industrial efficiency standards, which could eliminate the need for 140 giant power plants, prevent the release of 2.8 gigatons of $CO_2$, and accrue multi-billion dollar net savings by 2020 (Energy Foundation, 2004). In 2005, the government issued a procurement policy requiring government agencies to utilize energy efficient products. Nearly 1,500 product models from 84 manufacturers are included in the first list, encompassing eight product categories (CECP, 2005).

### *Energy Efficient Building and Appliances*

Standards, IRP, R&D efforts, and market transforming incentives are critical tools for ensuring top-of-the-line construction and operation of green buildings. China's building sector absorbs 40 to 45 percent of the nation's total energy consumption (Goldstein & Watson, 2002). By 2015 the World Bank estimates that half of the world's new building construction will take place in China (Langer & Watson, 2004).

Laws passed in 2005 call for all of China's cities to cut building energy consumption in half by 2010, and achieve two-third reductions by 2020. In addition, one-fourth of existing residential and public buildings in the country's large cities will be retrofitted to be greener by 2010. Over 80 million $m^2$ of building space will be powered by renewables (PRC, 2005). These are impressive goals, although a review by green building experts finds they still fall short of international standards (Goldstein & Watson, 2002). To help raise these standards, cities like Beijing are reaching out to international organizations and businesses to help them retrofit buildings with the most efficient technologies.[6]

In order to achieve these goals the government would have to require the equivalent of Leadership in Energy and Environmental Design (LEED) certification, which is an economically compelling option for this energy-starved country. The State of California is accruing impressive financial savings in buildings with new LEED-certified construction ranging from $400 to $700 per $m^2$ (Kats, et al., 2003). If the Chinese government does opt to promote LEED building certification, it will demand ongoing leadership and investment in many areas—training, R&D, resource tools, monitoring and benchmarking, market transformation initiatives, and incentives to spur superior results (Goldstein & Watson, 2002; ACEEE & CEE, 2005).

Standards and incentives for high-performance appliances and equipment accrue similarly large returns on investments (Nadel & deLaski, 2005). China's eight new minimum energy-performance standards and nine energy-efficiency endorsement labels implemented between 1999 and 2004 will save 200 billion kWh and 250 megatons of $CO_2$ in the first decade of implementation. This is equivalent to all of China's residential electricity consumption in 2002 (Wiel & McMahon, 2005).

Since 1999, China's Certification Center for Energy Conservation Products (CECP) has been partnering with *Energy Star*, the U.S. Environmental Protection Agency's (EPA) energy efficiency labeling program, leveraging the lessons learned through *Energy Star* to increase the success of CECP's own marketing programs (McNeil & Hathaway, 2005). Beginning in 2003, a number of owners and managers of large commercial buildings in Shanghai have been working directly with eeBuildings, an EPA voluntary market transformation initiative that helps managers identify low-cost and no-cost efficiency measures to immediately reduce building energy use, operating costs, and greenhouse gas emissions. Within the first year, the program trained 130 building owners and managers responsible for 135 large commercial buildings in Shanghai (Hathaway & McNeil, 2005).

### *High-Efficiency Co-, Tri- and Quad-generation Systems*

Instead of targeting massive investments into large-scale, central coal, nuclear, and hydroelectric generating stations, China could opt to develop economically competitive green and efficient technologies. One technology to more efficiently use coal for electricity would be decentralized combined heat and power (CHP). Whereas central thermal power plants vent 50 to 70 percent of the energy when generating electricity, CHP systems capture this waste heat to co-generate two, three or four different energy services. Moreover, in being sited close to the point of use, CHP systems require significantly less transmission and distribution (T&D) investment than centralized power plants, and avoid the 15 percent T&D line losses (WADE, 2004).

Recent assessments indicate if China moved to 100 percent high-efficiency decentralized CHP systems by 2021, retail and capital cost savings could reach $400 billion. At no extra cost, new emissions of $CO_2$ would drop 56 percent, avoiding 400 megatons of $CO_2$ emissions per year, and declines in $NO_x$ and $SO_x$ emissions by 90 percent. But these results are possible only if the Chinese government adopts key policies enabling a faster rate of implementation than the current annual CHP addition of 3 GW. Some 100 GW of CHP could be online by 2010 if a number of important power sector reforms occur (WADE, 2004).[7]

## Renewable Energy

### *Accelerating Wind Farms—Cash Cows of the 21st Century*

New estimates of global wind power claim turbines at 80 meters (the average height of modern multi-MW wind turbines) could generate 72 TW. The analysts concluded that capturing 20 percent of this power could satisfy 100 percent of the world's energy demand and even produce five times the world's electricity needs [~3 TW] (Archer & Jacobson, 2005). Wind power is cost competitive (about $0.04/kWh) with new coal, natural gas or nuclear power plants in North America and other parts of the world. Ongoing R&D innovations are expected to reduce wind costs below $0.03/kWh this decade and $0.02/kWh the following decade.

China's terrestrial and near offshore wind potential at 80 meters height is estimated at 2,000 GW—among the largest in the world. China's total installed electricity generating capacity in 2005 was 430 GW, of which just 0.7 GW was wind. Currently the Chinese government has a wind power goal of 30 GW by 2020, a recent estimate by wind experts puts China's installed potential at 400 GW before 2050 ("China Exclusive," 2005).

New wind farms in China are selling energy at $0.04 to $0.06 per kWh, compared to coal-powered plants at $0.035 per kWh at the busbar prior to transmission. However, given that most coal is located in the north, the price rises as high as $0.13/kWh when delivered to southern Chinese cities like Shanghai. In contrast, there are less transmission costs for the near offshore wind resources located in south China. Wind power also avoids the serious health and environmental damages that would, at a minimum, double coal costs if these externalities were included. The global export market growth opportunities in wind technologies and services for China are massive; a recent assessment indicates 12 percent of the world's electricity by 2020 can be wind powered.

Such high growth rates over 25 years are not unprecedented. Between 1956 and 1980, global installed nuclear capacity grew at an average rate of 40 percent per year. But, like nuclear power in its heyday, wind (and solar) will need supportive public policies to overcome barriers and market failures for sustaining such high growth rates.

Environmental and social issues related to rapid wind growth also need to be addressed at the outset. Wind farms can cause avian and bat mortality, particularly when poorly sited. At the same time, wind will displace many coal plants, thereby helping to reduce another source of bird mortality (AWEA, 2005). The Chinese wind industry can prevent many problems by taking advantage of the considerable research and best management practices undertaken in Europe and North America. Land tenure issues must also be addressed in an equitable and transparent manner; situating wind turbines by seizing land from local communities, as recently happened in southern China, leads to serious conflicts that are preventable by implementing standards and permitting guidelines (NWCC, 2002).

A large percentage of China's wind resources are located in sparsely populated parts, remote from large population centers (e.g., Inner Mongolia and islands off of the southern coast). While this presents critical transmission issues, it also represents an excellent opportunity to foster economic growth in these regions that are among the poorest in China (Brennand, 2000; Ni, Yin & Guo, 2000; Jaccard & Lott, 2000; PRC, 2002).

To the extent that remote wind farms are concentrated in farming and ranching regions, the income from wind royalties could be a major supplement to income for impoverished communities.[8] Besides helping poorer farmer communities, wind turbines also require several orders of magnitude less water per TWh than fossil or nuclear power plants, a critical benefit for China's water-stressed regions.

### *Large-Scale Solar Photovoltaic Power Systems*

The single largest sustainable energy source on earth is the 125 million GW of sunlight continuously shining upon the planet. Most areas of China have high levels of solar radiation, 1,670 kWh/m$^2$ per year, equivalent to 1,700 billion tons of coal nationwide (Gu & Liu, 2000). China already is the world leader in using solar thermal energy for hot water heaters, with 60 percent of the world's installed systems. The government has set a national target for 300 million m$^2$ of thermal energy systems by 2020, a 500 percent increase, annually replacing 40 megatons of coal (Li, 2005; Wang, 2004).

China has 0.05 GW of solar electric photovoltaic (PV) power systems, with projections of 8 GW by 2020 (UNDP, TWAS, & TWNSO, 2003). Notably, economic-engineering analysis of building-integrated photovoltaic (BIPV) systems in China indicates BIPV may already be economical. By using PV panels as façade-cladding components on buildings, the material savings combined with the energy generation greatly reduces the investment payback period by three to four years (Byrne, Alleng, & Zhou, 2001).

Faster growth rates could result from an innovative application for achieving highly competitive PV systems, according to recent engineering assessments (i.e., $1 per Watt fully installed, $0.05 per kWh delivered). This new application involves employing a similar cluster production process used in achieving breakthrough cost reductions and productivity gains in liquid crystal display manufacturing. Known as "solar city factories," these large-scale PV manufacturing systems—can produce low-cost solar cells that could become an extraordinary domestic and global export growth market for China. There are technical challenges in creating cluster PV production plants that demand focused and sustained R&D investments (Keshner & Arya, 2004).

Like wind farms, PV systems require less water than fossil fuel or nuclear power plants, an immense benefit given the utility sector consumes 10 percent of the nation's water. The versatility of PV systems to be sited at or near the point of use enables capturing a range of utility system benefits and savings, and risk reduction and management opportunities (Lovins, et al., 2002).

## BIOLOGICAL FOOD, FIBER, FOREST, FEED, AND FUEL FEEDSTOCKS

### Black Carbon Soot—Turning a Problem into Progress

China is the world's largest consumer of biomass energy, accounting for 20 percent of total global use. Burning crop residues—a common, although officially banned, practice in China—blankets rural villages in a gray fog, exacerbating smoke that is generated from rural families cooking and heating over coal or wood fires in homes. Black carbon (BC) aerosols are the active ingredient in this smoke and haze. BC emissions are concentrated in a curving west-to-east swath across the agricultural heartland of China, between Sichuan and Hebei provinces.

The bulk of BC particles are less than one micron in diameter and in China they are the cause of hundreds of thousands of premature deaths each year from respiratory illnesses. BC blocks sunlight, which may be responsible for a 30 percent reduction in China's crop yields for both wheat and rice (Chameides et al., 1999). Additionally, the increased summer floods in the south and droughts in the north—thought to be the largest changes in precipitation trends since 950 A.D.—may be explained in part by BC soot (Qun, 2001). Moreover, some prominent climate scientists believe BC to be the second most important global warming gas after $CO_2$ (Hansen & Sato, 2001; Jacobson, 2002). The largest emitting country in the world is China, releasing 17 percent of global BC emissions (Streets, 2004).

Assessments and demonstration projects initiated by the China Council on International Cooperation for Environment and Development (CCICED) have identified one promising solution to the BC problem. Instead of burning biomass, small village-scale gasifiers could turn the residues into clean energy. The available residues are enough to meet all rural cooking needs and generate 135 TWh per year of electricity—20 percent more capacity than the Three Gorges Dam (CCICED, 2000). Village-scale gasifiers are being installed in four provinces (Henan, Hubei, Jiangxi, and Shanxi) as part of the $77 million Efficient Utilization of Agricultural Wastes Project launched in 2002 with support from the Asian Development Bank (ADB, 2002). For the most part, however, the current technology focus is in using direct combustion rather than gasification power plants. The China Energy Conservation Investment Corporation is planning to construct 30 plants (each 24 MW in size) as part of the "Straws and Stalks" program, with longer term plans to construct 100 plants totaling 2.4 GW. Combustion of 20 million tons of crop straws and stalks will displace 10 million tons of coal and increase farm incomes by an estimated 6 billion Yuan (Zhou, 2006).

### Biogasification of Livestock Wastes for Energy

China's animal excrement exceeds 2 gigatons per year (Sun et al., 2004). The livestock pollutants—

particularly from the growing number of megafarms—impose heavy burdens on ecosystems, and are a major cause of non-point source water pollution in China (Zhu, 2000). Biogasification of livestock wastes could help reduce these serious health and environmental problems and provide energy to rural communities (*Editor's Note: See Commentary by Ben Greenhouse in this issue for an example*).

### Biogasification and Perennial Feedstocks for Protein Food and Flexi-Fuels

Regeneration of China's grasslands and pasturelands may offer new opportunities for applications of perennial prairie grasses for simultaneously growing protein for animal feed and cellulosic feedstocks for fuel production. This double-value scenario is being promoted in North America through the use of deep-rooting Switchgrass.

Experts estimate an aggressive plan to develop cellulosic biofuels between now and 2015 could enable the United States to produce the equivalent of roughly 8 million barrels of oil per day by 2025 (Greene et al., 2004). Farmers would gain $5 billion in increased profits per year, consumers would save $20 billion per year in fuel costs, and society would benefit from 80 percent reductions in U.S. transportation-related greenhouse gas emissions. No new land would be required for production of this substantial quantity of fuel feedstock, while still producing the amount of animal feed protein currently generated by this land now.

Further research on China's 400 million hectares of grassland and pasturelands—three times more than its arable lands—will determine if comparable opportunities exist as experts have identified for the United States. If so, this could play a key role in addressing two colossal growth trends looming in China—the need for more animal protein feed as the population consumes more meat, and the need for secure fuels for the expanding vehicle market. China's world-class leadership in agricultural genetics research and breeding innovations are promising indicators for taking advantage of this potential grasslands-based opportunity.[9]

## DRIVING CHINA'S VEHICLE FLEET TOWARDS EFFICIENCY

### New Materials for Car Construction

Vehicle production has been doubling every 24 months, and vehicle ownership is projected to increase to 100 million by 2020. China's adoption of vehicle fuel efficiency standards (higher than current U.S. standards, but less strict than European semi-voluntary standards) will displace more than 210 million barrels of oil (Bradsher, 2005a, 2005b). Expanding the standards to trucks and motorcycles is expected to double the savings (Energy Foundation, 2004). China now consumes 8 percent of world oil, and by some projections could triple consumption by 2020, absent efficiency standards (Wan, 2004). Growing oil demand has already caused concern internationally (fears of China's impact) and domestically (overdependence as a security threat). Replacing oil with bioenergy could provide a modest fraction of the fuel consumed by vehicles, given the large land, water, and agrichemical inputs required (Lynd et al., 2002). Thus, China will not only need to continue pushing high fuel efficiency, but also take advantage of smart transport planning and transit-oriented development (Litman, 2006). (*Editor's Note: See Hongyan He Oliver feature article in this issue for more discussion of clean vehicle policy options*).

### Smart Growth for China's Urban Society—Strategic Reserves at Point-of-Need

Improving vehicle fuel efficiency is a necessary, but not sufficient action. There are similarly large savings that could accrue from applying "smart growth" design practices to cities and communities (Newman & Kenworthy, 1989; Muro et al., 2004). "Smart growth" encompasses all the quality-of-life services, amenities, security, aesthetics, health, and clean environment that citizens want in their communities, improving mobility and access for all, but without the sprawl, auto congestion, pollution, and fuel costs (Litman, 2006).

Some cities are pursuing smart growth opportunities, like Kunming in Yunnan Province, which has been working with its sister city, Zurich, Switzerland, over the past decade. The goal of the joint effort is to develop an economically, ecologically, and socially beneficial development process. Comparing the more successful cities in the world, Kunming officials recognized that cities with strong public transport tend to be among the better off cities, while those investing mostly in road construction are less well off (Kunming, 2001). Given China's immense urban growth over the next generation, there are massive energy efficiency benefits to be gained from promoting smart growth policies, incentives, and regulations (Litman, 2006).

A handful of international initiatives are ongoing to help municipalities begin smart growth. For example, the Energy Foundation has been working with municipal officials in Beijing, Kunming, Xian, Shanghai, and Chengdu to implement bus rapid transit systems, with plans to expand to 15 more cities. In this program, high capacity hybrid buses run in express lanes. While they cost about $0.12 to $0.19 more to ride than other buses they are much faster and more fuel-efficient (Turner & Ellis, 2005).

These initiatives can strengthen national security by combining smart growth development with super-efficient vehicles. These two measures guarantee their equivalent of secure, widely distributed strategic petroleum reserves (SPRs) (Lovins & Lovins, 1981). The opportunity to displace several billion barrels of oil per year with these gains is equivalent to maintaining nearly seven cost-free dispersed SPRs (Goldwyn & Billig, 2005), thereby helping to strengthen national energy security by making China more resilient to foreign oil disruptions and volatile price hikes.

## COAL GASIFICATION WITH CARBON CAPTURE & STORAGE

China's policy and research communities are already immersed in assessing the economic and environmental costs and benefits of technologically leapfrogging the country's massive coal-dependent economy into one of the cleanest, state-of-the-art, coal conversion systems on the planet—coal gasification with carbon capture and storage (CCS) (CCICED, 2003; Ni et al., 2003; NDRC, 2003). Gasification allows for:

(1) Effective and relatively cheap cleaning of coal;
(2) Use of advanced gas turbines and combined cycles for greater energy efficiency;
(3) Power production and fuel synthesis to be economically combined in a polygeneration plants, enabling synergistic efficiencies;
(4) The starting point for the synthesis of high quality liquid fuels; and,
(5) Using oxygen-blown gasification and advanced membrane separation of exhaust gases that produce a very clean stream of $CO_2$ that could be geologically sequestered at an economically acceptable cost.[10]

Applying the government's vast coal expansion plans to the scrutiny of a rigorous and transparent IRP process will ensure all costs and risks are accounted for, so the coal gasification initiatives that do go forward are done cost-effectively, are environmentally sound, and do not exclude other lower-cost energy service options. Applying the IRP process as swiftly as possible to electricity expansion is especially important given the large number of proposed power plants that will burn pulverized coal, not gasified coal with CCS.

IRP can also ensure a rigorous and continuous process for assessing the viability of government plans to increase coal consumption by 225 percent from 2005 to 2050 (Ni, 2005). Each 0.6 GW coal plant competitively displaced by a comparable energy efficiency "power plant" program, wind farm, or solar factory replaces 1.5 to 4 megatons per year of bituminous or brown coal, respectively, which are shipped in 15,000 to 40,000 railroad cars (WCI, 2005).

## HYDRO SERVICES

### The Potential of Integrated Resource Planning for Hydro Services in China

In April 2005, China's National Development and Reform Commission (NDRC) and four ministries issued a joint announcement—the *China Water Conservation Technology Policy*—a codification to promote a water conservation society. This document notes that developed countries generate some 10 times more economic value per unit of water than China. Moreover, 55 percent of irrigation water in China never makes it to the fields. Thus, there is "a great potential for water conservation" (NDRC, 2005).

The announcement embraces many components constituting an integrated resource planning (IRP) process for delivering cost-effective, efficient water services. These include full water pricing mechanisms, requiring water conservation and efficiency be actively implemented in all water-related projects, setting water conservation targets, and putting water management systems in place that all levels of government must adopt. However, the announcement ultimately falls short of actually establishing an IRP requirement since it fails to include: (1) a thorough and regular comparison of the costs, benefits, and risks of water supply expansion projects; (2) a full range of demand-side conservation methods; and (3) highly efficient techniques for delivering water services. Without these measures, water use will remain unbalanced, investments for

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FEATURE BOX

# Recovery and Use of Methane from Coal Mines in China

By Casey Delhotal and Barbora Jemelkova

Methane is the primary component of natural gas and is an important clean energy resource. With a global warming potential 23 times greater than carbon dioxide and a relatively short atmospheric lifetime, it is also a potent greenhouse gas (GHG) that accounts for 16 percent of all global, human-induced GHG emissions. A reduction in methane emissions would have a rapid and significant effect on the atmosphere's warming potential.

About 8 percent of all human-induced methane emissions around the world are emitted from coalmines, making coalmine methane (CMM) recovery and utilization an attractive and effective climate change mitigation opportunity. In addition to benefiting the global environment, such projects also increase mine safety and productivity, reduce operational downtime, mitigate local air pollution, and make available a local, clean energy resource. China, the world's leading emitter of CMM, is well suited to host CMM projects for a number of reasons:

- The estimated 26,000 active coal mines in China emitted approximately 13.5 billion cubic meters of methane in 2004, making the coal mining industry China's primary source of methane emissions.
- Projects that drain explosive methane from underground mines can help decrease China's staggering miner fatality rate—at least 7,000 deaths are reported each year, the most of any country.
- As China's economy continues to grow, its demand for new sources of clean and unconventional energy grows as well.

CMM Project Construction at Jincheng Mine in Shanxi Province.
©U.S. Environmental Protection Agency

## CMM Projects in China

Thirty projects that utilize CMM are reported to be operating or in development in China. The methane captured at project sites is currently used for electricity generation, thermal power production, town gas distribution, vehicle fuel, chemical industry feedstock, and boiler fuel. These projects collectively generate over 100 MW of power and reduce methane emissions by over 630 million cubic meters annually, equivalent to 1 million metric ton of carbon equivalent (MMTCE). The largest operating project drains 126 million cubic meters per year from Laohutai mine in Fushun, of which 59 million cubic meters is delivered to the Shenyang gas pipeline network for residential distribution. Once the second stage of the project is completed, coalbed methane (CBM) from nearby virgin coal seams will be blended with methane from mining operations to increase gas production by more than 3 million cubic meters per year.

### Barriers to CMM Projects

CMM recovery and utilization projects around the world, especially in developing countries, face a number of barriers to development. For example, project developers may find it difficult to identify and secure a sufficient mix and quantity of debt and equity to finance what are typically capital-intensive endeavors. For example, the capital costs of a power generation project—the most common type of CMM project in China—can be about $1 million per installed MW.

A project in Jincheng (Shanxi Province), slated for completion in 2008, is considered a success story when it comes to addressing this financial barrier. The project will use engines to generate 120 MW of power at the Sihe mine, reducing GHG emissions by an expected 2.86 MMTCE per year. When completed it will be the largest single CMM project in the world. The portfolio includes a $117.4 million loan from the Asian Development Bank, a $20 million loan from the Japan Bank for International Cooperation, a $37.86 million loan from the Industrial Bank of China, and equity capital from the Jincheng municipal government and two mining industrial groups totaling $61.24 million. Technical assistance was provided early on from the U.S. Trade and Development Agency in the form of a $500,000 grant to conduct project design and data analysis. In addition, the Chinese government has reached a general agreement with the World Bank's Prototype Carbon Fund to sell emission reductions that will be generated under the Jincheng project.

### Methane to Markets Partnership

To help overcome financial—as well as regulatory, legal, and technical—barriers to methane project development, the United States launched the Methane to Markets Partnership in 2004. Eighteen national governments, including China, Japan, Australia, and nearly 200 private sector organizations are working collaboratively to advance the cost-effective recovery and use of methane from four major sources: landfills, underground coal mines, natural gas and oil systems, and livestock waste. With the help of this initiative, additional viable methane recovery opportunities will be identified and developed around the world, and countries like China will have the opportunity to make a noticeable impact on their climate footprint.

*To learn more, visit the Methane to Markets website at http://www.methanetomarkets.org or the website of the Coalbed Methane Outreach Program of the U.S. Environmental Protection Agency (EPA) at www.epa.gov/cmop. Barbora Jemelkova currently works in the Office of Air in EPA and she can be reached at jemelkova.barbora@epa.gov. Casey Delhotal, a former EPA employee, is currently working for RTI International in Beijing on Methane to Markets activities in China; she can be reached at: cdelhotal@rti.org.*

water projects will be misallocated, and cost-saving opportunities will be missed (Gleick, 2003a).

An IRP strategy for water examines the least-cost means and lowest risk of providing the water service at the point of use. Therein arises a host of opportunities for securing considerable savings, such as dramatically reducing storage requirements and distribution losses. The State of California, a pioneer in IRP for electricity, has expanded the process into energy and water (CEC, 2005; CPUC, 2005). Extensive research found that 20 percent of the state's total electricity and one-third of total natural gas use were consumed in pumping, distributing, heating and disposing of the state's water (Wilkinson, 2000). The assessments also found that the energy intensive end uses of water (e.g., clothes washing and showers) consume more energy than any other part of the urban water conveyance and treatment cycle. Employing demand-side management programs to increase water efficiency can reduce significant amounts of water, energy, and air pollution, while accruing substantial monetary savings (Cohen, Wolff, & Nelson, 2004; Gleick, Cooley, & Groves, 2005).

### *Potential IRP Water Applications in China*

Construction has already begun on China's ambitious south-to-north water project that will take water in three canals from the Yangtze Basin and carry it 3,000 km to the Yellow, Huai and Hai river basins in the north (GWP, 2005). The $60 billion price tag for the mega-scale water transfer scheme has been criticized for using outdated and inaccurate assumptions, exaggerating water consumption predictions, and neglecting to perform an integrated resource plan that compares the full costs, benefits and risks of the scheme and evaluates various demand-side management options (Postel, 2005a). For example, rectifying the negative affects of black carbon on China's national water crisis has not been factored into the many studies affirming the need for the south-to-north water transfer scheme. Nor has comprehensive application of super-efficient drip and micro-irrigation systems been factored into water needs assessments.

Obviously, hydroelectric dams and reservoirs will continue to develop across China, where rivers are abundant, large populations are without adequate power and water access, and growth rates for electricity demand and agriculture expansion are high. Notably, nearly half of the proposed new dams worldwide are probably not cost-effective or necessary when evaluated against a large and expanding pool of water and energy efficiency options. Worldwide, some 1,500 km$^3$ (1,500 trillion liters) of irrigation water is wasted annually (Gleick, 2003b). In China, such waste is driven by: (1) inadequate investments, excessive subsidies, and artificially low water prices (70 to 80 percent below prices in other countries) that create disincentives for conservation; (2) balkanized government decision-making that hinders cross-sectoral cooperation on water conservation; and (3) broad-scale failure to inventory and capture lost water savings opportunities (Butler, 2005).

Dam building in China has increasingly caused conflicts among communities refusing to be resettled and environmentalists demanding more transparency in the decision-making process. These problems also underscore one of the finest attributes of the IRP process—its capacity for establishing confidence among all stakeholders. The transparent process of fairly evaluating all supply and demand-side options for delivering services at the least cost and risk performs a vital role in resolving heated conflicts. Equally valuable is the IRP process of expanding the portfolio of viable options relative to traditional approaches. This enables greater flexibility in selecting dams sites, as well as deferring or foregoing projects that will fragment or destroy biodiversity habitats of global significance or risk resettlement of large numbers of resistant communities.

## Drip-by-Drip—Super Efficient Irrigation

One measure of water efficiency is the water effective utilization index (EUI), which is the ratio of the amount of water required by crops divided by the amount of water actually consumed in irrigation. Across China, the EUI is about 40 percent, with canals at 30 to 40 percent. By comparison, EUIs in most developed countries are 60 to 70 percent and over 90 percent in Israel (Li & Zuo, 1997).[11]

Drip irrigation, embraced in the Chinese government's 2005 water conservation announcement, holds great promise for improving the water productivity of the agricultural sector by two to threefold. Worldwide, researchers have made steady progress in designing drip irrigation systems for water intensive crops that can translate into water savings between 30 to 70 percent compared to conventional flood irrigation systems, while increasing crop yields by 20 to 90 percent (Postel, 2005b; Postel & Richter, 2003). Drip-irrigation techniques also can integrate and more precisely distribute chemical fertilizer and pesticide applications, cutting unnecessary applications by more than half

(OECD, 2005). Currently drip irrigation accounts for only 3 percent of China's irrigated area.

Since the 1990s, Xinjiang Uygur Autonomous Region has made exceptional progress implementing water-efficient agriculture, such as drip irrigation and other water-saving methods on 1.3 million hectares of farmland. This has resulted in reducing irrigation per hectare fifteen-fold. According to northwest China's regional agricultural bureau, 5 km$^3$ of water per year have been freed up and used to plant trees to improve local ecology ("Xinjiang," 2000). Water-stressed Shandong Province also took an early lead in disseminating conservation techniques on three-fourths of its farmland, which accounts for one-third of China's total farmland (U.S. Embassy, 1996).

## Reduce, Reuse, Recycle Water

In 2005, six Chinese ministries, led by the Ministry of Water Resources, jointly confirmed a ten-year goal for saving water in industrial companies. The rate of recycled water is targeted to increase to 65 percent by 2010 (although Shanghai has reportedly already reached 80 percent). China's leaders recognize that charging the full economic cost of providing water and wastewater services is important for spurring water conservation and efficiency measures.

Increasing water charges requires a delicate balance of differentiating prices that ensure poor families can afford sufficient access while large water consumers pay higher rates. The country's average urban water price rose nine-fold between 1998 and 2004 ("Cities," 2004). Beijing has proposed raising the average water price another threefold to 6 Yuan ($0.73) per m$^3$ ("Beijing," 2004). While half of China's 660 cities have imposed wastewater treatment fees, most rates capture only a small fraction of the full processing costs (SEPA, 2004). Moving to full pricing of water and wastewater services is essential, but insufficient if not complemented with an IRP process. The IRP methodology helps prevent resource allocation failures, such as expanding more expensive water supply when a lower level of incentives can deliver a comparable level of water services through efficiency improvements.

While cultural, economic, and educational conditions are dramatically different between China and other water-stressed nations like Israel, there is much to be gleaned from close study and assiduous adoption of best practices that are transferable. For example, Israel has used full pricing of water along with other policy measures to steadily drive down water use by a factor of six—from 45,000 m$^3$ per million dollars of GDP in 1960 to 7,500 m$^3$ in 2000. In addition, reuse of treated effluents by Israeli farmers is 75 percent of total domestic, commercial, and industrial sewerage flows (Arlosoroff, 2002).

## Desalination of Wastewater

The Chinese government expects desalination of waste and seawater to play a more important role in resolving China's water crisis, and recently initiated a $7 billion project that will build new plants beyond the country's ten existing desalination plants. Treated seawater is expected to make up 37 percent of the water supply in coastal areas by 2020. China's desalinization capacity may increase 100-fold by 2020 according to the report, "China Seawater Utilisation Special Topic Programme," jointly formulated by the NDRC, State Oceanic Administration, and Ministry of Finance. The city of Qingdao will be a national-level seawater desalinization and comprehensive demonstration city, with seven desalinization plants built by the end of 2006 with a capacity of 200,000 m$^3$ per day.

Desalination costs vary by a factor of seven or more, depending on the: (1) type of feedwater (brackish, waste, or seawater); (2) available concentrate disposal options; (3) proximity to distribution systems; and (4) availability and cost of power. Desalination's primary operation cost is for power—one km$^3$ (1 trillion liters) of seawater desalination requires about 500 MW of power. The reduction in unit energy use by desalinization plants has been among the most dramatic improvements in recent years due to enhanced energy recovery systems. Estimates considered valid for China today range from a cost of $0.60 per m$^3$ for brackish and wastewater desalination to $1 per m$^3$ for seawater desalination by reverse osmosis (Zhou & Tol, 2003).[12]

Desalination of wastewater has double benefits—it reduces contaminated discharges into rivers and expands the city's freshwater supplies at lower cost than importing remote water resources. China's total wastewater discharges annually exceed 60 km$^3$, and as of the late 1990s less than one-seventh of this was treated. Close to 600 million Chinese people have water supplies that are contaminated by animal and human waste. Harnessing 30 GW of cogeneration available in cities and industrial facilities potentially could operate reverse osmosis technologies to purify these wastewaters, while also providing ancillary energy services like space and water heating and cooling.

### Hydroelectricity Services

China generates 280 TWh per year from nearly 100 GW of hydropower. By some estimates, between 200 and 300 GW may be constructed in the coming decades. Adoption of a rigorous IRP process could stimulate a many highly competitive energy service options capable of being delivered at lower cost and risk than hydroelectric dams.

A growing body of Chinese scientists are cautioning against over construction of large hydropower projects in southwest China—particularly in the Yangtze River Basin (Chen, 2005). Experts on China's endemic ancient Chinese sturgeon and paddlefish are warning about the irreversible loss of these incredibly large species (up to 7 meters) that travel for 3,000 km from the sea up the Yangtze River. These and other aquatic species are threatened with extinction because dams will block their migration routes.[13]

The threat of massive loss of China's freshwater biodiversity, due to a range of causes in addition to hydropower systems, was reviewed by CCICED, which concluded that China's aquatic ecosystems have received much less attention in comparison with terrestrial ecosystems, with only a handful of major surveys on fish. The marked decline in fish species combined with the inadequate knowledge of freshwater ecosystems underscores the great need for stronger conservation of China's aquatic systems (Ping & Chen, 1998).

> A growing body of Chinese scientists are cautioning against over construction of large hydropower projects in southwest China.

Given the pace and scale of proposed dam projects in southwest China, it is vital to undertake and complete rapid assessments of the freshwater biodiversity in China's river basins. This will help inform the decision-making process as to the risks and costs associated with biodiversity loss from specific proposed projects. In addition to species assessments, another critical factor to assess is a river's carrying capacity, or necessary flows to sustain ecological health.

While the Ministry of Water Resources now acknowledges the importance of ecological flows, flow levels alone are insufficient for sustaining or restoring healthy freshwater ecosystems. Flow modifications that disrupt the magnitude, frequency, duration, timing, and rate of change of hydrologic conditions also disrupt habitats to which the myriad varieties of life in and along the river have become adapted (Postel, 2005b).

### Watershed Forest Protection and Regeneration

China's water crisis has been a long time coming, from centuries of human impact, especially from wide-scale deforestation and conversion of wetlands and grasslands to agriculture. The past half-century has witnessed an incredible explosion in the pace of these actions with the effect of: (1) a steady increase in the ferocity and frequency of devastating flood and drought cycles; (2) immense sedimentation run-off that is causing more terrestrial landscapes to desertify, and more reservoirs to fill with silt that shorten the lifespan of dams; and (3) feedback effects from these diverse impacts reducing precipitation, that in turn trigger declining river flows (Ma, 1999).

To reverse these water degradation trends, the Chinese government undertook one of the largest reforestation efforts in the world, planting some 50 billion pine, eucalyptus, and poplar trees since the 1950s. Unfortunately, this sea of monoculture trees has suffered devastating setbacks over the past several decades from severe pest attacks, making the trees more vulnerable to drought and wildfires, resulting in hundreds of millions of dollars in annual losses. The monoculture of trees also has not regenerated important ecosystem service benefits like prevention of floodwaters and soil erosion, let alone regeneration of water tables or soil fertility. Yet another example of how IRP could have been applied to evaluate the full costs of a major investment initiative.

In 2005, China's State Forestry Administration (SFA) began testing the recently developed Climate, Community, and Biodiversity (CCB) standards. The standards help in the design and evaluation of more resilient, multiple-benefit, native forest restoration projects. SFA is beginning such projects in Yunnan and Sichuan provinces, and is considering incorporating the standards into national reforestation criteria to develop projects that concurrently fight global warming, conserve biodiversity, and help local communities (CCBA, 2005).

Funds for watershed forest protection and regeneration have been abundant, but also erratic over time.

A funding mechanism proving to be quite effective and durable in many parts of the world is the allocation of water rights that can be traded. This has been proposed for restoration of the Yellow River, given that downstream water users can produce far more per unit of water consumed than upstream users. While currently "illegal" in China since all water rights reside with the state, some small experimental water trades have occurred.

Important water trade covenants can be contractually agreed upon, whereby some of the payments go towards maintaining and regenerating the upper watershed's forests, wetlands, and grasslands in order to sustain the quality and quantity of water flows (Appleton, 2002). Hydroelectric dam operators can obtain significant economic benefit from promoting such protection of watershed ecosystems in that reducing sedimentation—a major problem for many of China's dams—can significantly expand the lifespan of dams (Ma, 1999).

## CONCLUSION: HARMONIOUS ENERGY AND WATER OPPORTUNITIES

China stands at a crossroad—environmental policies and investments begun today will determine the country's ability to stem the growing ecological and human health threats from air pollution and watershed damage. In terms of air pollution threats, China could leverage the "four efficiencies" along with solar and wind power to cost-effectively achieve World Health Organization air quality standards. The World Bank calculates the health benefits of avoiding exposure to fossil fuel particulates for urban residents in China, compared to an emissions-as-usual scenario, could rise to nearly $400 billion in 2020, equivalent to adding 13 percent to the GDP (World Bank, 1997).

Implementation of pro-environment and secure energy and water options in China would be greatly accelerated if the external costs and risks incurred from fossil fuel combustion and watershed deterioration and diversion were reflected in market prices. The CCICED working group on Environmental Taxes and Pricing has been focusing on this issue for several years and new recommendations are forthcoming. Actions towards internalizing costs of pollution and ecologically destructive practices in China would not only improve the wellbeing of its citizens, but also help the country become one of the world's largest exporters of economically attractive energy efficiency, solar, wind, and bioenergy technologies (Porter, 1991; CCICED, 2005; "Wind," 2005).

By taking on global leadership in the use, manufacture, and export of products that promote efficient use of energy and water, China could promote sustainable prosperity and security, as well as conservation of irreplaceable biodiversity—within and beyond China—for generations to come.

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## NOTES

1. The six bottlenecks include: rural development, development of central and western regions, social undertakings, science and technology, protection of eco-system and environment, and infrastructure construction.

2. The State of California, sixth largest economy worldwide, has been an unparalleled innovative policy leader in spurring high-performance building, appliance, and vehicle standards, as well as mandating utility efficiency and renewable energy incentive programs, that have accrued myriad environmental and economic benefits. While Americans consume 12,000 kWh per capita per year, the California economy steadily grew while flattening consumption to 7,000 kWh/cap/year as a result of efficiency improvements. In addition, California's zero emission vehicle laws pushed the auto industry to produce cleaner cars that ultimately stimulated a market for them globally.

3. If China comprehensibly pursues the 4Es, efficiency gains matching GNP growth rates could enable China's economy to grow 400 percent without increasing energy from current levels, while freeing up significant capital from the energy sector for further economic growth ("Energy Efficiency Stressed," 2005).

4. As an illustration, China has 500 million kW of installed electric motors, pumps, compressors, consuming 60 percent of the nation's total electric output. Upgrading the motor drive systems with high-efficiency components could displace 100 million kW—equivalent

to 332 coal plants each of 300 MW—with net savings of $10 billion per year on electricity bills.

5. EPPs represent the capacity for "delivering electricity services" through the installation of an aggregated number of high-efficiency motors, pumps, compressors, lights, electronic ballasts, and other electricity consuming devices located in myriad factories and buildings. Just as a 300-MW coal power plant will generate 1.8 billion kWh per year, a 300-MW EPP will effectively provide 1.8 billion kWh of electricity services through the design improvements embedded in high-performance equipment and devices. For a technical discussion see Koomey, Rosenfeld, & Gadgil (1990).

6. For example, in April 2006, the Beijing Development and Reform Commission visited Washington, DC to secure agreements with the U.S. Department of Energy, energy NGOs (such as the Alliance to Save Energy), and businesses that will undertake building retrofits to help the city reach new energy efficiency goals.

7. Important power sector reforms identified by WADE include: (1) distributed energy (DE) generators should be permitted grid access on transparent and non-discriminatory terms; (2) the locational benefits of DE should be recognized in system charging; (3) emerging industry structures should not entrench market control in the hands of incumbent utilities; (4) the transmission and distribution costs associated with central generation should be fully taken into account in any system planning; (5) fuel and power pricing should be determined by markets; (6) private and foreign DE investors should face no undue commercial, legal or regulatory barriers in carrying out their business; and (7) the overall output efficiency (including usable heat) of utility plants should be rewarded.

8. In the United States, for example, Class 4 winds generating power at an average of $0.04 per kWh produce 20 kWh per m$^2$ per year. With a royalty rate to the landowner of 2.5 percent of revenues generated, the wind royalty amounts to about $200 per ha per year. For comparison, net farm income in the United States was approximately $125 per ha, half of which were direct government payments ($60/ha) (Williams, 2001).

9. Since 2004, Chinese experts have been engaged with the German government in a $3 million joint project they believe will lay a solid theoretical ground for improving scientific understanding of China's pastureland ecosystem, and its protection and restoration (MOST, 2004).

10. China has considerable experience in modern oxygen-blown coal gasification, operating 9 GW for nitrogen fertilizer production in the chemical industry (Farinelli, 2003).

11. Beginning in the 1950s, the Chinese government established some 400 experimental irrigation stations throughout the nation. The data gathered enabled scientists to set baselines for major crops under varying ecological conditions.

12. Extrapolating from technological trends, and the promise of ongoing innovations in lower-cost, higher performance membranes, seawater desalination costs will continue to fall. The average cost may decline to $0.30 per m$^3$ in 2025 (Zhou & Tol, 2003). For comparison, China's average water prices were about $0.20 to $0.25 per m$^3$ for domestic and industrial use, and $0.34 per m$^3$ for commercial use, to a high of $0.60/m$^3$ in Tianjin and Dalian (Water China, 2006).

13. Professor Wei Qiwei, at the Yangtze River Fisheries Research Institute calls the continued damming of the river the "ecological desertification of the Yangtze" (Haggart, 2005).

FEATURE BOX

# China, Nanotechnology, and the Environment

By Louise Yeung and Evan Michelson

Nanotechnology, the emerging field of manipulating matter at the molecular or atomic level, has experienced tremendous growth in recent years. New nano-enhanced products, ranging from stain-resistant fabrics to anti-aging creams, are already available for purchase on store shelves and over the Internet. As this new technology advances, many experts are hopeful that the beneficial applications of nanotechnology will not only lead to new consumer products, but that they will also provide remedies to numerous environmental problems. Promising environmental applications range from the development of new energy storage and conversion systems to advanced water and air purification treatments. China—which is one of the world's largest investors in nanotechnology research and development, with the Chinese government spending nearly $250 million on nanotechnology in 2005—could greatly benefit from such nanotechnology applications in order to address the country's growing pollution and severe energy shortages.[1]

A Selection of Nanotechnology Consumer Products. © 2006 - David Hawxhurst/Wilson Center.

## ENVIRONMENTAL APPLICATIONS FOR NANOTECHNOLOGY

***Water Purification.*** With nearly half of its rivers running black at Grade V or worse, water pollution is one of China's major challenges. Many scientists around the world are seeking to develop effective nano-enhanced water treatment products. A variety of approaches are currently being explored, including the development of nanotechnology membranes for water detoxification[2] and the use of nanomagnets or charged nanomaterials to remove arsenic, oil, heavy metals, salt, and other pollutants from the water.[3] Unlike traditional filters, many of these newly created systems use charged nanomaterials to attract pollutants, which can then be easily extracted from the water. These nanomaterials can later be separated from the pollutants for reuse. Even more advanced purification methods, such as the use of zinc sulfide or titanium dioxide nanomaterials as catalysts to oxidize pollutants, may also be possible in the future. The advantage of this process is that it breaks down pollutants into less toxic substances.[4]

***Air Purification.*** Sixteen of the twenty most polluted cities in the world are located in China and coal burning for energy has caused acid rain in nearly two-thirds of the country.[5] To help mitigate these air quality problems, ongoing research is hoping to develop nanomaterials with the capability of oxidizing airborne pollutants by photocatalysis, a process that converts contaminants into less toxic substances.[6]

***Energy Efficiency.*** Energy shortages and air pollution from coal are central national security concerns in China. Nanotechnology's potential to improve efficiency in energy storage, production, and conversion are developments that may be crucial to China's future. Scientists are currently fine-tuning cost-effective nano-enhanced photovoltaic films to generate solar power that can be cheaply installed.[7] New nano-enabled materials promise to make rechargeable batteries more efficient and longer lasting.[8] Finally, by engineering materials, like metals or ceramics, to be more lightweight and durable, nanotechnology can increase the energy efficiency of buildings and their heating and cooling systems.

## CHINESE NANOTECHNOLOGY INITIATIVES

China's investments in nanotechnology have begun to translate into world-class research results in terms of published papers, paper citations, and patents. For instance, a review by the Asia-Pacific Economic Cooperation (APEC) in 2001 indicated that China followed only the United States and Japan in terms of the number of nanotechnology papers published that year. In 2003, the number of nanotechnology related patent applications from China ranked third in the world, behind the United States and Japan.[9] Efforts by both government and industry have been behind China's rapid ascent to becoming a global nanotechnology leader, most notable is the National Center for Nanoscience and Technology and private company investments.

***National Center for Nanoscience and Technology (NCNST).*** Established in March 2003 by the Chinese Academy of Sciences and the Ministry of Education, NCNST is a nonprofit organization housed within both Beijing and Tsinghua universities. NCNST conducts research in nanoprocessing, nanomedicine, and nanostructures. One of its main focus areas includes environmental application research that has, for example, led to the development of nanoporous zinc sulfide nanomaterials that can be used for photodegradation (disintegration of toxic substances in water using sunlight). These materials evenly disperse throughout water without clumping and they are slightly larger than other types of nanomaterials, which allows for both effective cleanup and easy collection and separation from toxins. In fact, similar materials are already in use as part of a self-cleaning glass coating on the newly built National Opera House in Beijing.

***Private Companies.*** As is the case in many countries throughout the world, Chinese firms are beginning to make the transition from basic research to the commercialization of nanotechnology. In March 2006, the Project on Emerging Nanotechnologies at the Woodrow Wilson Center released an online inventory that now contains nearly 300 manufacturer-identified, nanotechnology-based consumer products that are available on the market from 15 countries, including China.[10] Products in the inventory cover a wide range of sectors—from cosmetics and personal care items to dietary supplements and cooking supplies, from automotive and home improvement products to stain-resistant clothing. Large and small enterprises are buying, selling, and marketing internationally many such nanotechnology-based products.

## NGO FOCUS ON POTENTIAL ENVIRONMENTAL, HEALTH, AND SAFETY RISKS

While nanotechnology holds the promise to alleviate many environmental problems, some researchers and citizen groups are concerned about the potential risks nanotechnology poses to the environment and human health, because of the technology's ability to manipulate matter in a novel way. The effects of nanomaterials—when ingested, inhaled, or applied dermally—remain largely unknown, and there are currently no internationally coordinated risk research and oversight strategies designed to investigate and manage any potential environmental, health, and safety risks that may arise. While such risk research has been ongoing in the United States and the United Kingdom for a few years, China has only recently begun to invest in such research through the establishment of a Nanosafety Lab under the auspices of the NCNST in Beijing. Though much more work needs to be done in this area, any real or perceived hazards that may emerge in the near future may have the effect of hindering public trust in government and industry—both in more developed countries, such as the United States, and in more developing countries, such as China—to manage the effects posed by this emerging technology.

Moreover, while there is an increasing number of Western nongovernmental organizations (NGOs), such as Friends of the Earth and the ETC Group, focused on mobilizing their constituencies around this issue, it appears that Chinese NGO attention on nanotechnology is lagging. A number of Western environmental organizations have called for a moratorium, or even an outright ban, on nanotechnology activities until more risk research can be conducted.[11] Additionally, many organizations have argued that misleading advertising, a lack of accurate labeling, and few life-cycle assessments are all serious safety and oversight issues that must be addressed, particularly because the potential long-term negative effects of nanotechnology in humans and the environment remain unclear.

Since developments in nanotechnology are expected to become a key, transformative technology of the 21st century, China, the United States, and the rest of the world have the opportunity to work with industry, government, NGOs, and the general public to ensure that nanotechnology's benefits are maximized and that risks are minimized right from the start.

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## NOTES

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