Navigating the Policy Path for Support of Wind Power in China

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Power generated by wind energy costs about twice as much as coal-fired electricity in China. Yet it has flourished in a number of countries because of governmental policies encouraging its development. Such support is typically justified based upon consideration of environmental externalities, the nascent stage of the renewable energy industry, and subsides already received by conventional technologies. Price and quantity types of wind energy support policies are examined in this paper, along with their relevance for China's situation. A wind resource concession mechanism similar in many respects to current oil and natural gas concessions has been proposed for China as another method to promote wind energy development. In order to stimulate such renewable energy in China, a phased approach, shifting from near-term price supports to a longer-term, market-oriented approach, is necessary. China should employ a similar evolutionary strategy for the development of wind resource concessions.

The rapid economic growth in China requires a supporting energy infrastructure, and historically the country has met increased demands for electricity by burning more coal. Environmental and health concerns about coal at the local, regional, and international level have led Chinese policymakers (as well as international donors) to shift attention to cleaner, renewable energy resources such as wind energy.

Wind energy was the fastest growing type of energy technology in the world during the past decade, with a worldwide installed capacity of more than 31,000 megawatts (MW) by the end of 2002. China had installed approximately 460 MW by the end of that year, a level well below that of developed countries like Germany (>12,000 MW), the United States (>4,600 MW), or even other large developing countries such as India (>1,700 MW). Consequently, China's Tenth Five-Year Plan calls for more than a three-fold increase in wind power capacity by the year 2005. China has abundant wind resources and the environmental benefits of utilizing this renewable resource are likely to be considerable.

However, wind power energy costs about twice as much as coal-based power generation in China, and it simply cannot currently compete with fossil fuels. This is also the case in much of the rest of the world, where conventional energy technologies typically have lower costs than wind power. Yet more than 6,000 MW of wind power were installed worldwide in 2001, a one-year increase of 31 percent. In 2001, Texas alone was responsible for 915 MW, more new wind capacity than had ever been added in the whole United States in any single year.

The seeming discrepancy between the high cost and continual growth of wind energy arises because governments around the world value the potential environmental and health benefits associated with this renewable resource. Wind power has flourished because governmental policies, rather than purely free markets, have encouraged its development. There exists a myriad of governmental support policies for renewable energy, such as research and development funds, production tax credits, customs tariff and tax relief.[1] But the two most significant—and at times ideologically differing—governmental support policies for renewable energy systems (RES) are those which:

- Offer **price-based** support, typically in the form of a "feed-in" tariff for RES electric power supplied to the grid; or,
- Employ **quantity-based** obligations, often met through the trading of "green certificates" associated with RES power generation.

The question of whether to use price- or quantity-based supports for renewable energy mirrors previous debates in the pollution control arena. In some respects, price supports for renewable energy are similar to a price-based tax on pollution (i.e., Pigouvian taxation), and the quantity obligations for RES resemble emissions trading programs to limit pollutants. Such a parallel is not surprising since both pollution control and renewable energy programs are designed to utilize economic principles and mechanisms to accomplish environmental goals that would not otherwise occur in an unregulated setting.

While Chinese policymakers have traditionally tended towards price-based rather than quantity-based policies, a new idea surfaced in the late 1990s: the potential use of wind resource concessions (WRC). Under WRC, the Chinese government would offer exclusive access to wind energy resources for development, and put such concessions out for bid—much like it currently does for oil and natural gas resources. In a UN Development Programme (UNDP) report on renewable energy in China, Brennand (2000) argued that a WRC policy mechanism could spur the development of large-scale wind energy projects, with international commercial financing and very large state-of-the-art turbines. He suggested that very large-scale wind projects were necessary to bring about the next major reduction in wind-generation costs, and analyzed the economics of a 500 MW concession bid. His approach also suggested concession tracts of a hundred square kilometers or more—capable of supporting 1,000 MW or more of electric power generation from wind turbines.

China's State Development Planning Commission (SDPC)[2] drafted guidelines for WRC in late 2001, and they were the topic of discussion in a broad-based meeting held in Guangzhou in November of that year, attended by wind power developers, power sector representatives, environmental nongovernmental organizations (NGOs), and governmental officials (Raufer & Wang, 2002). While the national WRC guidelines still remain in draft form, specific guidance for two WRC projects was issued in late 2002.

This paper begins by comparing the experiences of different countries with pollution control price and quantity policies, and then examining the same policies for renewable energy program support.[3] After addressing wind resource concessions, and its potential linkage to price versus quantity supports, we discuss how price and quantity strategies could be utilized within a Chinese context, including linkages to other broader market-oriented policies. In the concluding analysis we present a plan China might follow to support wind energy development.

PRICE VERSUS QUANTITY FOR POLLUTION CONTROL

Societies have traditionally developed "command and control" pollution control regulations based on an approach very compatible with an engineering worldview: (1) governments first set environmental goals (typically in the form of environmental quality standards setting ambient pollutant limits); and (2) then accomplish these goals by instituting prohibitions and/or technology-oriented requirements (e.g., emission standards and design standards) to achieve and maintain the targeted pollutant levels.

In recent decades, however, economists have offered an alternative to the above technology-oriented regulatory approach. Instead of employing environmental quality standards, governments would ideally set environmental goals at the point where marginal costs of pollution abatement (MC) equal the marginal benefits of such abatement (MB). All of the concerns about public health and ecosystem damage could theoretically be incorporated into these curves. And since there is no "invisible hand" that guides society to the point where MC=MB, economists offer two alternative regulatory means to achieve it:

- A price-based mechanism, developed by the English economist Arthur Pigou (1920) in his classic text *The Economics of Welfare*; pollution taxes are therefore referred to as Pigouvian taxation.
- A quantity-based approach suggested by Professor John Dales (1968) of the University of Toronto, in his book *Pollution, Property and Prices*.

Although from an efficiency viewpoint these price and quantity mechanisms are different sides of the same coin, there are important differences in their application—particularly within the political arena.

In much of the world, price-based taxes have been the normal economic instrument for pollution control because of its favorable revenue collection characteristics. Governments initially collected revenues at relatively low tax rates, primarily in the wastewater/water pollution control area. These early efforts were often too low to affect pollution behavior. Over time, however, as the tax rates rose, they began to have an effect on the levels of pollution emitted.

In the United States there is considerable resistance to any economic mechanism that results in a wealth transfer from the private to public sector. American economic and political systems are also strongly oriented towards the use of as credit markets for pollution control. It is thus not surprisingly that the United States began to move towards quantity- rather than price-based regulation in the mid-1970s when the U.S. EPA adopted its emissions trading program (ETP). This program grafted an economic mechanism allowing marginal cost thinking onto the traditional command and control regulatory system. The emissions trading program was successful in allowing emission sources to utilize less expensive methods for meeting emission goals. The success of ETP led Congress in 1990 to adopt a quantity-based approach to control acid rain, which subsequently led to the application of quantity-based mechanisms to tackle the problem of tropospheric ozone (through the NO_x Budget and similar city and regional markets) in the late 1990s.[4]

Most European and other industrialized countries were initially skeptical of the quantity-based pollution control approaches. However, a major international shift occurred during the UN Framework for Climate Change Convention's second Conference of the Parties in 1996, when the United States laid out a position calling for "realistic, verifiable and binding" targets for greenhouse gas pollutants, but noted that "international emissions trading must be part of any future regime" (UNFCCC, 1996). This proposal subsequently laid the groundwork for the quantity-based approach adopted in the Kyoto Protocol the following year.

Since that time, the European Union and numerous price-oriented countries have become enthusiastic proponents of the Kyoto quantity-based approach for reducing pollution emissions. The EU has introduced plans to start a carbon-trading scheme in 2005, and individual European countries such as the United Kingdom and Denmark have already adopted emissions trading programs. Other EU countries are closely studying the idea.

This support for quantity-based programs has sparked a nascent market in carbon credits, with more than a dozen organizations acting as "brokers" and/or exchanges; other entities willing to "certify" the credits; and individual firms specializing in carbon sequestering and "sink" credits. Deals worth more than $100 million have been transacted since 1996, and more than 65 of these trades have been for quantities greater than 1,000 metric tons of CO_2 equivalent. (Rosenzweig, Varilek & Janssen, 2002). The credits typically sell for between $0.60 and $3.00 per metric ton of CO_2 equivalent. The volume of such trades has been increasing, and the success of the market-oriented, quantity-based regulatory approach for pollution control now seems assured.

Price Versus Quantity for Renewable Energy

Renewable energy systems are not yet able to directly compete on an economic basis with conventional energy systems in most parts of the world. However, environmental externalities are not usually included in comparing costs of the two systems, and conventional energy systems have received considerable subsidies from governments. If new, environmentally promising renewable energy technologies have qualities that deserve societal support, then a policy question arises how governments might provide it in an economically efficient manner—and the debate similarly occurs along price versus quantity lines (Hvelplund, 2001; Menanteau, Finon & Lamy, forthcoming).

Price-Based Wind Energy Supports in the EU

The European Wind Energy Association noted in 2001, 4,500 MW of wind power capacity was added to European electricity grids, an increase of more than 35 percent. Germany topped the list, adding approximately 2,650 MW. Fully half of all European wind power capacity in Europe at the beginning of 2002 was located in Germany. Spain was the second largest market for wind power in 2001,

Box 1. Price-Based Policies that Created EU's Wind Giants

Germany's Electricity Feed Law, first introduced in 1991, required electric utilities to purchase renewable energy at guaranteed prices equal to 90 percent of retail prices. In 1997, wind units were obtaining 0.1715 Deutsche Mark ($0.105) per kilowatt-hour (kWh) for the life of the plant—a significant incentive for development (Guey-Lee, 1998). Since April 2000, Germany's renewables law lays out a more complex approach, with (1) a distinction between onshore and offshore units, (2) tariff changes after five years of operation for certain units, and (3) tariffs declining over time as technology advances and turbine size increases (Ondraczek, 2002).

Denmark's Windmill Law required that its electric utilities purchase output from private wind turbine owners at 85 percent of the consumer price for electricity, with a comparable 1997 figure of 0.62 Kroner ($0.09) per kWh (Guey-Lee, 1998). The Danish wind market also has been strengthened by a combination of production subsidies, a carbon tax, and various tax credits (Morthorst, 1999).

Under a 1997 law in Spain, all renewable energy systems are paid a guaranteed price set between 80 and 90 percent of the average sale price of electricity. Spanish wind units have two means of receiving payment: one varies each year according to a government decree, and a second is based upon the average market "pool" price of electricity, with an added variable environmental premium (again determined by the government). Wind producers can choose between the two (Aubrey, 2002).

Box 2. Green Power Initiatives in the United States

Consumers can choose their electricity supplier at the retail level in a number of U.S. states, and many have chosen to purchase electricity generated from renewable sources. One such retail supplier, the Green Mountain Energy Company, has 500,000 customers in six states. The company sells power at a premium price, and ensures its customers that their purchases were indeed generated by renewable energy sources through a "Green-e" certification system operated by the Center for Resource Solutions in California. In another example, one also can go to the Internet and purchase Pure Wind^{sm} Certificates, issued by the PG&E National Energy Group. For $40, the purchaser can acquire all of the environmental attributes associated with the generation of one MWh of electricity generated by the firm at its 11.5 MW wind facility in Madison County, New York. Such voluntary schemes can work, but they usually do not produce the quantity of power generation sought by governments and renewable energy system (RES) advocates. In the United States, there are about 160 green-pricing programs run by utilities, which only have a market share of about 1 percent (Lobsenz, 2002).

installing more than 1,000 MW, raising total installed capacity to 3,300. Denmark follows Spain as third with a total installed capacity of more than 2,400 MW. Together, these three countries are responsible for about 84 percent of EU's installed capacity for wind power (European Wind Energy Association, 2002).

Not surprisingly, these three top wind power countries have had powerful and effective price supports designed to encourage wind development. (See Box 1). The recent growth figures indicate the success of such price-based supports, but even they do not convey all of the ongoing activity.[5] Although such price-based supports (typically in the form of feed-in tariffs, which support "feeding" energy into a grid) are not necessarily "fixed," the level of support is nonetheless quite high, and there has correspondingly been a dramatic increase in wind power capacity within the EU. Wind developers and the environmental community obviously hailed such development. But Denmark's wind production subsidy alone was costing more than 0.5 billion Kroner ($80 million) by 1998, and was rapidly increasing as new capacity was being brought on-line. Many have argued that such price supports are extremely costly, and are contrary to the EU's idea of a liberalized, market-oriented approach to energy systems. Therefore in the EU (and the United States) attention has begun to focus on the quantity-based mechanism.

Quantity-Based Supports in the EU and U.S.

The Netherlands introduced a successful "green certificate" system in January 1998, which was developed by the private electricity sector within the framework of their Environmental Action Plan. The system set a voluntary target of producing 1,700 Gigawatt-hours (GWh) for the year 2000 and green certificates (called Green Labels) were produced to match voluntary demand in the market. In 2001, a Green Certificates Body (GCB) was established by government decree in the Dutch transmission system operator. The GCB ensures that any quantities of electricity deemed "green" are backed by corresponding generation from renewable sources. Certificate holders are then exempted from the regulatory energy tax. Since this initial European effort, green certificate schemes also have been established, or are under development, in Austria, Belgium, Denmark, Italy, Sweden, and the UK.

One key policy question in such schemes is the source of the "demand" for the green certificates. As noted with the initial Dutch program, one source can be the voluntary actions of consumers who wish to purchase environmentally attractive energy. Such an approach has been adopted in many places around the world, often under the title "green electricity" or "green power." (See Box 2 for U.S. examples).

But a much stronger program can be developed if governments simply mandate that a certain amount of RES be employed, which is typically done by instituting a renewable portfolio standard (RPS), or what in China has been labeled a mandatory market share (MMS). In such a program, the RPS/MMS (or "quota," or "obligation") requires that some specific portion of the power must be generated utilizing RES. The government might require individual energy companies or consumers to meet such an obligation directly, but more frequently some type of green certificate trading is allowed. The obligation then constitutes demand in the renewable energy marketplace, and individual RES projects creating green certificates generate the supply. These markets are just as artificial as those for pollution allowances or credits—in both cases the marketplace demand is created by governmental fiat.

In the United States, the Senate passed a federal RPS in April 2002 calling for ten percent of electric power in 2020 to be generated by renewable sources. The U. S. Department of Energy predicted that the 10 percent RPS would lead to a fivefold increase in wind power generation (DOE, 2002).[6] However, because the Bush administration delayed its energy policy legislation until 2003, a national

RPS has not yet been adopted—such efforts are nonetheless proceeding in individual states. By January 2003, eleven states had developed their own RPS and three had set renewable portfolio "goals" (DSIRE, 2003).[7] Most attention has been focused on Texas, because, as noted earlier, it added 915 MW of wind power in 2001. This increase arose through a renewable portfolio standards (RPS) in the Texas Public Utility Restructuring Act, mandating that 2,000 MW of new renewable capacity be added in the state by the year 2009. New demand will be met through a quantity-based renewable energy credit (REC) market program, to ensure that the capacity was added in an economically efficient manner. Texas thus offers an example of a successful quantity-based approach, comparable to the successful price-based systems in Europe noted earlier. (See Box 3).

Approximately four years ago, the European Parliament also called for such binding RPS-type targets for all European countries. In the final negotiated compromise, these mandates became "National Indicative Targets" for renewable energy in 2010 ("European Renewable Electricity Directive," 2002). Individual country targets range from 5.7 percent in Luxembourg to 78.1 percent in Austria, with a European-wide goal of 22 percent. While the full-scale RPS has not been adopted for Europe as a whole, a number of individual countries are nonetheless proceeding with quantity-based trading backed by RPS-type requirements.[8]

In addition, two pan-European programs have attempted to foster such market-oriented systems. The Renewable Electricity Certificate Trading project simulated trading in Tradable Green Certificates over a live, real-time, internet-enabled platform. This industry-led (but EU-supported) project, which spanned an eighteen-month period, had more than 140 participants from 27 partners in 16 countries. It concluded that quantity-based systems were "more cost-efficient and effective in achieving RES-E [RES-electricity] targets for EU Member States than a feed-in tariff system."(Energy for Sustainable Development, Ltd., 2001). Similarly, the Renewable Energy Certificate System (RECS) is an industry-led, independent initiative launched in 1999, whose goal is to promote international trade in renewable energy certificates. Supporters of RECS believe that international harmonization of the certificate trade is achievable, and would deliver larger benefits than disconnected, individual national initiatives (Eurelectric, 2000).[9]

Price to Quantity Shifts for Renewable Energy Policy

Interestingly, like the transformation from price- to quantity-based mechanisms in pollution control, Europe also has become a battleground for a similar price to quantity transition—but the transition for renewable energy has not been proceeding quite as smoothly. Recognizing that its price supports were costing the country considerable sums, Denmark decided to make the transition from feed-in price-based support to a green certificate quantity-based market program in 1999. In part, this was seen as a means of getting the government out of an increasing budgetary problem. As Morthorst (2000, p.156) noted: "almost as important as the environmental aspects is the release of the [Danish] Government from the pretty heavy burden of subsidizing renewable technologies."

Not surprisingly, wind power developers led by the Danish Wind Energy Association were fiercely opposed to any such move away from price supports and towards a quantity-based market-oriented scheme (Krohn, 2001a). New wind project development plummeted as the industry was weaned from its price supports, and moved into an uncertain market. In Danish Parliament hearings in September 2001, the industry convinced the government that the quantity-based scheme was impractical (at least over the short term), and the new market-oriented system was placed on indefinite hold.

Similarly, the Swedish Energy Organization's National Association (SERO) called the proposed Swedish green certificates program "a catastrophe for wind power and small hydropower"(Krohn , 2001b).[10] Another group, the

Box 3. The Texas Renewable Portfolio Standard Success Story

The Lawrence Berkeley National Lab (LBNL) identified several key components of the Texas RPS program which made it a success: (1) strong political support and regulatory commitment; (2) predictable, long-term purchase obligations; (3) credible and automatic enforcement; (4) flexibility mechanisms (e.g., a long "true-up" period and REC banking); (5) certificate (REC) trading; (6) favorable transmission rules and siting processes; and (7) the production tax credit (Wiser & Langniss, 2001). The LBNL determined that some of the other state RPS programs do not exhibit such characteristics, and thus "may do little to instill confidence" within the renewable energy industry.

Swedish Association of Wind Power Equipment Suppliers, did not focus on market risks, but instead on the specific design of the program. It anticipated that much of the new renewable capacity would not come from wind, small hydropower, or solar units, but rather by substituting biomass for coal in existing coal-fired stations. This would require very little capital investment, and the market price of the green certificates would reflect this fact. The development of new wind power capacity would therefore almost certainly suffer, at least in the short term.[11]

Wind Turbines on Nan'ao Island in Southern China

The Swedish and Danish wind industries recognize that an international green certificate trading scheme might ul-timately be appro-priate—but they prefer a harmonized EU system rather than individual country systems. In the long term, EU governments will probably favor a quantity-based approach for wind energy development although such a shift to an EU harmonized green certificate system (lessening the burden of price-supports for wind energy) is unlikely to be implemented before 2010 (Krohn, 2002a). The United States will almost certainly continue to follow the quantity-based approach for wind energy.

Such quantity-based markets for renewable energy are not easy to establish, however. The evaluation of the Texas RPS program noted that not all U.S. states were as successful—quantity-based markets demand sufficient political support, strong regulatory commitment, and predictable, long-term purchase obligations. Introducing such institutional factors on an international basis—particularly in developing countries like China, with little quantity-based institutional experience—may prove especially daunting.

THE WIND RESOURCE CONCESSION IN CHINA

To date, the Chinese government has prioritized oil and natural gas investment over wind. Certainly, wind power has its drawbacks. While petroleum products are static, storable, fungible commodities sold in large-scale international markets, wind power generates electricity intermittently, requires localized consumption, and storage tends to be very expensive. Even without considering the cost of storage technologies, wind power typically produces electricity at a cost well above competing alternatives. Nonetheless, wind (which can be developed both on and offshore) tends to be much more readily accessible than oil or natural gas reserves, and resource assessments are therefore both simpler from a technical viewpoint and much less expensive.

In the short term, wind power development in China will necessitate some type of support (whether price or quantity). In order to encourage private sector development of wind energy, the Chinese government has introduced another policy—the wind resource concession.

In his UNDP report, Brennand proposed the use of wind resource concessions (WRC) in China in order to get investors to consider larger-scale projects and to encourage a mechanism that could exert strong downward pressure on wind generation costs. Brennend's WRC approach tackled the high cost problem primarily through size, since there are significant economies of scale evident in production costs. Thus, as noted earlier, he analyzed the economics of a large 500 MW facility, and discussed the development of even larger facilities in individual concession areas. Brennand suggested China adopt price supports to encourage a large amount of wind concession development and also local ownership.[12]

Quantity-based systems also have their own attractions, including the important fact that market-oriented competition applies downward pressure on costs and prices. Such markets would help make renewable options more vigorously competitive with conventional, fossil-fired technologies, and such competitive pressures are not readily evident in price support schemes. Brennand recognized, however, that neither price nor quantity support systems had ever been applied to concession arrangements of the scale envisioned in his UNDP report.

Brennand was nevertheless sanguine about future projects within China for two reasons: (1) wind power generation costs should continue to drop over time; and (2) when China is able to manufacture the larger turbines that meet international quality standards, it should be able to do so at relatively low cost.

PRICE VERSUS QUANTITY IN CHINA

Like European countries, Chinese policymakers tend to think in terms of price-oriented mechanisms. The Chinese government has virtually no experience in utilizing quantity-oriented policies in environmental, renewable energy, or other policy spheres.

China's pollution control efforts illustrate this preference. Like other countries, China initially adopted a command and control regulatory approach and subsequently modified it to include a pollution levy system (PLS), adopted in the late 1970s. This levy system was designed to target those emission sources not in compliance, and collected a fee based on each kilogram of pollution above the level targeted by the command/control regulations. The PLS was thus not a full-fledged Pigouvian tax (since it applied only to excess emissions). While, PLS might be viewed as an incremental efficiency improvement over command and control regulations, laying the groundwork for a priced-oriented economic approach, actual implementation of PLS has displayed many problems:

- Only about half of the total levy fees are actually collected;
- The fees have fallen behind inflation (since they have not been indexed);
- PLS is rarely enforced for township and village enterprises;
- Levy fees are well below the marginal cost of pollution control (and even below the operating costs of control equipment); and,
- Industries sometimes shut down their emissions control equipment, which costs more to run than the fines imposed by local environmental protection bureaus (EPBs).

In the late 1990s, the Chinese government attempted to revise the levy system in order to bring it closer to the economic ideal of Pigouvian taxation. These revisions included: (1) collecting fees on all emissions, not just "excess" ones, (2) increasing the levy rates, and (3) adjusting the emissions to account for pollution equivalency and geographical considerations. Pilot projects to assess the effects of such revisions began in Hangzhou, Zhengzhou, and Jilin in 1998 (Bohm, et al., 1998).

In recent years, however, there has been increasing interest in quantity-based pollution control systems in China due to the current quantity-based approach of the Kyoto Protocol and the role China could play in the international market for trading carbon credits. Multilateral organizations, international NGOs, and Chinese government agencies have initiated a number of projects designed to explore the potential role of emissions trading and other comparable quantity-based approaches. (See Box 4).

Renewable Energy Price Supports in China

In the renewable energy area, China is currently pursuing small-scale, incremental steps along both price and quantity paths. On the price side, since 1994 Chinese policymakers have supported favorable prices for wind power generation by mandating that utilities purchase power generated by wind units. However as one Energy Foundation report notes, this wind power mandate is "a rule that is not currently followed or enforced" (Zhang et al., 2000, p.77). The country has never developed a fixed,

Box 4. Emissions Trading Projects in China

• *The Asian Development Bank* (ADB) supported an initial exploratory project of this approach, including analyses in Shaanxi province and other locations. It is currently funding an evaluation of emissions trading to address acid rain concerns in Shanxi and Anhui provinces, and its efforts in Taiyuan are raising international attention ("A Great Leap Forward," 2002). ADB case studies identified at least nine situations in China where the emissions trading approach has been applied, in as many provinces (Fernando, et al., 1999).

• *The Chinese government* also has indicated an interest in applying such quantity-based mechanisms at the national level to address the problem of acid rain. In late 1999, SEPA conducted a workshop in conjunction with the U.S. EPA, and the workshop explored how China's market reforms might provide an opportunity to utilize quantity-based mechanisms to address SO_2 emissions, much as the United States had done earlier in the decade. At its conclusion, the two national regulatory agencies agreed to work collaboratively on a feasibility study addressing such an approach (Yang & Benkovic, 2002).

• *Environmental Defense*, together with a Chinese NGO (Beijing Environment and Development Institute), is working with SEPA to develop strategies for implementing China's Total Emissions Control (TEC) policy, including emissions trading (Dudek, et al., 2001). They developed pilot trading activities in two cities, Benxi and Nantong, and are currently working with universities and research institutes on a number of emissions trading issues.

high feed-in tariff at the national level to foster the development of wind power, but instead provides favorable power purchase agreements (PPAs) on a project-specific basis, spreading out the burden of the higher prices over the grid. But the status of PPA agreements currently presents a significant concern for foreign investors in China. Meizhou Wan, for example, is a 725 MW coal-fired power plant built in Fujian province,[13] in which the owners held a 20-year PPA with the Fujian Provincial Electric Power Bureau. Yet the province apparently backed away from the agreement when the facility was completed, because there was no longer a power shortage in the area.

The "burden-sharing" of high price PPAs for wind power also has become problematic. In May 1998, China received World Bank/Global Environment Facility (GEF) loans under the China Renewable Energy Development Project (REDP) to build five wind farms: 100 MW at Huitingxile in Inner Mongolia; 50 MW at Zhangbei in Hebei province; 20 MW at Pingtan in Fujian province; and 20 MW at two sites in Shanghai. Unfortunately, the Huitingxile, Zhangbei, and Pingtan facilities ran into problems when SDPC decided to restructure the North Power China Grid. As the project restructuring document noted, in deleting 170 of the proposed 190 MW "[the higher price] could not be spread over the regional grids. This created difficulties in concluding PPAs with the provinces, especially for the large windfarms in the REDP" (Sumi, 2001, p.1). This same document suggested that such problems highlighted the need for a national, rather than grid or project-oriented policy framework.

Renewable Energy Quantity-Based Approaches in China

On the quantity-based side, China's Tenth Five-Year Plan includes a proposal for a mandated market share/trading mechanism for renewable energy. The World Bank and GEF are supporting such an approach under the China Renewable Energy Scale-Up Program.[14] Although this program is ongoing, a renewable portfolio standard (RPS) has not been able to garner significant political support, given both the uncertainty about the electric power restructuring and the recognition that an RPS would ultimately bring about higher costs—the exact opposite intention of the restructuring efforts.

Whether such quantity-based approaches in the pollution control or renewable energy areas will become feasible in China remains to be seen, given the considerable rule of law compliance problems, the uncertain status of property rights within the country, and the unfamiliarity with such artificial market systems that are created solely by the government. Nevertheless, growing international acceptance of quantity-based systems for renewables, as well as China's ongoing push towards a market-oriented economy, certainly encourage such developments. This shift in China will take time, for even the United States spent almost twenty years developing its own quantity-based system for pollution control, moving first through a "controlled trading" stage before tackling the full quantity-based system.

LINKAGES TO CDM AND CARBON MARKETS

The potential use of market mechanisms in both the pollution control and renewable energy arenas presents some challenges and innovative options for individual countries. For instance, while customers may be willing to pay more for "green" electricity generated by wind farms or solar panels, it is not possible to ensure that the specific electrons delivered to them were from renewables—in an electrical power grid it is impossible to track the linkage between a specific producer to a particular end user. Such tracking is not necessary under the "green certificate" market approach, in which a RES (such as a wind power unit) produces two individual products for two different markets: (1) the electricity, and (2) an "environmental" commodity of some type, represented by the green certificate. The electricity is traded and consumed locally and its price is typically based upon traditionally regulated tariffs. Conversely, the environmental benefits reflected in the certificates can be sold in local, national, or even international markets, depending upon how the commodity is defined and certified. As such, open market forces can determine the value of green certificates, and the income derived from such a commodity could provide funds for additional wind power project development.

While green certificates promote renewable energy development, they also could be viewed as a quantity-based market for pollution control, especially if an RES displaces some alternative pollution-generating energy facility. The Kyoto Protocol, which aims to lower the emissions of greenhouse gases, encourages this type of green certificate approach by allowing renewable energy systems to sell their pollution reductions in an international marketplace. Specifically, the Kyoto Protocol has three "flexibility mechanisms" designed to establish such a global marketplace for carbon dioxide (CO_2) and other greenhouse gas emissions: (1) international emissions trading (IET); (2) joint implementation (JI); and (3) one most relevant for China, the Clean Development Mechanism (CDM). Under CDM, individual energy projects can offer "certified emission reductions" (CERs) associated with individual projects. To offset their own carbon emissions, Japan or Germany, for example, might purchase CERs generated from a wind farm in China.

China's potential role in CDM has drawn considerable attention in recent years. Woerdman (2000) examined potential markets evolving from the Kyoto Protocol flexibility mechanisms and suggested that, "CDM is about 3 times as cheap as JI, and about 6 times as cheap as IET." Countries such as China would thus be well situated to benefit under the development of such carbon markets. China alone could gain about $4 billion in 2010 from the carbon-trading market (Edmonds et al., 1999). Zhang (2000) estimated that China could capture 60 percent of the CDM market by itself, leading some to analysts to cynically suggest that CDM as an acronym really stood for a "China Development Mechanism."

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Events since the Bonn and Marrakesh international climate change negotiations in 2001 have dampened the enthusiasm for CDM initiatives. First, and perhaps most importantly, the U.S. withdrawal from the Kyoto Protocol significantly dropped the demand (and hence the price) of carbon credits in the marketplace. The technical compromises at Marrakesh necessary to accomplish political agreement on moving forward with the Kyoto Protocol also had the effect of easing demand for CDM credits, and many believe that CERs will be "crowded out" by the relatively cheap carbon credits available from Russia and Ukraine, at least in the short term. Thus, the market in carbon credits will be much smaller, and generate much less revenue for energy projects in developing countries such as China.

Nonetheless, multilateral and bilateral donors are still interested in implementing this flexibility mechanism, particularly in China. Several CDM projects currently underway in China include:

- Power sector projects (funded by the World Bank, Germany, and Switzerland);
- Provincial-level energy efficiency and renewable energy projects (funded by the Asian Development Bank);
- Transportation and carbon sequestering projects (funded by Canada); and,
- Energy conservation (funded by the UN Foundation and UNDP).[15]

Since the green certificates discussed above represent some type of "environmental commodity" associated with the wind power facility, then an obvious policy question arises whether carbon is already "bundled" within the green certificate, or whether it can be "unbundled" and sold in the CDM marketplace. This issue has received considerable attention in both the United States (Center for Resource Solutions, 2001) and Europe (Eurelectric, 2000).

Unbundling multiple environmental attributes offers the advantage of delivering multiple income streams to a renewable energy project, which is important since RES projects tend to be expensive when compared to other greenhouse gas and pollution control options, and are only marginally profitable. Unbundling, however, does pose a number of challenges. Specifically, even under a straightforward green certificate transaction, there exists the possibility of "double counting." This might occur if one MW of wind power is sold to two customers, or if one customer used that MW to meet two regulatory requirements (e.g., an RPS *and* pollution control requirements). Under an unbundled scenario the opportunities for such double counting increase significantly.[16] Other problems might occur as well, particularly in regulatory areas where pollution control markets already exist.[17] The certification, verification, and certificate tracking systems for green certificates therefore must be designed to prevent such double counting actions.

Whether it is worthwhile to bundle or unbundle carbon depends ultimately upon the goals of the government program. For example, China might decide to support RES in order to: (1) foster technological development in the energy field, (2) develop an electric grid that is resilient and has a greater mix of energy technologies, and (3) improve environmental conditions in urban areas. If environmental benefits associated with greenhouse gas control plays a relatively small role in the Chinese government's priorities for renewable energy development, then it might be willing to unbundle the carbon to sell in international markets.[18]

If China eventually plays an important a role in the international CDM market, the country will receive many benefits. The clean development mechanism not only could help support market-oriented energy efficiency and renewable energy projects, but also might introduce to China environmental accountability and transparency at levels meeting international commercial standards. The policy and institutional development necessary to support emissions trading markets for the Kyoto Protocol should prove useful for the development of comparable markets for renewable energy systems in China.

BUILDING SUPPORT FOR WIND POWER IN CHINA

Wind resource concessions (WRCs) only indirectly deal with the principal problem of wind power development in China—its high price. Such concessions aim to encourage more private sector development of large-scale wind power units, backed by international financing, which could lower the costs and make this renewable resource economically competitive. The WRC strategies, however, do not deal with the current situation in which wind cannot compete with traditional fossil-fueled units. Therefore some sort of "support" policy (whether price- or quantity-based) is still necessary in China.

Price supports might be preferable in the early stages in order to favor the development of a wind industry, not only to promote an environmentally friendly industry, but also to create jobs. Studies in Denmark estimate that 17 person-years of employment are created for every MW of wind energy manufactured and about 5 person-years for every MW installed (Krohn, 1998). Given such numbers, the European Wind Energy Association and Greenpeace (2002) suggest that China could be employing almost a quarter of a million persons in a localized wind industry by 2020.

Fully 70 percent of all wind power generation in the world today is located within Europe, and 84 percent of that amount is found in only three countries—Germany, Denmark, and Spain. These countries developed strong price supports and established strong linkages between national energy policy and industrial policy. While these three European governments have successfully promoted the wind industry, the failure of the much-touted MITI industrial policy model in Japan has made many economists leery about government efforts to assure industrial success in other countries such as China. China is currently making the difficult transition from a centrally planned to a market-oriented economy, and calls to provide special subsidies or government favoritism to industries—no matter how well meaning—are met with special wariness among policymakers and even wind developers.[19]

Nonetheless, China's existing wind industry needs government support in the short term in order to grow, and as the previous EU discussion illustrated, the price support mechanism can stimulate wind power development. Moreover, price supports may have dynamic efficiency advantages over more market-oriented policy approaches (Menanteau, et al., forthcoming). Notably, China has historically relied upon price mechanisms, and has virtually no experience with quantity-based

Table 1. Policy Transition for Wind Power Development in China

	2003-2007 The Take Off	2008-2014 Maturation Phase	Post 2015 RES Markets
Government Priority	Develop wind industry	Provide cost effective wind power	Regulatory support for full-scale RES markets
Wind Power Project Size	Small (<40MW)	Medium (40-150 MW)	Large (>100MW)
Wind Resource Concessions	Narrowly defined, site-specific project development rights	Broader, with assessment risks taken on by bidders	Large-scale tracts
Price-Based Support	Extensive national program	Shift towards provincial governments	Lesser role
Quantity-Based Policies	Participation in Clean Development Mechanism (CDM)	Participation in CDM; Provincial-level experimentation with Revewable Portfolio Standards (RPS) (with renewable energy credit/REC trading)	Participation in CDM; Further development of RPS (as needed) with REC trading

instruments. The latter are much more difficult to implement within China's current governmental and industrial structure. Thus, we believe China should adopt a price-based support program in its early stages of fostering wind industry development. Eventually, however, Chinese policymakers should move policies towards the more market-oriented quantity approach, following the same transition currently occurring in Europe. Such a transition could take place in three phases over the next twenty years. (See Table 1).

2003-2007—The Takeoff

The European Wind Energy Association and Greenpeace (2002) suggest that 2004 could be the "takeoff year" for large-scale wind power development in China, but given the problems identified in a recent Tsinghua University report (Ni, et al., 2000) addressing slow implementation of WRC, this seems somewhat optimistic. Wind developers, somewhat disillusioned with China's progress, have labeled the country a "perennial 'also ran'" (Gipe, 2002). The authoritative annual survey *International Wind Energy Development* characterized China's wind development status as "slow," primarily due to institutional barriers (BTM Consult ApS, 2001). A number of Chinese researchers have called for institutional changes within the Chinese government for wind energy (Gan, 1999; Liu, Gan, & Zhang, 2002). To stimulate wind power the first order of business will be to bring the country's "institutional house" in order.

If wind power is to play an important role in China's near-term future, it must have an institutional champion that has sufficient power and authority to bring relevant policies into existence and ensure that they are implemented nationally. The current power sector restructuring offers an opportunity for the creation of exactly such an entity. Given the political complexities incumbent in such a transition, this paper does not offer a definitive institutional restructuring scheme. Instead, however, we suggest that an institution (such as a new office within the recently established State Electricity Regulatory Commission) should have as its fundamental purpose the promotion of wind power generation within the electricity sector. Its tasks might include:

- Enforcing existing regulations that encourage the use of wind power;
- Creating new regulations to foster wind power utilization;
- Developing standardized power purchase agreements, concession contracts, bidding materials, and similar documents for wind utilization;
- Increasing wind generation capacity within each of the sub-regional grid systems;
- Serving as an institutional base for coordinating governmental efforts on wind resource concessions; and,
- Tracking the localization of wind turbine production.

Perhaps the most important initial focus of this organization should be the development of a broad, project development scheme designed to bring market-oriented wind power experience to a wide range of institutions throughout the country. Germany has found that its strong support program has encouraged wind power development even in areas of lesser wind speed. Similarly, these initial projects in China should be relatively small-scale, designed as much to "prime the pump" of the country's wind turbine industry and to foster institutional development as to provide cost effective electrical power.

Although SDPC's new WRC guidelines are applicable only for projects greater than 50MW, numerous smaller projects should be included in this early phase. While small projects are less efficient, they ensure that financial risk associated with any individual project effort would be small. One developer privately suggested to us that small developments in China would help to remove the intense political pressure that normally accompanies larger-scale development projects.

This wind power development program should be based on national price supports. In order to create a strong wind power market, Chinese policymakers should try to develop the internal capacity to implement such a program and should begin to limit their wind power's dependency on foreign donors and multilateral agencies for support.[20] There is still an important role for institutional support from these groups and NGOs, and project funding not linked to specific vendors; but ultimately, Chinese wind power development must depend upon Chinese resources. The relatively small-scale project sizes envisioned in this early phase should be awarded on the basis of competitive bidding. The bid requirements could be fashioned to cover a range of project characteristics, including turbine size, location, ownership, technology, and financial arrangements. Virtually any privileged project arrangement can be termed a "concession," and the ability to narrowly define these characteristics would be useful in these early-stage projects. Concessions under the WRC would thus initially represent little more than specific "project development rights" at a specified site, but these should still attract a

Box 5. Future Transformation of the Wind Industry

Andersen and Jensen (2000) have examined the development of wind power worldwide since the early 1960s, and then tried to extrapolate how such development might continue through 2030. Such an exercise is fraught with peril, for new ideas or technological shifts might radically change a given technology. They note, however, that all of the imaginable concepts of wind turbines were available in the early 1960s, and that "no really new concepts have been developed since then, and only a few concepts have a significant market share today." They suggest that the technology of the future will increase design flexibility along three fronts (structural, drive trains and controls). Moreover, over the next decade the expansion of wind markets and new companies will lead to a greater availability of both wind energy concepts and designs. Over time, however, as the market matures, only a few companies would establish a dominant position. Their view is essentially one of incremental technological change, with at least one more scale up of turbine units, into the 4-6 MW range.

mix of domestic, joint venture, and foreign developers in response.

China could use this takeoff phase of development to meet its Tenth Five-Year Plan commitment of providing 1,500 MW by 2005, and continue such efforts in following years until both the institutions and wind industry capabilities are more firmly established.

2008-2014—Maturation Phase

With an institutional base established, the developing Chinese wind industry should be well positioned to move towards larger scale projects. These would still require price supports, but the focus on larger projects and bigger units would dictate an increasing attention to the wind resource for site selection. These projects also would rely on a tendering system, although the concept of the "concession" should be broadened in this phase to shift the wind resource assessment task (and attendant risks) onto the bidder.

As the projects increase in size and are sited in better locations, production costs associated with wind power should drop, and the "burden sharing" associated with wind power also should shift away from the national government and towards the grid region/provincial level where the power is generated and used.

During this phase China should watch the development of quantity-based markets for renewable energy, particularly as these go into effect on a broader scale in Europe. In the early years of the next decade, China might begin to experiment with a quantity-based renewable portfolio standard (RPS) within a specific province or regional grid. Such a quota should be opened to all renewable energy systems, not just wind power.

Post-2015—Shift to the Market

With a mature regulatory infrastructure, more than a dozen years of experience with a restructured power sector, and a Chinese renewable energy industry developed through price supports, the time would be ripe to move this industry further towards a market orientation, and the type of WRC envisioned in Brennand's report.

The current decade promises to be exceedingly vibrant for the wind turbine industry worldwide, driven by market expansion and growth. (See Box 5). China is obviously in a "catch-up" position now with respect to its wind development industry. However, over the long term China can take advantage of the growing dynamism of the wind power industry and technology. Moreover, China's great need for an environmentally acceptable alternative to coal and ability to manufacture high technology goods at low cost suggest that the country is very well positioned to broaden its wind power sector.

In a post-2015 world, the principal question is whether wind will need the "artificial markets" of an RPS or quota system or whether it will be able to fully compete against conventional energy technologies. If China manages to reform its environmental protection infrastructure and forces industry to fully "internalize" pollution externalities, then its wind sector could be competitive. Realistically, its environmental program will face considerable difficulties in making adjustments for a variety of structural and contextual reasons (Jenner, 1992; Sims, 1999; Raufer, Zhuang & Tang, 2000). As China's economy grows it is likely to come under increasing pressure from the international community to more actively participate in the international framework for climate change mitigation, moving towards certain greenhouse gas emission controls, or at a minimum, expanding the role of CDM.

If China opts to participate in CDM projects and employ controls on greenhouse gases, a transition from a price- to a quantity-based renewable energy support program, coupled with WRC, would be feasible. At that time, China could decide whether it should bundle or unbundle the carbon in any renewable energy credit (REC) program it developed. Either way, the REC programs will create commodities that can be traded in the international markets, which will strengthen China's wind energy sector.

Conclusions

Given China's projected energy needs and the important environmental benefits associated with wind power, it is apparent that wind resource concessions (WRC) deserve further governmental attention. Such concessions could act as a renewable energy policy mechanism to push China's private power developers to utilize international commercial financing to invest in large, state-of-the-art wind units.[21] The cost savings of WRC would help promote the use of turbines manufactured within China, which would meet international quality standards but at a price lower than that of international competitors.

It seems unlikely that a WRC program alone would be able to accomplish such a major transition in China. Such concessions only indirectly address the most important problem with wind power—its high price. Moreover, the scale economies and siting advantages garnered through WRC alone will not overcome the fact that these units cannot currently compete with fossil fuel energy. Therefore, wind units within concessions initially will require government support. Both price and quantity mechanisms are available to provide such support, but China will have to create stronger government institutions to increase the development of the wind industry. In short, addressing the new forms of policy support requires that Chinese policymakers tackle the country's institutional infrastructure.

This paper therefore suggests a relatively measured, slow, "learn-as-you-go" approach for developing wind power. China should initially adopt a price-based support program (2003-2007), fostering industrial development in wind energy. There should be numerous relatively small-scale projects designed to give the country time to build up its institutional infrastructure in this area.

A second phase (2008-2014) would move towards larger-scale projects, more rigorously sited. The emphasis would begin to shift from institution building towards more cost effective power delivery. More risks would be shifted towards the concessionaire, and in the latter stages, the government would begin to move more towards a market-oriented quantity approach, beginning RPS-type pilot projects in individual provinces or regions.

Having learned from the U.S. and EU experiences with market-based approaches, in the post-2015 period China will have developed industrial and institutional frameworks, moving towards a fully market-oriented system for wind energy. To complete this transition China will need to do the following:

- Create a support scheme, national in scope, with a commitment to wean the nascent wind industry from donor and multilateral agency funding support;
- Change the nature of the concessions granted over time, beginning with narrow "project development rights" in the initial phase, but moving towards large-scale concession tracts similar to oil and natural gas concessions after 2015; and,
- Empower an institutional "champion" for wind power charged with increasing the installed capacity of this renewable resource and implementing the wind power concessions.

China should aim to make the transition from price- to quantity-oriented support over time, when it has developed both the industrial and institutional capacity to do so. If it follows such a plan, then China will be well situated to assume a dominant position in this important renewable energy industry in the future—one which will help the country meet its growing energy needs in a sustainable manner, serve to reduce its unwelcome reliance on coal, and provide an environmentally appropriate livelihood for hundreds of thousands of its citizens.

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Endnotes

[1] To see a recent overview of these forms of government supports within China, see a recent Packard/Energy Foundation report addressing renewable energy development (Zhang, et al., 2000).

[2] In 2003, to reflect its changing mission SDPC was renamed the Development and Reform Commission (SDPC).

[3] These programs are inextricably linked. As discussed below, for example, the design of markets in renewable energy credits (RECs) established to support wind power could have implications for the greenhouse gas markets established under the Kyoto Protocol's "flexibility mechanisms," depending upon whether the carbon dioxide is "bundled" or "unbundled" within the definition of RECs.

[4] See Raufer (1998) for a discussion of these programs.

[5] A ministerial order published in France in April 2000 imposed an obligation on EDF and independent distribution system operators to buy electricity generated by renewable energy systems. The French government had an objective of establishing a base of more than 5,000 MW of wind power in 2010, but by October 2001, it had already received offers for 13,000 MW because of the attractive pricing structure. Project offers have continued to come in since that time, and limited grid capacity is now a major factor affecting wind power development in the country (Belhomme, 2002).

[6] Coal utilization is expected to decrease by 5 percent, as firms shift to co-firing biomass in their existing coal-fired units to meet the mandated target.

[7] The eleven RPS states are AZ, CA, CT, IA, ME, MA, NV, NJ, NM, TX, and WI; the three states with goals are HI, IL, and MN.

[8] See, for example, renewable obligation certificates issued to the generators by the Office of Gas and Electricity Markets (Ofgem, 2002) in the UK, and tradable green certificates issued by the national grid company GRTN under the Bersani Decree in Italy (Salvaderi, 2002).

[9] RECS began with voluntary efforts in individual countries, but is now moving towards a more formal international marketplace through an Association of Issuing Bodies. RECS has 135 organizations participating in its program, from 20 different countries.

[10] Sweden's plan was designed to increase electricity production from renewable sources by 10 TWh from 2003 to 2010.

[11] Such design concerns could always be addressed, of course, by making such co-firing ineligible, or by introducing separate purchase bands for wind power.

[12] Since the implementation of bidding for WRCs would be affected under price supports, he suggested that bidding might be conducted on the basis of two variables: (1) a discount off the fixed payment, and/or (b) a curtailment of the period over which the fixed payment would apply.

[13] The first power station in China to receive limited recourse, private-sector financing from ADB, the $700 million facility was developed on build-operate-transfer (BOT) principles, and was the first fully foreign-owned power project to receive approvals from the State Council and the State Planning Commission. It was also the first international power station in China to receive both direct equity investment and debt financing from the Asian Development Bank. (See InterGen, 2001).

[14] This program is part of the World Bank's Strategic Partnership for Renewable Energy with GEF, which began in 1999 and is

designed to shift projects away from one-time interventions and towards longer-term, programmatic approaches.

[15] See the Environment, Science and Technology Web site at the U.S. Embassy [Beijing] (2002).

[16]The Center for Resource Solutions (2001) conducted an extensive analysis of the forms of double counting, and suggested that these would fall in a category labeled "partial double sale." CRS identified both actual and perceived partial double sales. For example, a perceived double counting might occur when a green certificate customer purchases the certificate because of global warming concerns, yet is not aware that the carbon credit has been sold separately, and that their action therefore has no climate change value. Preventing double counting depends primarily on tight regulatory oversight of transactions, and adequate information for the customer.

[17] In the United States, for example, both SO_2 and NO_x markets already exist, and any claimed reduction in these pollutants from RES offsetting fossil-fueled power generation may not occur unless their pollutant allowances are also retired; otherwise, the corresponding pollutant reduction might just be sold to another emission source.

[18] In the Texas REC system, all of the environmental attributes associated with the renewable energy system are bundled, and remain with the REC (Holt, 2001). This has been the case with most of the renewable portfolio standards (RPS) developed to date.

[19] Wind development supporters often try to keep their distance from avowed advocacy of such industrial policy approaches. Denmark currently has a 50 percent market share of wind turbines worldwide, but Danish wind industry representatives claim that there was never any "clever, co-ordinated, long term political planning," and that, instead, Denmark was simply lucky in terms of timing and in hitting the commercially right technology (Krohn, 2002b). Academics have similarly proposed that Danish governmental wind support was never a "means-ends, rational choice activity," but rather a "process of policy learning" (Gregersen & Johnson, 2000). And even if there were extra costs for society in these countries, it has been argued that the economic valuation of the reduced environmental impacts associated with the renewable energy more than compensates for the additional wind power support (Krewitt & Nitsch, forthcoming).

[20] There is still an important role for institutional support from these groups and NGOs, and project funding not linked to specific vendors; but ultimately, Chinese wind power development must depend upon Chinese resources.

[21] The current system relies primarily on small domestically manufactured turbine units, often for localized consumption by residential/commercial units on an intermittent basis; or else slightly larger (often imported) units for power generation linked to the nearby grid. The country does not yet manufacture the 1.5 MW, state-of-the-art wind power units used currently in Europe and the United States.

Collaborative Industrial Ecology in Asia
An Initiative of the Yale School of Forestry and Environmental Studies

As a region of considerable economic enterprise and growth, Asia poses important challenges in the quest for worldwide sustainable development. In particular, vigorous industrial activity in Asia imposes conspicuous burdens on the environment. The consumption that arises as a desired outcome of economic growth further fuels resource use and waste management challenges. Yet, the economic growth that drives these environmental challenges also provides unique opportunities.

Most of the industrial stock that will be in place twenty-five years from now does not yet exist. In China, for example, 80 percent of the industrial stock of plants and equipment that will be in place in 2020 has not yet been built. Integrating environmental concerns into the design and choice of industrial processes, consumer products, and public policy at this time of rapid growth is therefore crucial.

It is this opportunity that prompted the Yale University School of Forestry and Environmental Studies (F&ES) to initiate the project, *Collaborative Industrial Ecology in Asia*. In 2001, with funding from the Henry Luce Foundation's Program in Environment and Public Policy, F&ES established a multi-year program of educational exchange with Asian—primarily Chinese—institutions to adapt and disseminate the preventative environmental management concepts of industrial ecology with the aim of helping to integrate environmental concepts into industrial and public decision-making.

Yale is a leading center for the emerging field of industrial ecology. F&ES's Center for Industrial Ecology, headed by Professor Thomas Graedel, houses the prestigious *Journal of Industrial Ecology* (http://mitpress.mit.edu/JIE), the International Society for Industrial Ecology (www.yale.edu/is4ie), and several major research projects in industrial ecology. Researchers in this new field study: (1) the flows of materials and energy in industrial and consumer activities,

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(2) the effects of these flows on the environment, and (3) the influences of economic, political, regulatory, and social factors on the flow, use, and transformation of biophysical resources.

In order to effectively promote collaborative industrial ecology in China, the project has chosen the approach of "training the trainers"—educating current and future decision-makers. This approach is being pursued by:

· Developing curricular and research materials in Chinese;
· Providing scholarships for Asian students to attend F&ES;
· Establishing scholarly exchange with Asian institutions;
· Increasing the Asian content in *Journal of Industrial Ecology*; and,
· Conducting executive education courses in China and bringing Asian professionals to F&ES for training.

The project organization is based on the premise that training and exchange activities will be most successful if relationships are established and nurtured with specific Asian educational institutions. Towards this end, partnerships with a select group of institutions were established. These partners include: Tsinghua University (Beijing), Jiaotong University (Shanghai), The Centre for Environmentally Sound Technology Transfer (Beijing), and National University of Singapore. After eighteen months of activities, this project has made some important progress towards the goal of promoting the concept of preventative environmental management:

Translating research and educational materials for Asian readers. In order to expose a broad readership to industrial ecology and to provide convenient field reference materials, two textbooks, *Industrial Ecology* (by Thomas Graedel and Brad Allenby) and *Greening the Industrial Facility* (by Thomas Graedel and Jennifer Howard-Grenville with Reid Lifset and Bill Ellis) are being translated into Chinese.

Awarding scholarships. An important component of *Collaborative Industrial Ecology in Asia* is to give talented Asian students who have keen interest in the environment an opportunity to study and at F&ES advance their careers.

Promoting Educational Exchange. An important part of this project is to use exchange programs to supplement the industrial ecology literature from an Asian perspective. Visiting scholars and faculty are collaborating in the writing of Chinese language versions of key industrial ecology textbooks and case studies. In spring 2002 the first Luce fellow came to F&ES, where his direct interactions with faculty and students at Yale helped further promote mutual learning and a better understanding of China's environmental challenges. In fall 2002 F&ES hosted a visiting professor from Tsinghua University, who continued this process of mutual learning and participated in project activities. Reciprocal learning and information sharing also have been reinforced by Yale faculty working in Asia, including teaching of environmental management at National University of Singapore.

Creating executive environmental education programs. The collaborative industrial ecology project brought Asian participants to F&ES's world-renowned environmental management executive training program, the Corporate Environmental Leadership Seminar (CELS). These CELS scholarship recipients represented both public agencies and private corporations from China, Singapore, India, and Thailand. Additionally, the F&ES China-based executive training program—the Sustainable Development Leadership Program—has organized training courses in collaboration with the Nanjing Forestry University, Sino-Forests, Inc., and Shanghai Jiaotong University. These training programs, led by F&ES faculty Thomas Graedel and Marian Chertow, included Chinese participants from a variety of companies and organizations including multinationals such as Exxon Mobil, Unilever, Motorola, Johnson and Johnson, and Carrier.

The Journal of Industrial Ecology. To increase interactions between Asian scholars and others from around the world, this peer-reviewed international quarterly based at F&ES and published by MIT Press, has increased the Asian content, Asian readership, and contributions from Asian scholars by: (1) actively soliciting articles and reviewers in Asia, (2) providing subscriptions to selected Asian universities, research institutions and nongovernmental organizations, and (3) translating the abstracts of all its published articles into Chinese.

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