Unclassified **ENV/EPOC/GSP/RD(2007)10/FINAL**

Organisation de Coopération et de Développement Economiques
Organisation for Economic Co-operation and Development

20-Feb-2008

English - Or. English

ENVIRONMENT DIRECTORATE
ENVIRONMENT POLICY COMMITTEE

ENV/EPOC/GSP/RD(2007)10/FINAL
Unclassified

Working Party on Global and Structural Policies

ENVIRONMENTAL INNOVATION IN CHINA

English - Or. English

JT03240763

Document complet disponible sur OLIS dans son format d'origine
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Abstract

This report explores the key features of environmental innovation in China. It provides an overview of the evolving environmental policy framework and highlights factors that contribute to stimulating environmental innovation, such as growing awareness and demand, and those which hamper innovation, such as lack of funding and insufficient intellectual property rights protection. The report draws on the recent literature, as well as on three case studies based on interviews with companies operating in China.

Acknowledgements

A first draft of this report, including the case studies, was prepared by Patrick Schaufelberger (Asia Compete). The draft was revised, edited and completed by Cristina Tébar Less (OECD Environment Directorate), with the assistance of Diana Woo. The report was submitted to the Working Party on Global and Structural Policies in May 2007, and cleared for declassification. It is published under the responsibility of the Secretary General.

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EXECUTIVE SUMMARY

After years of pursuing economic growth at any cost, the Chinese authorities have become more aware of the increasing deterioration of the environment in the country and are promoting more balanced patterns of development in order to achieve sustainable growth in a "harmonious society". Environmental regulation has been strengthened, and environment institutions reformed and given "teeth" to enforce environmental policies more efficiently. Public expenditure for environmental projects has increased, and the national innovation system is being upgraded.

All these developments also affect environmental innovation in the country. Increased environmental awareness and strengthened regulation and enforcement are putting pressure on public and private entities to improve their environmental performance, and have created incentives to innovate in the field of environmental goods and services. China is also an important recipient of environmental technologies through the Clean Development Mechanism (CDM).

The market for environmental goods and services in China is huge (it was estimated at USD 32 billion in 2005) and will continue growing at double digit rates until 2010. The domestic environmental industry is still underdeveloped, and faces a number of constraints, such as fragmentation, use of obsolete and low-quality technologies and production methods, lack of capacity to bridge the gap between research and development and commercialisation, and insufficient demand. However, it is quickly catching up, *inter alia*, thanks to efforts by the government to promote the development of the domestic environmental industry and to foreign investors which are bringing in new technologies and practices. The cases of two Chinese companies, Dalian East Corporation in the cement industry, and Giant Hemu in the pulp and paper sector reflect the importance of strengthened environmental regulation as a driver of environmental innovation in China and of the role of government in supporting research and innovation, and the emergence of partnerships and external sources of funding to develop new technologies.

Foreign investors in China are showing a growing interest and determination to set up R&D activities in China in response to the demand, including in the environmental and renewable energies markets. Clear signals set by the Chinese authorities, such as ambitious targets for renewable energy use, stimulate investment from foreign companies with a well established expertise. However, there are also hampering factors to innovation, including in the environmental industry, for foreign companies, such as the "innovator's dilemma" and insufficient intellectual property rights protection.

There is a huge potential for environmental innovation and investment in the environmental industry in China. Many stakeholders play a crucial role in realising this potential, primarily government at all levels and the business sector, but also the financial sector, foreign investors and civil society.

1. Introduction

China's remarkable economic growth over the last 15 years, at an average rate of over 10%, has generated high pressure on the environment, with consequent damage to health and natural resources (OECD, 2007a). Chinese authorities, aware of the deterioration of the environment, are now promoting more balanced patterns of development, using concepts such as "harmonious society", and "scientific development". One important factor for environmental improvement is access to innovative environmental goods and services, technologies and know-how, which are adapted to the country's needs and capacity.

This report explores the main drivers of, and obstacles to environmental innovation in China, drawing on the recent literature and on case studies based on interviews with representatives from companies.

The report starts with an overview of the environmental protection framework in China and outlines some sources of funding for investment in environmental technologies. The next section provides an overview of the environmental industry in China, covering the development of the industry, its key features and the challenges ahead to get it up to speed. The report continues with three case studies based on interviews with representatives of companies in the cement, pulp and paper and wind energy sectors, respectively, focussing on the key drivers and obstacles for innovation in their sectors. The report concludes with a section summarising the key findings emerging form the report.

2. Overview of China's environmental policy framework[1]

Environmental laws and targets

China has had a negative environmental record for many years and energy use has been growing faster than the country's gross domestic product (GDP) (in 2004, GDP grew by 10%, while energy use grew by 15%). However, awareness of environmental problems has gradually changed, and the government is now moving from pushing to attain its economic goals at any cost to a more sustainable approach.

The beginnings of the Chinese environmental policy framework date back to the early 1980s. The 1982 Constitution establishes that the State must ensure the rational use of natural resources, protect rare animals and plants protect and improve the environment; prevent and control pollution and other hazards; and institutionalise and encourage reforestation and the protection of forests. The Environmental Protection Law of 1979 amended in 1989 sets forth the basis of national policy and defines national government and territorial responsibilities for environmental protection. This Law requires the State to adopt economic and technological policies and measures for environmental protection so as to co-ordinate the work of environmental protection with economic construction and social development. The State must also encourage the development of education in the science of environmental protection.

Since 1996, China has thoroughly revised and adapted its environmental laws. In total, over 660 central and local policies and regulations have been formulated and promulgated. In 2005, the Chinese government set forth clear requirements on how to receive, report, handle, compute, and analyse information concerning environmental emergencies, and how to monitor and release early-warning information. Environmental enforcement and compliance assurance have been enhanced.

[1] A detailed description and assessment of China's environmental policy framework is provided in the OECD's Environmental Performance Review of China (OECD, 2007a). Unless otherwise indicated, the information contained in this section is extracted from that report.

Responsibility for compliance assurance lies principally at the sub-national level, while the State Environmental Protection Administration (SEPA) is responsible for providing guidance to national and local enforcement staff for investigating non-compliance and taking enforcement actions. Environmental inspection agencies have now been established, and more than two million inspections have been conducted in recent years, with 80 000 to 120 000 violations having been punished.

The Chinese Premier announced in April 2006 three new policy directions: discontinue pursuing economic growth while ignoring environmental protection; synchronising environmental protection and economic growth; and making comprehensive use of legal, economic, technical, and necessary administrative measures. These include centralised actions to achieve scientific breakthroughs in key areas, establishment of an environmental monitoring and early-warning system, and a sound environmental law enforcement and supervision system.

In the 11th Five-Year Programme for National Economic and Social Development (FYP), China has set forth its goals for environmental protection for the next five years (2006-2010). These include achieving the following improvements by 2010:

- Energy intensity to be reduced by 20%
- Water consumption per unit of industrial value-added to be reduced by 30%
- Water for irrigation in agriculture maintained at current levels
- Recycling of industrial solid waste to be increased by 60%;
- Area of farmland to be retained at 120 million hectares
- Total discharge of major pollutants reduced by 10%
- Forest coverage to reach 20%
- Control of greenhouse gases to "generate good results".

For the period 2006-10, the Chinese authorities have announced that CNY 1400 billion[2] (approximately 1.5% of China's expected GDP for the period) will be spent for environmental protection throughout the country (i.e., expenditure by different levels of government and by the private sector).

Selected measures aimed at environmental improvement

This section briefly describes a range of measures aimed at improving environmental performance in the country, with a focus on measures addressed at companies.

Cleaner production and the "circular economy"

In the 1980s, the "cleaner production" (CP) concept was introduced in China. In 1997, SEPA issued the 1997 Recommendation on Promoting CP in China, requiring local environmental protection agencies to integrate CP into environmental management policies. A comprehensive Law on Promotion of Cleaner Production came into effect in January 2003.

In recent years, Chinese leaders have promoted the idea of the "circular economy", and this concept underlies the 11th FYP. The term "circular economy" refers to an alternative economic growth model, no longer based on intensive use of energy and other primary resources and the generation of waste and pollution. The concept has become widely accepted as a result of the rising prices of many materials (*e.g.*

[2] 100 Chinese Yuan (CNY) = 9,41977 Euro (December 2007)

copper, zinc, nickel, aluminium, and steel) on world markets and related import costs, and of concerns about sustainable development. The concept of the circular economy includes, *i.a.,* closing material loops; reducing the material intensity of the economy; improving resource productivity; waste reduction, reuse, and recycling; and changing production and consumption patterns (Ren, 2006).

So far, over 5 000 enterprises in the sectors of chemicals, light industry, power-generating, coal, machinery, and building materials have "passed the examination" for clean production. More than 12 000 enterprises across China have received the ISO14000 Environmental Management System certification; over 800 enterprises and over 18 000 products of diverse types and specifications have received environmental labelling certification. Their annual output value is worth CNY 60 billion.

In addition, the recycling industry is being vigorously developed in industry-concentrated areas so that wastes from "upstream" enterprises can easily become raw materials for enterprises "downstream". This has effectively extended the production chain, minimising the amount of waste produced. For this purpose, environmental industrial zones have been established where resources are being used in the most efficient way. At present, 17 ecological industrial parks of different kinds have been set up nationwide.

Several studies show that CP practices have both reduced pollution and increased the production efficiency of enterprises in China. These practices contributed to 20% reduction in emissions while generating economic returns of CNY 500 million annually (Wang, 2003, cited in OECD, 2007a).

Environmental impact assessment

The first legal provision for environmental assessment of pollution prevention and control equipment in investment projects was in the 1989 Environmental Protection Law. The Law requires that equipment for pollution prevention and control be taken into account in the design, construction, and operation of potentially polluting investment projects (also known as "three simultaneities" or "3S")

All proposed pollution prevention and control technology or equipment must be submitted for approval by local Environmental Protection Bureaus (EPBs) before the investment project is carried out. In 2004, 79 500 investment projects were subject to the "3S" procedure, out of a total of 127 500 investment projects. In slightly more than 76 000 cases, the "3S" procedure was approved (SEPA, 2000, 2004).

The 1989 Environmental Protection Law also requires projects with potentially negative environmental effects to be subject to environmental impact assessment (EIA) before approval by local Development Research Centres of the State Council. Due to widespread dissatisfaction with the EIA system, many projects were implemented without an EIA.

In 2002, the Law on Environmental Impact Assessment was adopted as part of a sustainable development strategy, to prevent adverse impacts on the environment that might result from policies, plans, and projects. The Law addresses the shortcomings of the 1989 Environmental Protection Law. Its requirements were later addressed in SEPA's "Measures on Public Participation in the Environmental Impact Assessment Project", which took effect in March 2006. These measures clarify the rights and responsibilities of the various parties with an interest in the EIA and the forms of public participation.

In 2004, some 310 000 out of a total of 321 000 projects were subject to EIA. During a campaign carried out by SEPA in December 2004, the construction of some 30 large projects, most involving hydro or thermal power plants, was suspended as they failed to satisfy EIA requirements.

Economic instruments

China uses a range of economic instruments as part of its environmental policies. Pollution charges have been used for over twenty years and produce significant financial resources. In 2004, the total revenue from the pollution levy system was CNY 9. 42 billion, collected from nearly 740 000 enterprises.

User charges have been gradually applied on household and industry use of environmental services and natural resources, such as charges for water use for farmers and households, waste water treatment and municipal solid waste collection. The use of tradable permits is still mainly at a pilot project level.

The government has also put in place a number of environment-related taxes. In the category of consumption taxes, unleaded fuels (gasoline and diesel) are taxed at a lower rate than leaded ones. A registration tax is levied on the sale of motor vehicles, motorcycles, and motor cars. Excise tax is also applicable, from which road motor vehicles that meet stipulated low-pollution standards are exempt from 30%. A tax is applied to road motor vehicles and vessels. In March 2006, several additional environment-related taxes were introduced, such as a differentiated tax for motor vehicles, determined according to engine size. The scope of oil products subject to taxation was also broadened.

Implementation of environmental regulation

Environmental institutions

Environmental institutions are expected to play an important role in environment protection implementation. The Environmental and Resources Protection Committee is responsible for developing, reviewing, and enacting environmental laws. The second important institution is the State Environmental Protection Administration (SEPA), previously called the State Environmental Protection Bureau. Since 1998, when the Chinese government changed its name and elevated it to ministerial level, SEPA has been the highest administrative body for environmental protection, and is responsible for exercising overall supervision and management of China's environmental protection work.

In China’s new environmental management system, sub-national administrative units are responsible for the environmental quality of the areas within their jurisdiction. The competent administrative departments in charge of environmental protection have the power of overall supervision and management, while other relevant departments exercise such supervision and management functions according to the provisions of the law.

In 2004, China had more than 3 000 environmental inspection agencies with about 50 000 people involved at the state, province, city, and county levels (SEPA, 2000-04). They are engaged in environmental administration, monitoring, scientific research, publicity, and education. Several provinces and centrally administered municipalities, such as Henan, Hubei, Beijing, and Tianking, have established independent institutions, separate from the environmental protection agencies, to take charge of inspections.

Enforcement of environmental regulation

Chinese legislation provides a comprehensive array of tools to enforce environmental laws and to promote compliance with them. SEPA and other departments under the State Council have worked hard to promote the effective use of these tools with the limited means at their disposal. Even though environmental authorities have imposed a number of sanctions for non-compliance, a wide gap exists between what EPBs are authorised to do and what they actually do when enterprises violate environmental rules. In many cases, approved and installed pollution control equipment is put into operation only when inspectors are expected, as the polluters are more interested in saving operation costs.

A significant proportion of small and medium-sized enterprises are not inspected due to lack of capacity, the constraints of "pragmatic" enforcement (considerable discretion is applied by the EPBs in determining how they will enforce environmental requirements), or conflicts of interest between the economic and environmental parts of the administration. Pragmatism is reflected in the EPBs' reliance on their relationship with regulated enterprises, *i.e.* in developing mutual understanding, providing technical and financial assistance, and negotiating reasonable compliance deadlines. The "pragmatic" approach has been applied with some success in China, but EPB staff frequently stops short of revoking permits for serious violations of their conditions, or choose not to fine enterprises for non-compliance in order to maintain harmonious relations.

Chinese leaders have identified inadequate enforcement as one of the key factors in China's deteriorating environmental situation. The 9th, 10th, and 11th Fops emphasise the need to strengthen environmental enforcement and compliance assurance. Responsibility for compliance assurance lies principally at the sub-national level, while SEPA is responsible for providing guidance to national and local enforcement staff for investigating non-compliance and taking enforcement actions. However, SEPA is involved in compliance assurance actions concerning companies under the direct supervision of the State Council, and it also supports the Environmental Protection Bureaus (EPBs) in carrying out enforcement campaigns. In 2003, the Supervision and Enforcement Bureau was established as part of SEPA.

Enforcement has relied on three key elements: inspections by the local EPBs; joint inspections (campaigns) carried out by the central government and EPBs; and mobilising the population, including media and NGOs, to help promote compliance with environmental requirements. The level of compliance with national pollution standards is checked through environmental inspections. In case of non-compliance, inspectors have recourse to a variety of instruments, including warning letters, fines, withdrawal of license or permits, and in case of persistent non-compliance, shutting down the facility.

In recent years, more than two million inspections have been conducted annually in China, and 80 000 to 120 000 violations penalised according to the Environmental Protection Law. EPBs can gain court assistance to collect fees and fines. This law also provides for the application of criminal sanctions in the case of particularly egregious cases. To date, a number of high profile cases of environmental crime have been brought to court, but this avenue has been used infrequently due to uncertainty over the legal responsibilities and long judiciary procedures.

3. Sources of environmental funding

This section describes three sources of funding for environmental improvements in China: public expenditure, private financing, and the Clean Development Mechanism established under the Kyoto Protocol.[3]

Public environmental expenditure

Public environmental expenditure has gradually increased. In the period 1996-2000, it averaged 0.8% of GDP, reaching 1.1% in 2000. Between 2001 and 2005, it continued to grow, reaching 1.4% of GDP in 2004 (CNY 191 billion) and surpassing the 1.3% target set in the 10th FYP[4]. Expenditure for environmental protection has been formally itemised in the State's financial budget as from 2006.

3 Funding by multilateral or regional developments banks (e.g., the World Bank and the Asian Development Bank) and bilateral development institutions are other important sources in support of environmentally-related projects, but will not be described in this report.

4 The Chinese definition of environmental investment expenditure and the OECD definition of pollution and abatement control (PAC) investment expenditure: i) cover public and private investment expenditure; and ii) exclude water supply and

In 2004, investments related to urban environmental infrastructure accounted for 60% of environmental investment, or CNY 114 billion. This mainly reflects investment in wastewater treatment and waste management infrastructure in the context of rapid urbanisation. In the same year, investment in industrial pollution abatement and control accounted for 40% of environmental investment, or CNY 77 billion, more than doubling that of the period 1999-2004 at current prices.

Over the period 2001-2005, environmental investment expenditure in China was allocated mainly to air pollution (40%), water pollution (38.5%), and waste management (12.9%), and was financed by both public (57%) and private funding sources (47%).

According to SEPA (2007), in 2006, the total investment in environmental pollution treatment across China was CNY 240.28 billion, of which 131.43 billion went to urban environmental infrastructure construction; 49.27 billion were for industrial pollution source treatment; while 59.58 billion were investment in environmental protection ("three simultaneities") of new construction projects. In 2006, the total investment in environmental pollution treatment of the country represented 1.15% of GDP.

For the period 2006-2010, Chinese authorities have announced that CNY 1 400 billion (USD 175 billion), or 1.5% of GDP, will be spent for environmental investment addressing mainly air and water pollution, and waste management.

Private environmental financing

Private environmental financing comes from the banking system. The Chinese banking system is dominated by large state-owned banks. Their business largely consists of giving loans to large State-owned enterprises (SOEs). As many of these SOEs have been operating at a loss, large amounts of non-performing “bad” loans have accumulated (OECD, 2007b).

Some important constraints of China’s financial system affect innovative activity in the business sector (OECD, 2007b):

China’s financial system does not meet the funding needs of private firms, notably small and medium-sized enterprises (SME). The capital market is underdeveloped and SMEs find it difficult to secure loans since banks favour large companies, particularly SOEs. Smaller, privately-owned firms thus largely depend on self-funding. Recent initiatives to address this issue propose funding mechanisms to support science and technology, and innovation activities;

There is a severe lack of capital financing for new ventures, which are one important source of innovation. China lacks both the expertise and the necessary legal and regulatory conditions for an adequately functioning venture capital system. Domestic venture capital firms have been set up by the government, at national or provincial level, and are run by government officials who do not always have adequate technical, commercial, or managerial skills to make the decision to finance innovating projects or not.

While there appears to be sufficient liquidity in the system – with a large number of wealthy business people and foreign venture capital firms looking for profitable investments – there seems to be a shortage of firms and professionals with the experience to identify and invest in high-risk ventures, and firms and

nature protection expenditure. However, the Chinese definition differs by including a number of additional elements (*e.g*. investment expenditure in energy efficiency, in fuel switching, in urban amenities). This results in Chinese estimates of environmental investment expenditure being significantly higher than the PAC investment expenditure as defined by the OECD (OECD, 2007a). Data in this section are based on the Chinese definition of environmental investment expenditure.

"business angels" that are prepared to invest in sectors in which an investment may take a long time to yield returns.

The number of private domestic and foreign venture capital firms has been increasing but funds are still short and there is too little management and business expertise of the sort offered by "business angels" available to small innovative firms.

The Medium to Long-Term Strategic Plan for the Development of Science and Technology proposes to introduce several new funding mechanisms for "policy banks" and commercial banks, and several initiatives have been taken to increase access to funding for small high-technology SMEs and start-ups (OECD, 2007b).

The Clean Development Mechanism

Under the Clean Development Mechanism (CDM), established under the Kyoto Protocol to the UN Convention on Climate Change, developed countries can finance greenhouse-gas emission reduction or removal projects in developing countries, and receive credits for doing so, which they may apply towards meeting mandatory limits on their own emissions (http://unfccc.int/essential_background/glossary/items/3666.php).

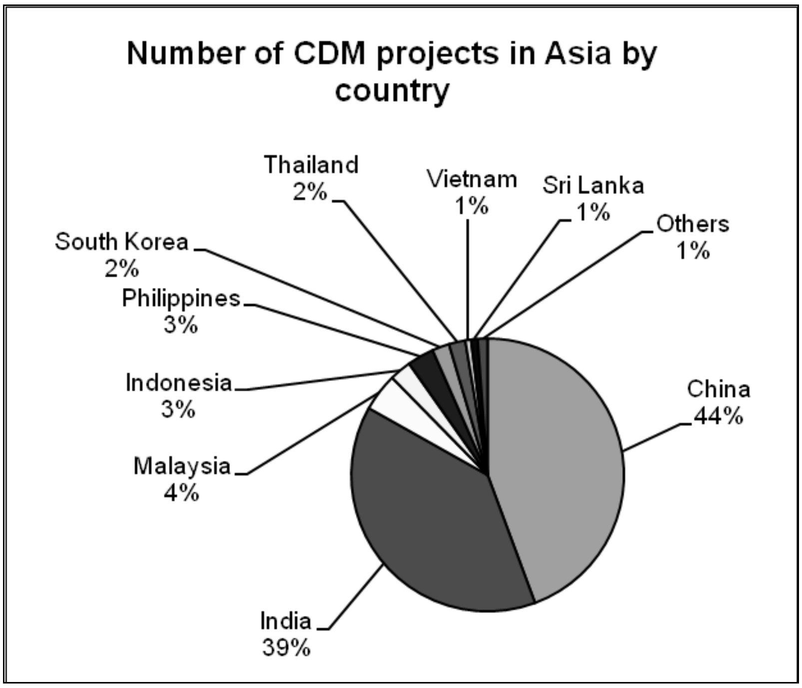
The Chinese government ratified the Kyoto Protocol in August 2002, passed regulations in keeping with the CDM, *ad interim*, in June 2004, and revised them in October 2005. Under the CDM, China can sell emission reduction certificates to industries from developed countries. These funds are an important incentive for Chinese companies to technologically enhance obsolete production plants, improving economical output, reducing emissions, and providing safer work environments for employees.

In 2007, China dominated the CDM market for the second consecutive year on the supply side with 61% market share of volumes transacted, down slightly from 73% in 2005 (World Bank, 2007). Historically, China has represented 60% of the cumulative CDM market since 2002 and 50% of the UNEP (United Nations Environment Programme)/RISOE[5] CDM pipeline[6] as of the end of March 2007 (Joergen Fenhann *et al*, 2007).

[5] The UNEP RISOE Centre on Energy, Climate, and Sustainable Development supports the United Nations Environment Programme in its aim to incorporate environmental aspects into energy planning and policy worldwide, with a special emphasis to assist developing countries (http://uneprisoe.org/).

[6] The UNEP-RISOE Pipeline is a crucial source of information for CDM project buyers. It provides all the methodological, administrative, and up-to-date information about CDM projects in each host country. More concretely, it is a spreadsheet containing the most important information from all the Project Design Documents, and the new and approved methodologies. The pipeline contains a large amount of analysis like time-series, status of project in the project cycle, types of projects, issuance success, etc. The UNEP/RISOE CDM Pipeline used in this paper is the version of December 2007.

Figure 1. Number of CDM projects in Asia, by country



Source : UNEP/RISOE, CDM Pipeline.

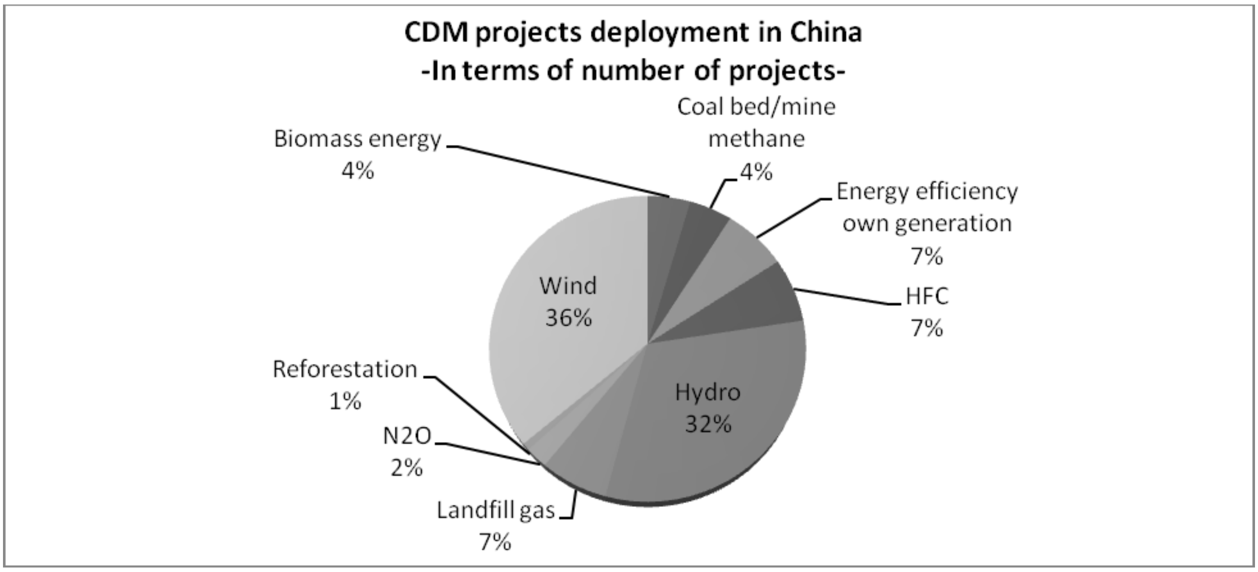
Statistics from the Office of the National Co-ordination Committee on Climate Change in China show that, as of October 2007, the country had 120 CDM projects successfully registered with the UN and 20 had been issued with CER (Certified Emission Reduction) credits[7]. OECD data indicates that China has experienced a huge growth in the proportion of total expected credits due from investment in CDM projects, showing an increase in the project funds coming from Chinese sources: from slightly more than 25% of 163 MT per year in January 2006 to more than 50% of 302 MT per year in March 2007 (Ellis, J and Kamel, S., 2007). Indeed, CDM projects in China must be majority Chinese-owned, with most of the project funds coming from Chinese sources.

Despite some concerns about post-2012 prospects and geographical concentration of high volumes of carbon, China is still extremely attractive for investors in CDMs. In interviews led by the World Bank (2007), investors confirmed their efforts to diversify geographical distribution among the different CDM project host countries of their portfolio., but they also acknowledge the huge potential still available from China (bringing economies of scale in exploration, sourcing, and transactions costs) together with its favourable carbon investment climate (strong support from institutions and experienced project developers).

In addition to building a significant pipeline, Chinese institutions have also been able to diversify its content. They reoriented CDM project deployment towards priority sectors, such as renewable energy (wind and hydro, which have long been present; and biomass, which is newer), energy efficiency improvement in the industrial sector, and methane recovery and utilisation (World Bank, 2007).

7 A CER is a credit equivalent to one tonne of CO2 reduced under the Clean Development Mechanism.

Figure 2. Figure 2. CDM projects deployment in China – in terms of number of projects



Source: UNEP/RISOE CDM pipeline and UNFCCC (http://cdm.unfccc.int).

The CDM market in China is very dynamic and evolving very fast. Some large buyers, who built their project portfolios in China, have begun to look for diversification from industrial assets in China and they are reportedly seeking to resell parts of their existing portfolios to others, including small buyers. Meanwhile, carbon funds and other large buyers are busy closing transactions for new primary assets in China (renewable energy, biomass, etc.) as well as in other regions and countries. This injects liquidity into the Chinese market, and allows a diversification of CDM projects.

4. The environmental industry in China[8]

Development of a domestic environmental industry

Increasing concerns about environmental degradation and strengthened environmental regulation triggered the development of a market for environmental goods and services in China. The domestic environmental industry[9] developed in China in the 1980s, under its "import substituting policy", with light air, water and soil pollution measuring instruments assembled initially by state-owned enterprises (SOE), and increasingly thereafter by so-called town-and-village enterprises (TVEs), and subsequently their parts and components manufactured by those enterprises.

In 1989, the Chinese government incorporated the environmental industry into the priority list of on-going industrial restructuring. It defined the environmental industry as covering "such economic activities as technology development, goods production, commercial distribution, resource utilization, information

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[8] This section is based to a large extent on recent reports by Hirono R. (2004) and Liu Y. (2005) analyzing the environmental industry in China. It explores the key features of the *domestic* environmental industry but does not deal with *foreign* companies operating in China's environmental industry market.

[9] There is no agreed definition of environmental industry. Most countries, e.g., the US and Japan use a broad definition, which includes a diversity of products and services related to environmental improvements during the overall lifespan of materials and products that could pollute the environment. China's definition is narrower, since it takes account only of products and services aiming at clean-up actions and remedial measures, with a strong focus on end-of-pipe technologies (Liu, Y. 2005).

services, engineering and contracting, with the aim of preventing and controlling environmental pollution, rehabilitate the natural environment and conserve natural resources". The government also established a co-ordination group, under the leadership of the State Council environmental protection committee, with the mandate to develop policies and programs for the development of the environmental industry.

Since 1997 the Communist Party has convened an annual symposium to discuss population, resources and environment with a range of authorities at national, provincial and local levels, which have served to lay the foundations for new government policies and guidelines to accelerate the development of the environmental industry in China. More recently, the "National Proposals on Accelerating the Development of Environmental Protection Industry was issued jointly by 8 ministries. These "National Proposals" identified three priority areas for the environmental protection industry: (1), environmental technology, goods and equipment such vehicle emission controls, recycling, solid waste disposal and treatment, cleaner production, environmental monitoring, etc.; (2) resource utilisation, mainly including recycling of industrial wastes and used goods; (3) environmental services such as consultancy, information and technical services, and environmental engineering.

The "National Proposals" also stressed the importance of developing technological and quality standards, installing independent third party certification, removing direct government intervention in company's decision on concrete environmental technology and equipment, and dismantling local and sector protectionism towards environmental industry". Great importance is also attached to "building the market demand for environmental technologies and products", and "encouraging the private sector to actively participate in the development of the environmental industry". In its latest "five-year development plans" the government has also become "increasingly aggressive in fostering the environmental protection industry as part of its rapid industrial modernisation programmes".

The National Proposals recommend a mix of potential sources of financing environmental industry development, including increasing the allocation from government budgets, larger pollution levies raised through more stringent application of the polluter-pays principle, more investments from private companies and capital markets, and increased use of international funds.

With the rising demand for meeting increasingly tighter environmental standards in the 1990s, imports from Japan and other industrialized countries of small and large-scale pollution abatement machinery also began to rise. Imports of those equipments were then gradually replaced by their production by SOEs and TVEs. Today, with the exception of large-scale pollution abatement equipment installed in electric power generating plants, as well as in large-scale waste treatment plants under municipal authorities, most of these anti-pollution machinery, equipment and instruments are manufactured domestically, in some cases under foreign licensing arrangements (Hirono R., 2004).

Key features of China's environmental industry

The market for environmental goods and services in China is huge, and the country's environmental industry has been steadily growing. According to estimates by the US Office of Energy and Environmental Industries (OEEI), the total market for environmental goods and services in China was ca USD 32 billion in 2005, and will grow at an annual rate of 30% out to 2010 (EBJ, 2005).

As regards China's environmental protection industry, the number of environmental enterprises (including state-owned or non-state owned enterprises or institutions across China with annual revenue over CNY 2 million) in 2006 was about 12 500 with around 1.7 million employees, and an annual revenue of about CNY 600 billion (SEPA, 2007). SEPA estimates the Chinese environmental industry will grow at a rate of 10% until 2010, after which it will become one important exporting sector (SEPA quoted by Hirono R., 2004).

In spite of the growing demand, the domestic environmental industry is still at a relatively immature level, which is characterised by the following features (Liu, 2005):

The Chinese environmental protection industry is made up of thousands of small and medium size enterprises (TVEs), which largely use old equipment in manufacturing environmental products. Even larger companies (typically SOEs) producing larger scale environmental protection equipment have not reached the level of environmental technology attained in industrialised countries, as can be observed in energy and resources saving technology

The quality of most environmental equipment, products and services is rather low, and mass production of standards, low quality technology and even simple imitation are prevalent, especially among TVEs. Innovative capabilities are predominantly geared towards absorbing, adapting and duplicating technologies already developed in industrialised countries.

Technological innovation and research takes place primarily in academic and public institutions, and hardly in the industries themselves. Academic R&D results do often not match industry needs, which results in low levels of commercialization and utilization of environmental R&D results.

Incomplete and inadequate competition caused by an immature market mechanism and regional protectionisms undermines the innovative and research and development capacity of the Chinese environmental industry, and results in a disadvantageous position in the global market.

Most enterprises focus on end of pipe technologies rather than on preventive technologies, environmental management and services, consultation, etc.

Hirono and Lui have analysed the difficulties that need to be overcome to put China's environmental industry up to speed and provide suggestions of possible solutions. One constraint of the Chinese environmental industry is its fragmentation – the vast majority of enterprises are of small scale [10] - and its low level of quality. Fragmentation also exists at the government level - the combination of weakened centralism and incomplete liberalism results in compartmentalization of administration and regulation, market fragmentation and regional protectionism.

Linked to this fragmentation is the fact that China's environmental industry has not been stimulated strongly by governmental regulation and enforcement. SEPA lacks power to adequately mainstream environmental concerns into all national, provincial and local development programmes and projects of the government.

Further, there is insufficient public awareness about environmental problems and lack of public pressure on the government. The capacity of non-governmental (NGOs) and civil society organizations (CSOs) in terms of expertise, financial resources and management capabilities, necessary to raise awareness and put pressure on the government to enhance environmental policies and enforcement, is still very weak. Following China's entry into the WTO, there has been a better spread of information and communications technology among all segments of the population, but interaction of Chinese NGOs with counterparts in the world is still limited, including in the area of environment. Therefore, according to Lui and Hirono, government efforts are needed to contribute to the development and empowerment of NGOs and CSOs, and to assist them in raising their expertise, finance and management skills and know-how through interaction with counterparts in the rest of the world. This would greatly contribute to

[10] Hirono quotes the figure of 94% of small enterprises in the Chinese environmental industry, according to data from the China Association of Environmental Protection Industry (CAEPI).

strengthening environmental awareness in the country and raise the demand for more efficient environmental technologies.

According to Hirono (2004), more government funds are needed to provide both financial and technical support to the modernization and expansion of the environmental protection industry and the development of high and emerging environmental technology in the country. In addition, measures such as better empowerment to SEPA in terms of inter-ministerial authority and implementation capacity; better enforcement of existing regulation would also be needed.

Another problem is that sufficient and efficient fiscal and financial incentives are missing. Better use could also be made of tax and financial incentive schemes, including private and public environmental funds to be made available to those firm willing and ready to improve environmental performance. This would contribute to increasing domestic demand for appropriate environmental technologies and would in tune lad to the further development of the environmental protection industry in the country.

Finally, China lacks capacity to commercialise scientific and technical R&D results developed domestically, and has not been very successful in absorbing imported environmental technologies. The organizational structure of R&D fails to bring together research results of scientific and technological research institutions, environmental improvement demands of industrial firms and State environmental regulation and policy. This weakens the "supply side", namely the effective and sufficient provision of advanced environmental equipments, products and services. However, this trend is changing - Chinese companies are catching up and are increasingly developing capacity to serve the environmental goods and services market (EJB, 2005).

Among the key mechanisms to develop the Chinese environmental industry, analysts highlight the following (Hirono, R., 2004, Liu, Y., 2005): [11]

- One way to modernize the industry is through foreign direct investment associated with advanced environmental technology and management services, which would need to be adequately protected in terms of intellectual property rights. So far, lack of protection of IPR, both for domestic and foreign firms has been one of the major barriers to importation of the most advanced environmental technologies into the country. Indeed, lack of IPR protection was signaled by foreign investors as a major obstacle for conducting investment in China, in the 2007 Business Confidence Survey by the European Chamber. Most companies had experienced violations of their trademarks, copyrights or patents, which over a quarter qualified as "serious".
- To overcome the current fragmentation of the sector, mergers and acquisitions of small –scale enterprises by larger ones should be promoted, and modern management systems introduced at all levels.
- Responsibilities between government and the industry sector would need to be rationalized, with government focusing on environmental policy formulation and implementation, and leaving design, production distribution of environmental goods to the industry, under an effective competition framework.
- The government should deepen the on-going reforms of the scientific research system, including in the field of R&D of environmental technologies and services. The quality of environmental products and technology should be vastly improved through the installation of a combined system of manufacturing, human resources development and scientific and technological research.
- Public funds should be better targeted and incentives provided to companies to invest in environmental technologies (e.g., through tax reductions). Further, both government and the

[11] These mechanisms focus specifically on the development of the environmental industry. Other factors, such as growing public demand for environmental quality, better enforcement of regulation etc are not analysed here.

private sector should come up with innovative financing mechanisms, including, *inter alia*, the establishment of environmental protection funds to encourage innovation in environmental technology and commercialisation of new technologies.

China's emerging innovation framework

This sub-section provides a brief overview of China's emerging innovation system. Though not focussed on environmental innovation, this system will provide the framework for innovation, *inter alia*, in the environmental industry.

The 2006 National Science and Innovation Conference and the adoption of the Medium- to Long-Terms Strategic Plan for the Development of Science and Technology (S&T) are the most recent phases in the construction of China's national innovation system. It will be supported by new and enhanced S&T policies and measures (OECD, 2007b).

Chinese S&T policy is a policy mix, of which R&D programs are the most important instrument. Since the birth of the first programmes in the early years of the 2000 decade, S&T programs have mushroomed in China, initially as an attempt to reform the old S&T system by injecting competitive funding mechanisms, and later as a response to the central leadership's call to enhance S&T and innovation. The funds allocated from the central government to the main programmes represented as much as 17% of total S&T public expenditure in the first half of the 2000 decade.

There are three main programs: the National Key Technologies R&D Program, the National High-Tech R&D Program and the National Program on Key Basic Research Projects. The government's share of programme funding varies considerably from nearly 90% for basic research to around 50% for applied research, and considerably less, around 20%, for technology innovation.

The State Council also announced late in 2006 a new policy package which will include enhanced public funding, extended tax incentives for S&T, government support for the development of financial market funding channels, and public funding to support the absorption of imported technology.

5. Case studies

This section includes three case studies, describing drivers of, and barriers to environmental innovation for companies operating in the cement, pulp and paper, and wind turbine industries, respectively. They are based on input received from the following companies:

Dalian East Corporation, which focuses on energy generation through processing waste heat recovery from the cement industry. The study describes the role of government and partnerships in technological development.

- **Giant Hemu Corporation**, which owns a technology patent for clean production in paper mills. The study shows how the Chinese framework supports the development of a promising "green" start-up company.

- **Vestas Corporation**, a Danish technology leader in the wind turbine industry, and its plans to carry out R&D in China. This case looks particularly at the company's decision on where to set up a new R&D centre in Asia and the reasons for and against locating it in China.

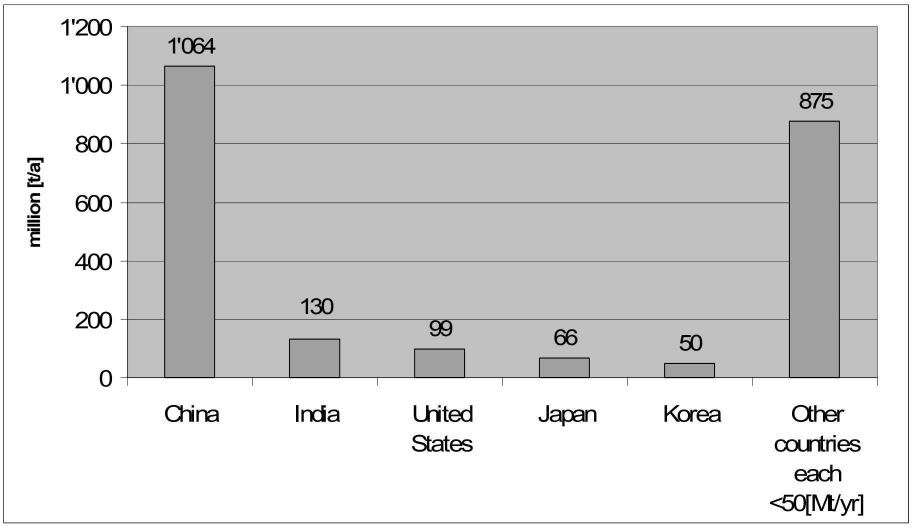
The cement industry: Dalian East Corporation

Background and terminology

Cement is used mostly to produce concrete. Concrete itself is made by mixing a cementing material (such as Portland cement) and a mineral aggregate (such as sand and gravel) with enough water to cause the cement to set and bind the entire mass. Cement constitutes about 10 to 15% of the total mass of concrete. Concrete requires reinforcement if used as a building material because of its poor ability to withstand the effects of wind or earthquakes on the buildings. Concrete becomes stronger as it gets older. Because its basic constituents are available virtually anywhere and because of the relative high transport costs, cement (and concrete) is produced in most countries around the world.

The most common type of cement is Portland cement. To prepare it, a stony matter called clinker is produced by fusing, at around 1500^{o}C, a mixture of clay and limestone, or similar materials, in a rotating horizontal kiln or a vertical kiln. The clinker is then very finely ground while adding a small amount of gypsum to control the cement's rate of hardening. About 80% of cement is clinker. For each ton of material that is fed into the kiln, two thirds come out of the discharge as clinker.

Figure 3. Figure 3. Top 5 world cement producers in 2005



Source: Taylor et al. (2007).

The production of cement consists of the following three phases: raw material processing, clinker burning process, and finishing grinding process. The raw material and the clinker burning process can follow two different methodologies: the wet or the dry process. In the wet process, raw materials are first crushed, mixed, and then water is added in the proportion of 35-40%. The mixture is refined before being put into a storage tank, where corrective materials are added. Then the preparation is sent to a rotary kiln to be burnt at 1500^{o}C for clinker production. The mixture to be burnt in the clinker can be easily prepared, but the process consumes a large amount of energy. In the dry process, crushed raw materials are first dried, then mixed, grounded, and placed in a storage tanks. The resulting mixture gets further processed and then sent to a rotary kiln for burning.

The advantages of the wet process lie in the lower plant construction cost and easy manufacture of good-quality products. The dry process advantages lie in lower energy consumption and lower running costs. However, thanks to technological progress, the difference in quality has been eliminated, making the dry process the only energy-efficient way to produce high-quality clinker.

Waste heat in cement plants is only partially re-circulated within the clinker process to pre-heat input fuel and raw materials. The majority of the heat is lost in the atmosphere. By capturing the waste heat, power can be generated by a steam turbine.

China's cement industry

China has been the world's leading cement producer since 1985. At that time it produced about 100 million tons of cement per year. Twenty years later, in 2005 the number soared to 1 065 tons, representing 46.6% of the world's total production of 2 284 million tons. Historically, probably because of an inconvenient logistic infrastructure and high transport costs, China developed a multitude of small local cement producers, many originating from township enterprises. Most smaller plants are today obsolete, energy inefficient, polluting, and produce relatively low quality cement. The government has estimated that about 70% of the cement plants do not meet the necessary governmental requirements and are targeted to be closed.

The central government is pursuing a difficult strategy to consolidate the sector and reduce the huge number of plants. Well aware of the environmental situation, of the shortage of raw materials, including coal, electricity, and water, and of the sinking price of cement in China, the Chinese authorities adopted a set of measures to support the implementation of Cleaner Production (CP) mechanisms, to promote the Circular Economy (CE) approach, and to improve the average plant production capacity, while eliminating outdated plants. The number of producers diminished from estimates of 9 000 units in 2000 to less than 6 000 units in 2006. Average plant production in 2004 was 181 000 tons per year and the country plans to raise it to about 500 000 by 2015 (Soule *et al*, 2002; Chinese Government, 2004). This implies that obsolete plants are either refitted or reengineered, or shut down.

Plants using the dry preparation process are the most advanced. Since the year 2000 the amount of dry plants has steadily increased in absolute and relative numbers, exceeding 30% in 2004. Between 2000 and 2004 the proportion of dry method production to total production more than doubled, while the dry method production capacity in 2004 was about five times the capacity in 2000. This shows that the major companies invested strongly in new plants. A large part of the investments were made by the ten biggest corporations, which account for about one third of the dry method cement production in the country. The year 2004 denoted a still stronger increase in investments. To control them, China's central government put restrictions on land use and bank loans, and generally increased interest rates.

Environmental implications of the cement industry and the government's reaction

Cement production is an energy-intensive process. It accounts worldwide for about 5% of the global carbon dioxide (CO_2) emissions. In China it accounts for about 8% of the domestic emissions (400 million tons in 2000). Half of the emissions originate from the calcination process and half from the combustion process. Other polluting emissions include NO_2 (one million tons in 2000), SO_2 (0.5 million tons in 2000), and powdered dust (12 million tons in 2000). Globally, it is the CO_2 emission problem that needs to be addressed, but locally, powdered dust is the biggest concern. Wang (2004) calculated that Chinese industries, on average, consume 47% more energy and emit 13 times more dust than those in developed countries.

The Chinese authorities announced in 2004 that steel mills, aluminium and cement manufacture would be subject to control. In the cement industry, no plants with capacity below 4 000 t/d are allowed to be built, and new plants must use best technologies for pollution control and prevention. Construction of plants that did not meet these requirements had to be stopped and banks are not allowed to provide them any loans. This was a clear signal to "blind-eyed" local authorities who focussed too strongly on economic benefits as compared to environmental protection, and therefore granted construction permits for obsolete and polluting plants.

Other measures adopted included measures taken from the World Business Council for Sustainable Development (WBCSD) report "Toward a Sustainable Cement Industry – Trends, Challenges, and Opportunities in China's Cement". The report identified eight areas in which the industry needs to improve performance, and developed recommendations and actions for each. These include: regional development, community well-being, employee well-being, ecological stewardship, emission reduction, climate protection, resource productivity, and shareholder value. In addition, several recommendations were made in three cross-cutting areas: business integration of sustainable development, innovation, and co-operation between cement companies and other organisations.

The Chinese government has adopted a broad set of measures, including capacity building and technological retrofitting. Changing from a strictly defined composition criteria for cement, they have put the focus on cement performance criteria, which allows a wider use of blended products. This also allows the burning of alternative and waste fuels (such as old tires), but requires installation of equipment for toxic emissions collection and the adoption of an effective emission management system. This includes emission inventories, reporting, and communication processes; emission reduction cost estimates; and emission reduction targets and timetables.

Dalian East Corporation

Dalian East Energy Engineering Corporation is mainly engaged in engineering design, technical consultancy, complete set equipment supply, equipment installation and testing, general contracting, and installation of waste heat recovering power systems for cement factory plants. It employs a pool of over 80 engineers in the fields of thermodynamics, plant processing, mechanics, electrical engineering, and civil construction. One special competence of the team is the research and development of waste heat power generation systems, a field in which the company holds three patents.

The company has an annual turnover of USD 50 million. It started its activity in 1985 and focused until 1999 on the R&D of high temperature waste heat recovering power generation systems for long kilns. Until 2003 it researched and developed a two-stage waste heat recovering power generation for long kilns; and until 2004 focused on technical renovation and retrofitting of long kilns to improve plant efficiency.

In March 2006, Dalian East Engineering entered a USD 50 million joint venture named "Dalian East Energy Development" (DEED), together with Transition Energy (TrE), a firm from Maryland (United States) with many years of energy-efficiency investment experience and the China Global Environmental Institute that will support the company's applications for emissions credits under the Clean Development Mechanism. DEED plans to reduce Chinese carbon dioxide emissions by one million tons per year over at least the next five years, provide reliable electric power at a reduced cost to China's cement industry, and generate healthy returns for investors and good salaries for employees. By saving money for customers, DEED expects to create a profitable business, which should serve as a model for clean, sustainable development in China and elsewhere.

Dalian East heat recovery systems have been developed through tight co-operation with the government. Dalian East Energy Engineering Co. Ltd., together with the state-owned partner institution

China International Engineering Corporation (CIPPRC), played the main role during the whole process of China's research, development, and dissemination of the technology for cement kilns, resulting in several national patents. CIPPRC is a large state-owned enterprise with over 50 years' history, more than 1 000 employees, and annual turnover of USD 120 million. Its activities range from project consulting, design, and engineering and contracting, to import and export for various industrial areas. It has project experiences, *inter alia*, in Pakistan, Myanmar, Saudi Arabia, and the United States.

In 1990, the Chinese government started a key research project on Waste Heat Recovery Systems, in which Dalian East participated. One goal was research and development of technology and equipment for medium and low-temperature waste heat recovery power generation with a supplementary firing. The project aimed at developing a technology that could make use of existing, old Chinese steam turbines with a waste heat of below 400°C. It took six years to develop the technology, which resulted, by 2005, in 28 power generating sets with a total installed capacity of 453.6 MW. These sets have been installed for 36 lines of 1 000 to 4 000 t/d pre-calcinating kilns in 23 cement plants in China. As a supplementary fuel for boilers, gangue, municipal waste, and low calorie coal has been used in order to achieve better economic efficiency.

After the first system was developed, Japanese products were taken as benchmarks to improve domestic heat recovery systems. For this purpose, Dalian East co-operated with the Japanese NEDO. The reference was a 6.48 MW low-temperature waste heat recovery power plant for a 4 000 t/d cement kiln constructed by Nippon KHI Corporation in 1995. Two years later a first experimental low temperature waste heat recovering power plant with a nominal capacity of three MW for a 2 000 t/d clinker production line was put into operation. Four years later, in 2001, another experimental generator of 2.5 MW for a 1 500 t/d cement production line was put into operation. Both plants were completely built with Chinese-made equipment. Later, and until 2005, dozens of generators with an installed capacity of two, three and six MW were used for dry cement kilns with a capacity of 1 200, 2 500, and 5 000 t/d. This is considered the first generation of waste heat recovery power generation technology.

The pulp and paper industry: Giant Hemu

Background and terminology

Papermaking was invented in China around 2 000 years ago and today it basically follows the same main steps as in the past: raw materials (wood, cotton, hemp, bagasse, jute, bamboo or straw) are processed to obtain pulp, which is then bleached for whitening, processed for consistency, and then finished to get the desired end-characteristics. The process of papermaking needs large quantities of purified water to distribute fibres and additives uniformly. The purpose of a pulping system is to break down the raw materials into individual fibres for further papermaking processing. This is done by removing the materials that hold the fibres together. Pulps can be processed mechanically or chemically.

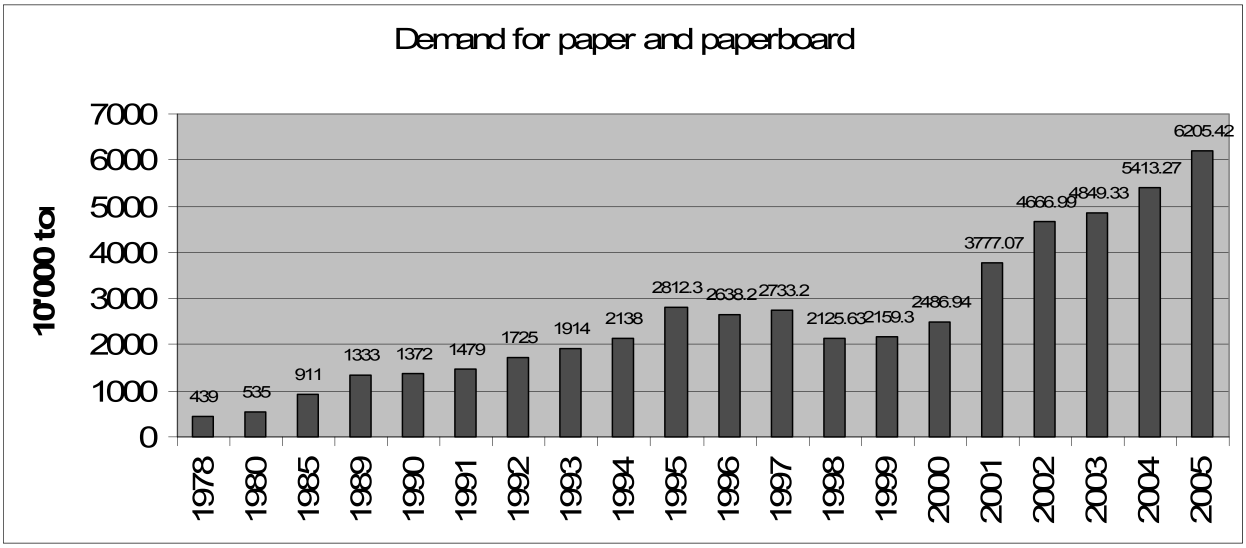
China's pulp and paper industry

Paper and paperboard demand in China has expanded rapidly over the last two decades: from 4.4 million tons in 1978 it grew to 24.87 million tons in 2000, and soared to 62.05 million tons in 2005. The country consumed, in 2003, almost 14% of global paper supply. The increasing demand is strongly correlated with the country's GDP growth and is a result of rising consumer purchasing power, a rapid increase in advertising expenditures and increasing literacy rates (He D. and Barr C., 2004).

In the 1980s, supply was controlled by the central government. For example, nine state-owned enterprises produced most of the newsprint demand, while the government controlled prices and blocked foreign investments in and imports to the sector. In 1996, these restrictions were lifted, resulting in increased imports and putting the sector under pressure to modernise operations in order to remain competitive. With government support, many state-owned newsprint producers have taken steps to upgrade their machines or to expand capacity in recent years.

Before the restrictions were lifted, there were thousands of small and medium obsolete paper mills. Because of limited domestic wood resources, these older mills used straw as raw material for chemical pulp plants. After 1996, new and bigger plants focussed on wood pulping instead, because of the strong environmental degradation related to old, non-wood paper mills, and because of increasing consumer demand for high grade paper. Non-wood pulp demand dropped from 39.9% of total demand in 2000 to 24% in 2005.

Figure 4. Figure 4. Demand for paper and paperboard in China 1978-2005



Source : China Statistical Bureau, 2007.

The import of timber and pulp to be processed into finished products for export has become a feature of trade in the region. For example, in 2003 China imported 6.9 million tons of pulp and exported 1.2 million tons of printing and writing paper. To compensate for the shortage of wood, huge amounts of recycled paper are used instead. In 2005, 54% of total pulp demand was recycled paper.

Environmental impacts

Two areas in the papermaking process are of major environmental impact: black liquor treatment and bleaching. Black liquor results as a side product of the pulping process. Untreated liquor is highly toxic to humans and animals in case of ingestion, skin and eye contact, and inhalation, and it is proven to be very harmful to aquatic life forms. Black liquor can be used for energy production and the chemicals contained can be recovered with the proper technology. Current bleaching research focuses on the use of new chlorine-free (TCF) bleaching additives to improve the effectiveness of bleaching, while reducing the environmental impact.

In 1995, paper plants discharged 3.2 million tons of COD (Chemical Oxygen Demand), accounting for 41.8% of total industry pollution load. In 2004 discharges reached 1.48 million tons of COD, accounting for 33% of the total industrial pollution. Although the paper industry is a major polluter, it only contributed 2.2% of the country's economic growth. Sixty per cent of the pollution caused by China's pulp and paper sector comes from non-wood paper mills (Savcor Indufur Ltd., 2007). The data gathered in 1995 prompted the authorities to redefine environmental standards and to close down obsolete plants, resulting in the shutdown of more than 4 000 paper mills (Paananen P., 2005).

In October 2006, the International Finance Corporation (IFC), supported by the Finnish Ministry of Trade and Industry, concluded a major study on the pulp and paper sector in China. The technical assistance project was supported by two leading Finnish consulting firms – Savcor-Indufor and Pöyry Forest Industry – as well as the China Paper Association and the China National Pulp and Paper Research Institute. The study suggests renovating obsolete non-wood pulp and paper plants in order to secure jobs, solve China's wood deficit problem, and reduce the environmental impact, as well as to lower water and energy consumption. Non-wood paper industry sustains, directly and indirectly, eight million people. This cleaner production approach would also promote the conservation of forestlands. At present, China imports most of its wood fibre, but the country has abundant and under-utilised non-wood fibre resources (China Paper Association, www.chinappi.org and Savcor Indufur Ltd., 2007).

Giant Hemu Corporation

Beijing Giant Hemu Technology Co., Ltd. (Giant Hemu) is a joint venture company founded by the "China Environment Fund 2002 & 2004, LP", which is managed by Tsinghua Venture Capital Management Co., Ltd. ("THVC"), and has, among others, capital support from the Asian Development Bank (ADB), the IFC, Capital Steel Group, and other domestic investors.

Giant Hemu owns a patented technology for clean pulping and comprehensive use of renewable resources. This technology allows for clean production in pulp preparation, as well as the production of a multi-element organic compound fertiliser from the recovered substances (that can be used, for example, against desertification and in agriculture). This technology allows a zero discharge target of black liquor to be met, and the reduction of the discharge of pulp mill pipe-end effluent below the legal minimum, thus giving medium or small paper mills an opportunity to survive under the new strict environmental regulations in China. This innovative technology won an important national award from the Chinese Academy of Sciences and the State Environmental Protection Administration. The inventor of the technology worked for the Chinese Academy of Science. After he retired he looked for a partner to turn his research into a product, and he partnered with Giant Hemu.

To test the technology, and to sell its own pulp, Giant Hemu constructed two clean pulp plants in Linzhang in the Hebei province, employing 260 people. As at April 2007 it was constructing three additional plants in Jiyuan in the Henan province, and was actively hiring hundreds of additional workers. It planned to employ around 800 people in total by the end of 2007. The plants have a production capacity of 20 000 tons of pulp and additionally produce 50 000 tons of cement water reducing agent and 150 000 tons of organic compound (fertiliser).

Gaint Hemu purchases 300 000 tons of agricultural waste and straw every year as feedstock for the pulp, lignin, and compound fertiliser production. The company's technology can reduce 14 000 tons of CO_2 and 40 tons of SO_2, as well as 100 tons reduction of smoke and dust per 10 000 tons of straw, compared with the coal burning. In total, Giant Hemu calculates that its technology can reduce 420 000 tons of CO_2 per year.

De facto, Giant Hemu turns a highly polluting papermaking process into useful by-products such as fertilisers or water reducing agents, this while producing pulp without using precious wood. The company hopes to export its technology to neighbouring Asian countries.

In an interview, a representative from Giant Hemu considered that the opportunities created for the company derive directly from the new environmental protection policies and related laws and regulations, which have created the necessary climate for the company's development: paper mills either must comply with the new standards or have to close.

For Giant Hemu, R&D is key to effectively push the technology to the market and to become the top clean pulp technology provider in China. The main difficulty in developing clean pulping technologies lies in the huge amount of investment needed. A second and important difficulty is to obtain enough funding and support from the Chinese government. The company currently benefits from a tax exemption measure for the development of environmentally-friendly technologies.

The company's R&D centre is based in Beijing, near policy makers. It is also relatively close to the pulp and paper market and to research institutions. In order to achieve its targets, the company co-operates with universities, scientific institutions, and customers to improve its technology. The main reason for co-operation lies in the availability of highly-skilled researchers and in their R&D experience. At the time being, Giant Hemu prefers not to co-operate with foreign companies, seeing them as unfamiliar with the specific situation of the country.

Co-operation with institutions is done on a project basis, because this kind of partnership covers the actual needs for R&D, focusing only on what is really necessary at this specific time. Long-term co-operation is seen as too expensive, and short-term co-operation as not having the necessary depth. Co-operation is never done horizontally with competitors, but vertically with clients in order to complement each other's needs. This kind of co-operation is not seen as particularly dangerous or having particular disadvantages.

Giant Hemu's representative believes that the main reasons for carrying out R&D for his company, as a leader in this technology field, lie, firstly, in the need to create products that meet Chinese environmental regulations and in improving the company's image. Secondly, it is important to carry out R&D to comply with regulations abroad and therefore be able to export products, to reduce costs for the client thanks to more efficient production, and to access new markets and improve its market share. R&D carried out as a need to react to competitors' innovations ranks only third, and is rated of lower importance. Giant Hemu is investing its energy in testing and implementing its technology as fast as possible and is not focusing on monitoring and reacting to competitors' technological innovations.

The major reasons for carrying out R&D in China, compared with doing it abroad, are the cheaper infrastructure and research costs; the availability of large numbers of qualified engineers and scientific experts; and the presence of centres of excellence such as science parks, universities, and institutes.

Wind energy: Vestas

Wind energy in China

China is the second largest consumer of energy in the world, and it is expected to soon become the first. It therefore has a very high motivation to invest in renewable energies, and especially in wind energy production. The government ratified the Kyoto Protocol and has given some signals to show that it is a "responsible member of the global community". For example, Beijing pledged to stage a "Green Olympic Games", which would be more environmentally friendly than any previous Games. The 2008 Beijing Olympic Games will use different renewable-energy technologies and 20% of its power will be supplied by wind-generated electricity.

In response to the energy crisis, pollution problems, and commitment to the international community, China has passed numerous governmental policies to support renewable energy expansion and particularly wind power. The National Development and Reform Commission (NDRC) is in charge, at the national level, of renewable energies planning and implementation, and does so by releasing policies, approving projects, and setting tariffs.

China has set clear goals for wind energy production. Promulgated by the NDRC, the renewable energy law (effective since January 2006) set the goal to produce 30 GW[12] of wind power by 2020. The production, in 2005, was 2.5 GW. This means that China will need to install two GW of wind energy each year between 2006 and 2020, or install 1 000 innovative wind turbines (two MW each) per year. The NDRC also mandated the compulsory purchase of renewable electricity by utilities (wind farms), it set a reduction of VAT from 17% to 8.5% and the goal of achieving 5% of electricity purchases by 2010 and 10% by 2020 from renewable energy sources.

The power grid is 100% state owned and 75% of generation is owned by the central government, 20% by local governments, and 5% by foreign/private investors. This is important since wind power customers are the entities generating power and controlling the grid.

Current regulations and policies on renewable energy promote technology transfer and the development of local players. These include:

- The “Renewables Law”: grid operators are obliged to support renewable suppliers. They have to accept any energy from renewable suppliers at any time, and incur penalties for failure to support them;
- The “Renewable Energy Industry Development Guidance Catalogue” is a catalogue of projects eligible for tax breaks, such as design, manufacturing and support systems, equipment, components, and materials;
- The “Circular Regarding Requirements of Administration of Wind Power Construction” regulates location of projects (close to grid) and requires 70% of local equipment content;
- The “Relevant Provisions for the Administration of Generation of Electricity using Renewable Energy Resources”: NDRC approval is required for projects of 50 000KW or more, and confirms the policy of passing on excess costs to end-users;
- The “Ride the Wind Programme”: the goal is to attract cutting edge technology in wind turbine manufacturing (successful joint ventures include those with NORDEX, Germany; and MADE, Spain);
- The “National Debt Wind Power Programme”: encourages use of locally-made turbines through soft loans, as compensation for the risk of using such turbines. These loans funded the construction of demonstration project wind farms with a total installed capacity of eight megawatts. This programme has now been completed.

China’s wind energy industry

The wind turbine industry is currently dominated by foreign wind turbine producers but domestic producers are quickly catching up with the technology expertise of the mature foreign players. China’s domestic wind turbine industry has been developing for over 20 years but is still considered to be in an early phase. By 2002, there were nearly 10 wind turbine generator manufacturers in China: six generator manufacturers, two joint ventures, and three research and development entities. By the end of 2004, the

12 The goal was initially set at 20 GW, then raised to 30 GW following industry pressure. It is estimated that this goal will be reached earlier than planned.

installed capacity of locally-made wind turbine generators reached 48.5 megawatts, accounting for 18% of China's accumulated wind turbine generators. That figure increased to 28% by 2005. China still has to import 90% of its large-capacity wind turbine generators. The table below shows the growth in the wind turbine market from 2003 to 2005:

Table 1. Wind Turbine Market in China (estimates in USD million)

	2003	2004	2005
Total Market Size	61.900	188.600	315.300
Total Local Production	26.000	79.000	104.200
Total Exports	0.020	0.400	0.400
Total Imports	35.900	110.000	211.500

Source: Based on Gordon, F. (2006).

Vestas

Vestas is the world market leader in wind technology and a driving force in wind power R&D. Vestas' core business comprises the development, manufacture, sale, marketing, and maintenance of power systems that use wind energy to generate electricity. Vestas started to manufacture wind turbines in 1979 and began to grow thanks to the preferential wind power policies instituted in Denmark, its home market, in the 1980s, and in the United States, one of its largest markets. It has played a leading role in the industry ever since. In 1987, Vestas began to concentrate exclusively on wind energy and since then, the company has grown from a staff of around 60 to a global corporation with more than 10 000 employees.

Vestas' strategy is to supply customised wind power solutions based on standard wind turbines and standardised options that can generate electricity of the optimal quality at the most competitive price. Trusting that wind will be perceived as an energy source equal to oil and gas, Vestas has formulated its vision as: "Wind, Oil, and Gas" (www.vestas.dk).

Vestas distinguishes itself from many of its competitors by a high degree of vertical integration. It manufactures all core components in-house and purchases only standardised parts from external suppliers. By manufacturing the principal parts of the turbine itself, Vestas increases the flexibility of its product development, reduces its dependence on suppliers, and maintains its high level of manufacturing know-how. This strategy also warrants a high commitment to R&D.

The principal factor that has been driving the wind power industry's success over the last decade is the falling price per kWh. Since wind power solutions are sold from business to business and the central competitive parameter is price per kWh, technological innovation is essential: if Vestas wants to retain its market share and develop it markets it must have a strong R&D commitment. So far the technology race for reducing kWh cost has been "won" by Vestas but the increasing complexity of wind turbines has dramatically increased R&D costs.

Vestas sold its first turbines in China in 1985. Its Beijing Representative Office was established in 1997. In 2004, the total installed capacity amounted to approximately 400 MW and Vestas had a market share of 50%. China is considered to be of strategic importance for the future development of Vestas. The company decided to shift focus from the USA (which has not ratified the Kyoto Protocol and, in the companies' view, has not given any clear indication of concrete domestic targets for renewable energy use) to China (which has made a clear commitment towards increased use of wind power).

The company has two key R&D locations: the headquarters in Aarhus (Denmark) and an R&D offshore centre in Warwick (UK). Additionally it has a technology sourcing office in Shanghai. Because of Vestas' commitment to lead through innovation and patents ("Vestas will be the leader in patenting new technologies") and future plans in China, Vestas opened a new technology R&D centre in Asia. The new centre trains staff in Asia, in order to put technology development and trends into a new and wider perspective and support the sourcing office in Shanghai. It is also responsible for the systematic patenting of core technologies.

The choice of the location was kept secret as long as possible, and there was speculation whether the centre would be opened in China, India, or Singapore. One of the problems Vestas had to face was the "innovator's dilemma": how much knowledge to give, and in which form, in order to access the Chinese market, this being a strategic necessity in order to keep sales going and further reduce costs.[13]

In 2005, and before a decision was made to open the centre elsewhere, the following information was gleaned from an interview with the Head of R&D Projects at Vestas' R&D centre in the UK. He mentioned the following reasons in favour of locating an R&D centre in China:

Getting close to the Chinese supply chain: Seventy per cent local production is required for all projects in order to obtain a construction permit. Vestas cannot meet this requirement yet, but must ally itself with a range of local subcontractors. One of the key functions of the R&D centre would be quality control of these subcontractors and co-operation in R&D so they can meet Vestas' high quality standards. The R&D centre would also be in charge of examining the potential of the supply chain and creating a strategy to exploit the local supply chain. Being located in China, it would have the advantage of better understanding the local culture and environment.

- *Proximity to market*: since the Renewable Energy Law is expected to effectively boost the wind power market in China from the beginning of 2006, it is essential for Vestas to have the right connections and meet the requirements in order to win the large projects. One strategy is to set up R&D in China in order to have technological expertise closer to the decision-making entities.
- *Proximity to existing production facilities*: a location close to the existing representative office in Beijing or the production facilities in construction in Tianjin would yield significant advantages. For example, it would greatly reduce administration and set-up time, and the new R&D centre could rely on an already-existing network.
- *Hiring highly qualified R&D personal*: a location in Beijing would give access to the people with the right key skills. The vast majority of Chinese wind power research institutions are also situated in Beijing, for example, Tsinghua University. There is a clear possibility of being able to set up joint ventures with these institutions.
- *Government incentives*: China offers tax relief for setting up R&D, as well as land for the physical placement of the R&D centre. If it was situated in Beijing, it would enable co-operation with government experts in controlling institutions. Since 95% of the power generation and 100% of power grid is owned by either central government or local government it is of outmost importance to have strong connections to the controlling institutions – primarily the National Development and Reform Commission.

The following reasons spoke against locating Vestas' new R&D centre in China:

[13] The "innovator's dilemma" is explained in more detail later in this report.

- *Intellectual property rights (IPR) protection*: the government's strategy is to nationalise the wind industry. One of the reasons for the 70% local production requirement is to ensure technology transfer to the country' producers (and future competitors). There is a strong sense that technological edge is what drives Vestas and an understanding that intellectual property is of utmost importance: "We are fully aware that only through well-protected patents, we will be able to protect our future earnings". But even if Vestas systematically patents its core technologies, it may very well see itself creating strong Chinese competitors not only on the Chinese market but also on the global market. This is due to the fact that IPR protection has proven to be very difficult in China. If Vestas collaborates with the local subcontractors in R&D, they may very well be working against their own interests. With the same technology, or only a slight technological advantage in Vestas' favour, the company would lose the Chinese market since local companies would probably be able to offer slightly cheaper prices for the same technology when competing for the concession orders.
- Cultural and language differences: there are a number of potential problems – cultural integration and effective communication are potentially the most difficult to overcome. Very few people in Vestas speak Chinese. This problem is however not underestimated at Vestas and Chinese language programmes have been set up internally within the company. Furthermore, Vestas intends to grow slowly and also provide English language courses for its Chinese staff. Since the common core of communication will be technological, this is perceived as a starting point.

The company finally decided, and announced in February 2006 that its new R&D centre would be built in Singapore. When fully established, the new USD 500 million R&D centre will employ more than 150 people. The centre was scheduled to be put into operation in 2007.

6. Environmental innovation in China: key drivers and obstacles

This section summarises the incentives for Chinese and foreign enterprises to innovate in China, and the obstacles to innovation, based on the recent literature and the three case studies.

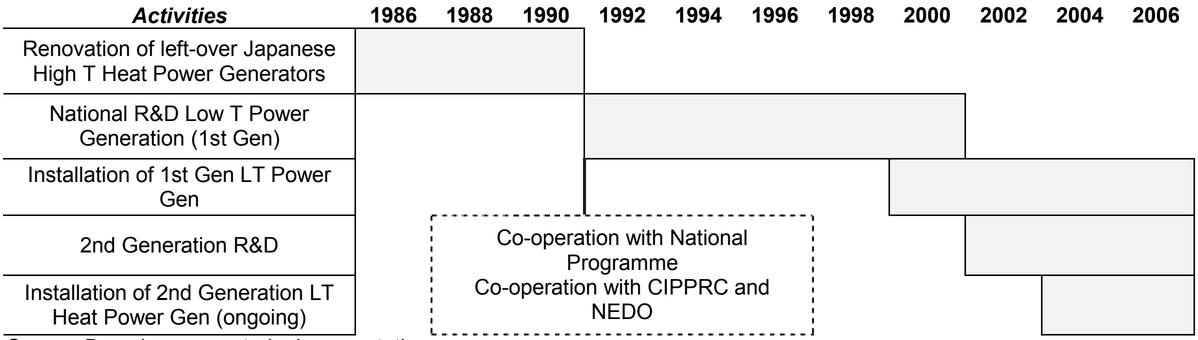
What drives Chinese companies to innovate?

The shift in government approach to environmental problems, and tightened environmental laws and targets are having a clear impact on companies' approach to environmental issues. This can be measured, *inter alia*, by the number of polluting plants closed and of new plants having to undergo environmental impact assessment before being allowed to operate. However, while the regulatory framework plays a key role in providing a framework that induces change, a number of other factors play an important role for Chinese companies to engage in environmental innovation.

An important factor for Chinese enterprises to innovate is the role of the State in promoting and supporting research. For example, both Giant Hemu and Dalian East acquired their technology through co-operation with national scientific institutions. The core technology of Dalian East was initially developed by analysing Japanese equipment. Through a nationally-funded key research programme, national competences have been developed: the technologies were first adapted to work with local equipment, and then with Japanese equipment as a benchmark, and since then efficiency has been continuously improved.

Figure 5.

Figure 6. Figure 6. Timeframe of development of Dalian East's heat recovery power generators



Source: Based on case study documentation.

Note: NEDO co-operation may have started even earlier; information on co-operation is vague and may not be accurate.

The first technology generation took around 10 years to be developed, while the second generation took half as much time and led to national patents. There is not enough detailed data to fully understand why and how the research and development was able to accelerate, but it seems that since a first co-operation with the Japanese New Energy and Industrial Technology Development Organisation (NEDO), during the nineties, the development time has been reduced. Other reasons may be experience gathered with past developments, better research equipment, and simultaneous engineering. For the second generation, Japanese products have been taken as a benchmark to set clear development targets.

Giant Hemu's technology originally came from research at the Chinese Academy of Science. Then, the inventor of the technology, upon his retirement, transferred the know-how to Giant Hemu. The company and the inventor then looked for capital and set up two production plants to implement and test the technology (and also earn from pulp sales). Two years later, they added three more plants.

In both cases the core technology comes from national research programmes: the pulp and paper, and cement industries are important sectors of the Chinese economy, and the government funds specific national research programmes to improve energy efficiency and emission reduction in an economically-effective way. While government R&D programmes were crucial for the development of technologies in Giant Hemu and Dalian East, on the other hand, a clearer separation of roles between government and the private sector would be beneficial to stimulate the development of the environmental industry (see the section on the environmental industry in China).

Innovation patterns in Chinese companies

An "Innovation Survey of Industrial Enterprises of China – an Overview and a Comparison with CIS" (2007) was performed by the National Bureau of Statistics of China and Statistics Sweden. The first part consisted of a questionnaire sent to Chinese enterprises on their investment and innovation behaviour. The second part was a comparison with the innovation behaviour of European enterprises, from their answers to the same questionnaire. Concerning Chinese enterprises' innovation behaviour in the manufacturing sector, findings were:

Innovation-active enterprises: among the surveyed enterprises, 30% had innovation activities in the observation period 2004-2006.

A breakdown by "size class" revealed that the share of large and medium-sized enterprises with innovation activities is much higher than the share of small enterprises.

The breakdown of different types of innovation activities suggests that intramural R&D and acquisition of machinery, equipment, and software, as well as training, are the most frequently conducted innovation activities across all different size classes among innovation active enterprises. Extramural R&D and acquisition of other external knowledge are conducted less frequently.

Generally speaking, the share of innovation-active enterprises that co-operated in their innovation activities was rather low, at around 15%; therefore the majority of enterprises undertook their innovation activities independently. Larger enterprises seemed to be more engaged in innovation co-operation than smaller ones;

Product-oriented effects such as increased market share, improved quality, and range of products are the most important effects of innovation for Chinese enterprises.

Financial resource-related impeding factors exist due to the functioning of the Chinese financial system. The low technological standards (immature technologies, mismatch between new technology and production capacity, and lack of technical personnel or "brain drain") are the most important hampering factors for Chinese enterprises in undertaking innovation activities.

What drives foreign companies in China to innovate?

The Business Confidence Survey (2007), led by the European Chamber, presents European Union investors' reasons for investing or expanding their activities in China.[14] For the last two years, EU investors' most important reason for investing in China has been marketing products and services, rather than taking advantage of the country's low labour and sourcing costs, as is widely believed. The second most important factor behind the decision to set up a business in China is to keep closer control over suppliers.

According to that survey, and concerning R&D, European enterprises showed a strong interest and willingness to invest in R&D centres in China, especially among large companies. Among the surveyed companies with more than 100 employees, 31% have already set up R&D centres in China, and 32% want to open or enlarge their R&D centres in the next two years.

The primary motive for investing in R&D and building up capacity in this area is the opportunity to lower their development costs for products sold on the Chinese market. Another main reason that motivates companies is responses to the market. They need to develop, adapt, or improve their product range in order to meet the needs and preferences of Chinese customers, as well as to meet the standards and regulations of the Chinese market at a manageable cost level.

These drivers are also reflected in the case study of Vestas, which focuses on the company's decision to set up an R&D centre in Asia, and its consideration of different locations. Key considerations in favour of doing R&D in China were to gain better access to the local market and supply; to acquire skilled engineers; to reduce R&D costs, through consistent tax incentives and relatively lower personnel costs compared to other locations; and to gain access to key governmental officials.

If a company wants to sell to China it needs to adapt its products to local needs; and if it wants to adapt products, it needs to co-operate with suppliers for integration, and with customers to understand their

[14] The survey covered many sectors, and did not focus on the environmental industry in particular.

needs. Additionally, research costs can be relatively reduced and advantages can arise from governmental support. However, as the case study of Vestas also shows, carrying out R&D in China also means partially distributing know-how to local companies, which could sooner or later become potential competitors. Vestas did not feel confident enough to be able to protect its advantage if it carried out R&D in China (see the description of the "innovator's dilemma" below), and therefore opted for Singapore for its research unit.

It should also be noted that competition does not only come from local Chinese companies that are working hard to catch up, but also from foreign players who may decide to do R&D in China, and give up part of their technology, in exchange for (potentially) more efficient localised R&D.

What prevents foreign companies from innovating?

The "innovator's dilemma"

The "innovator's dilemma" affects many foreign companies that carry out R&D in China. The problem facing foreign investors is that China's governmental policies tend to lean towards domestic market growth, and many Chinese policies are drafted to promote local Chinese companies' development. This means that the government wants domestic companies to advance in technology and skills in order to provide cheaper and just as effective solutions to the country. This creates a dilemma for foreign investors who want to carrying out R&D as well as manufacturing in China: transferring technology means creating local competitors, but at the same time it is the only way to gain access to the Chinese market.

Foreign manufacturers have the advantage that their top tier technology is ahead of its time compared to local producers and that it can be sold at a premium. Because of this premium, the Chinese government is putting policies in place to help the domestic market and small R&D companies to absorb the technology in order to develop it at a lower cost.

Taking the wind turbine sector as an example, this creates a long-term challenge for foreign wind turbine producers. Because, in the short run, the Chinese wind turbine producers will not catch up with the technology expertise and will be positioned in the lower market segment, foreign producers can continue to sell their wind turbines at a premium, although somewhat reduced price, thanks to the transfer of production and product development in China. Yet, in the long run, Chinese companies will re-engineer, somehow gain access to, or recruit top R&D experts in order to gain technology "know-how" and start to climb the ladder to gain access to higher market segments. For this reason, many leading manufacturers are unwilling to license proprietary information for fear of creating competitors, especially in developing countries where companies may easily create an identical, but cheaper, product due to lower labour and materials costs.

In other words, foreign producers will need to compete with local companies in foreign territory. To stay always one step ahead, innovating faster is compulsory, putting the accent on reaching faster R&D output than competitors. If, on the one hand, there is a (possibly controlled) drain of knowledge due to selling turbines to the local market, on the other hand, there is also the opportunity to lower global costs through flexible and cost-efficient production, as well as access to large numbers of qualified engineers and scientific experts, and the presence of centres of excellence such as science parks, universities, and institutes.

IPR protection

Infringement on intellectual property rights is another issue that prevents foreign companies from innovating more in China. Since China joined the World Trade Organisation and signed the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS), the Chinese patent system is in line with international standards and conventions. As a consequence, applications to the Chinese Patent Office have picked up considerably. Nevertheless, the situation still falls short of the needs of both domestic and foreign-owned innovative enterprises operating in China. Infringement of intellectual property rights (IPR), particularly of copyright and trademark, remains a concern (OECD, 2007b).

The lack of effective IPR protection affects innovative activity in China in various ways (OECD, 2007b):

Foreign firms hesitate to transfer technology to China: the threat of IPR infringement may even limit their willingness to produce in, or even export goods, to China.

Concerns about IPR protection have reportedly reduced Chinese investors' propensity to commercialise the results of their R&D.

IPR infringements, combined with low standards of quality, may also affect the national and international reputation of Chinese firms, notably when poor quality affects the health and safety of consumers.

In contrast, sound IPR policies can facilitate the transfer of research results from public research organisations to business enterprises and from foreign firms to the Chinese economy.

Partnerships as a model for innovation?

In the case studies included in this paper, Giant Hemu and Dalian East made partnerships on a project basis. This was instigated by the fact that, on their own, the companies would not have had the necessary capital nor research skills to develop and implement the technologies, from scratch, in a reasonable timeframe. Co-operation created the necessary synergy for success.

For Vestas, co-operation in China would appear to be more of a drawback than an advantage. However, it developed the technology also thanks to governmental support in the home country and it is now strong enough to do all its production in-house.

At present, partnerships involving foreign investors must be Chinese majority-owned. They generally take the form of a joint venture. One example are CDM projects. Given the particular form of this kind of project, CDM projects are expected to be the source of increased transfers of ecological technologies.

Some studies analyse what factors improve host countries' ability to attract technology transfer through the CDM. The study by A. Velasco (2007) has narrowed down the definition of technology transfers to "transfers of technologies that are not business-as-usual in the host country and where the knowledge and resources necessary to make them operational do not exist in the target location". The results from this study found that 35% of the CDM projects considered involve transfers of new technologies. It was also found that some countries have a higher potential to attract new technologies than others. China is among these, since it attracted the highest number of CDM projects with transfers of new technologies. Moreover, technology transfers are found more frequently in larger projects involving foreign investors.

This study also showed, through a model developed by the author, that 32% of the variation in new technology transfer through the CDM could be explained by the following key variables:

Countries with high Foreign Direct Investment (FDI) have a relatively high probability to receive new technologies through the CDM.

Countries with experienced, transparent, and effective climate policy institutions have lower transaction costs with regard to CDM investments and are more able to attract technology transfers [15].

Countries with a large hydropower capacity have a lower ability to attract new technology transfers through the CDM, as they usually have already developed local technologies to exploit this resource and have low emissions in their greenhouse gas (GHG) emissions baseline due to the high percentage of renewable energy in their generation power mix.

These results are reflected in the case of China, since this country has one of the highest potentials to attract new technology transfers. First, it has attracted the highest FDI inflows among developing countries. In 2006, China and Hong Kong (China) remained the largest FDI recipients among all developing economies, attracting USD 69 billion and USD 43 billion of inward FDI respectively (UNCTAD, 2007).

Partnerships with local companies emerge as a model for innovation and a way to quickly bring new locally-developed knowledge to the market. In the specific cases of CDM projects and the Chinese context, foreign investors are likely to play a significant role in technology transfers, especially in the areas of renewable energies, biomass, energy-efficiency, and methane recovery and utilisation.

In conclusion, there is still a huge potential for environmental innovation and investment in the environmental industry in China. Many stakeholders play a crucial role in realising this potential, primarily government at all levels and the domestic environmental industry sector, but also the financial sector, responding to financing needs and devising innovative financial mechanisms, foreign investors contributing expertise and high quality technology and civil society, raising awareness and demand for environmental quality.

[15] For example, Point Carbon provides carbon price forecasts and analysis of greenhouse gas emissions trading markets (http://www.pointcarbon.com/). It was founded in 2000, and is the institution of reference on the Carbon World Market. It counsels enterprises, governments, and international organisations.

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