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An Emerging Revolution: Clean Technology Research, Development and Innovation in China

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Technology has long powered human progress, and remains central to global development. In the decades ahead, developing and deploying clean energy, low carbon technologies will also play a crucial role in countering perhaps the biggest global threat of our times: climate change.

Our ability to deploy effective technologies, on a scale large enough to significantly reduce greenhouse gas (GHG) emissions, depends on two key factors: the direction, and the pace, of technological innovation. The direction of technological innovation, to a large extent, is contingent on a balanced, technology-neutral approach to energy policy (Weiss and Bonvillian, 2009; Diazanadon, etc. 2009). The pace of technological innovation, on the other hand, depends on a range of factors including, critically, the presence of effective domestic policies to spur research and innovation. Such policies will be particularly important in major developing countries whose emissions are accelerating and which lack the long established research and development (R&D) infrastructure of industrialized countries.

This working paper examines efforts made by China – the world's largest gross emitter of greenhouse gases – to create an enabling environment for R&D and innovation in the field of clean technology. The goal is to highlight how governments in developing countries can craft effective technology policies against the backdrop of a pending international climate agreement expected to trigger significant new financing for clean technology assistance. The paper summarizes China's policies to prioritize, fund and deploy clean technology R&D and innovation over the short and medium term. These comprehensive policies reflect China's ambition of emerging as a global power in science and technology through clean technology R&D and innovation.

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1. MEDIUM TERM TECHNOLOGY DEVELOPMENT

China is keenly aware that the next phase of the science and technology revolution will center on clean energy, and is determined to emerge as a global power in science and technology development. By staying at the forefront of the clean energy revolution, China hopes to transform the label "made in China" to the moniker "created in China."

In pursuit of this goal, in January 2006 China's government published the Medium-to-Long-Term Science and Technology National Plan (S&T National Plan). The plan establishes the government's front-and-center role in determining the direction, quality, and quantity of China's R&D and innovation efforts to 2020. The plan sets four quantitative targets and five strategic focuses, under which there are 11 key fields and 68 priority subjects. Of the five strategic focuses, top priority is given to developing technologies related to energy, water resources and environmental protection (Table 1).

2. SHORT TERM TECHNOLOGY DEVELOPMENT

Based on the S&T National Plan, the Ministry of Science and Technology (MOST) formulated the National 11th Five-year Development Plan of Science and Technology. This provided short-term targets and goals for China's R&D and innovation activities from 2006 to 2010. Consistent with the S&T National Plan, the 11th Five Year S&T Plan lists energy and environmental protection as key areas to be targeted. Specifically, the plan highlights three key clean technologies: building key energy-saving technologies, 2-3 MW wind turbine commercialization, and high quality transmission technology and equipment (±800 KV DC/AC 1000 KV UHV).

Table 2 | **China's 11th Five-Year S&T Plan: Key Elements**

BY 2010
Invest 2% of GDP in R&D
Reduce China's dependence on foreign technologies to 40%
Increase the contribution of technologies to economic growth to 45%
Rank in the world's top 10 countries in citations used in international science paper
Rank in the world's top 15 countries in patents granted
Increase the ratio of added value of high-tech products versus added value of manufacturing reach to 18%
Have 50 million people working in the field of S&T, including 7 million scientists, technicians and engineers
Data source: China Ministry of Science and Technology

3. FUNDING OF CLEAN TECHNOLOGY R&D AND INNOVATION

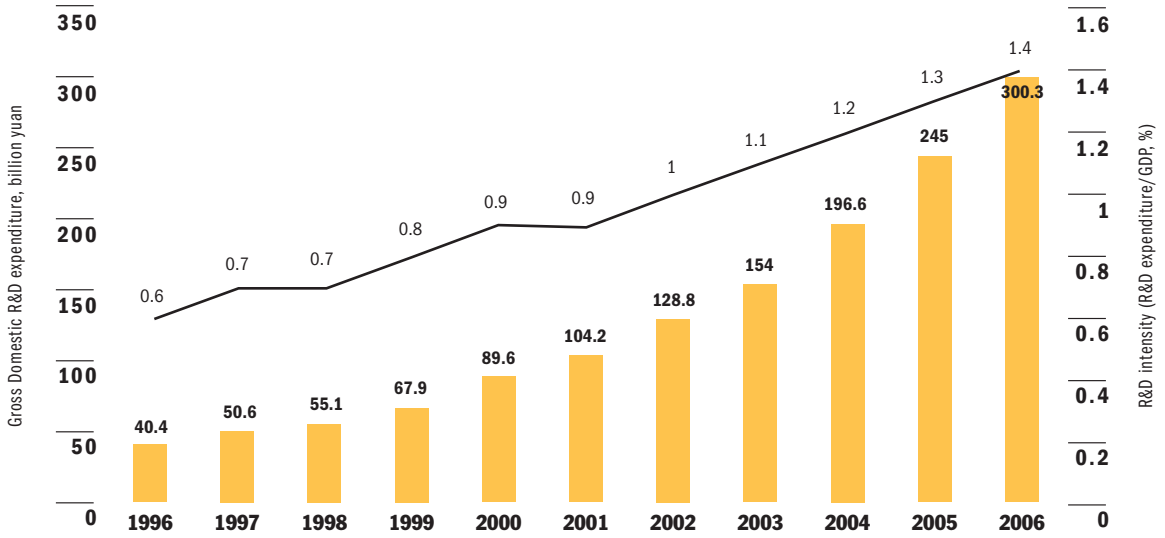
In the past five years government R&D appropriations have increased dramatically, from 70.3 billion yuan ($11 billion) in 2001 to 168.9 billion yuan ($26 billion) in 2006. As a result, the share of R&D in total government expenditure increased from 3.7% to 4.2% 2001 - 2006 (MOST 2007). Among the various publicly-funded S&T programs (Table 3), the 863 & 973 programs provide the most direct funding sources for clean technologies.

863 Program: Also known as the State High-Tech Development Plan, the 863 Program was created to stimulate the development of advanced technologies in a wide range of fields in order to render China independent of financial

Table 1 | **China's S&T National Plan: Key Elements**

BY 2020	
Four Targets	**Five Strategic Focuses**
Invest 2.5% of GDP in R&D	Develop technologies in energy, water resources and environmental protection
Reduce China's dependence on foreign technologies to 30%	Provide innovation in IT and new materials to improve China's technologies in manufacturing
Increase the contribution of technologies to economic growth to 60%	Develop biotechnology to further its application in agriculture, industry, human and health services
Rank in the world's top five countries in patents granted and citations used in international science paper	Accelerate the development of aerospace and marine technology
	Strengthen R&D in basic science and cutting-edge technology
Data source: China Ministry of Science and Technology	

Figure 1 | **China's R&D Expenditure and Intensity, 1996–2006**



Data source: China Science & Technology Statistics Data Book, 2007

obligations for foreign technologies. The title "863" refers to the date when the program was proposed, the third month of 1986. In that month, four Chinese scientists composed a joint letter to former Chinese leader Deng Xiaoping, proposing that the government establish a program to fund high-tech R&D. Deng Xiaoping swiftly

Table 3 | **Government Funded R&D in China**

PROGRAM	SUBJECT	FUNDING, BILLION YUAN
863: National High-Tech R&D Program	IT, energy, resources and environment, advanced materials, biotechnology and agricultural technology, advanced manufacturing and automation, marine, space and laser technologies.	20
National Natural Science Fund	Basic and applied research in the natural sciences with most funding directed to life sciences and engineering.	10.5
Key Technologies R&D Program	R&D in agricultural processing and biotechnology, key manufacturing technologies, IT and high-tech industries, environment, traditional Chinese medicine, and social development.	6.3
973: National Basic Research Program	Basic and applied research in energy, agriculture, information, environment, population, and health, materials and synthesis.	4
Innovation Fund for Small, Technology-based Firms	Development support in the areas of electronics and IT, biotechnology, materials, automation, environment and energy for technology-based small to medium enterprises (SMEs).	2.6
Agricultural Science and Technology Transfer Fund	Development support for agricultural technology generation, transfer and application.	1.4
National New Products Program	Publication of annual list of new products that contain self-owned intellectual property rights (IPRs), have high export potential, replace import products, are made primarily with domestic parts or that adopt international standards for support through grants and other policies.	0.7
Torch	Development support in areas of new materials, biological and medical technology, electronic information, integrated light and electronics and their machinery, new and efficient energy.	0.3
Spark	Support of R&D and S&T education for rural economies, advanced technologies for township enterprises, the improvement of labor conditions and skills, and the creation of sustainable agricultural technologies.	0.5
*Funds were allocated during 2001-2005.		
Data source: China Ministry of Science and Technology		

approved the proposal which has since played a vital role in driving China's science and technology development.

The program has changing focuses and priorities, depending on the needs of national economic development. During the 11th Five Year Plan, the 863 program set up 10 focus areas, including energy technologies. Within the energy category there are four technology priorities: hydrogen and fuel cell, energy efficiency, clean coal and renewable energy. A total of 1.12 billion yuan ($172 million) has been invested in these priorities, with hydrogen and efficiency technologies receiving the majority of funding (table 4).

Table 4 | **863 Program's Energy Focus - 11th Five Year Plan**

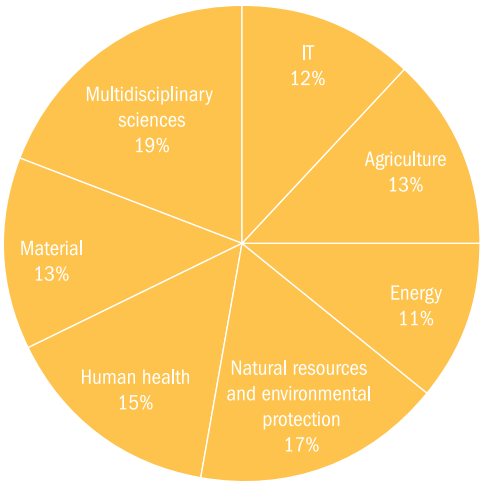
PRIORITY	FUNDING, MILLION YUAN
Hydrogen and fuel cell technologies	75/year
Energy efficiency technologies	75/year
Clean coal technologies	45/year
Renewable energy technologies	29/year
Data source: 2006 Application Guideline for 863 Program Energy Technology Field	

973 Program: Complementing the 863 Program, which focuses on specific technologies, is the National Basic Research Program, also called the "973 Program." The title "973" is again derived from the timing of the program's initiation, at the 3rd meeting of the National Science and Technology Committee in 1997. Since its inception, a core focus of the 973 program has been energy, natural resources conservation, and environmental protection. From 1998 to 2008, the program supported 382 projects with a total funding level of 8.2 billion yuan ($1.3 billion) (973 Program News 2008), of which 28% went to energy, natural resources conservation and environmental protection (Figure 2).

During the 11th Five Year Plan period, the 973 Program's energy focus and financing targets the following topics:

- Basic research on the distribution and safe mining of deep coal resources and coal-bed methane.
- Basic research on efficient and environmentally sound usage of coal.

Figure 2 | **973 Program Funding by Strategic Focus**

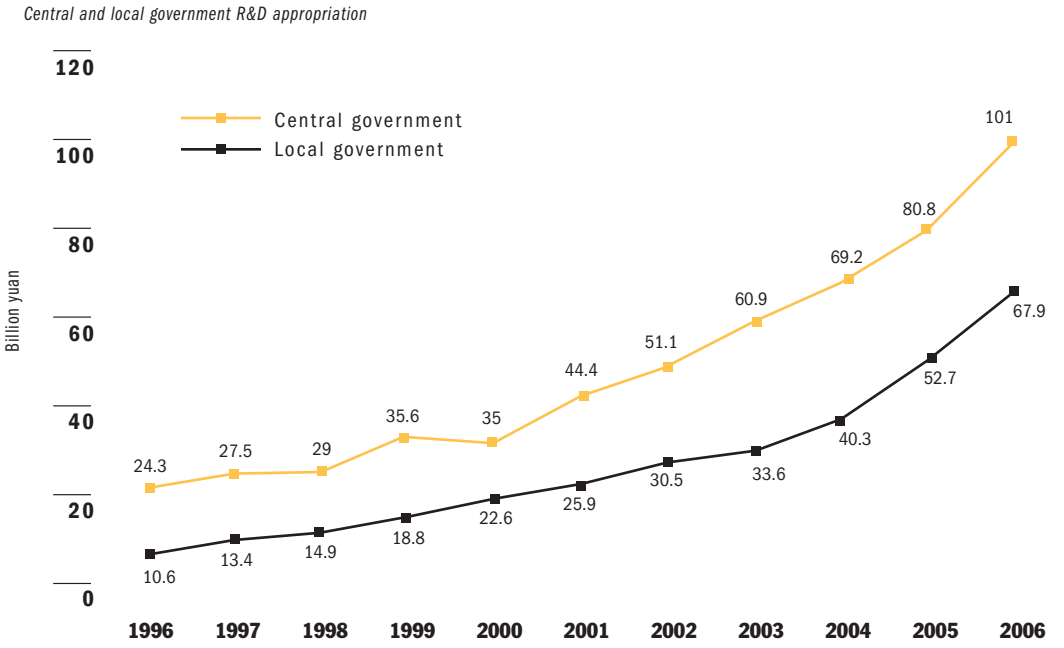


Data source: National Basic Science Research Data Base, 2004

- New theories and methods on more efficient exploitation and utilization of oil and natural gas.
- Major scientific issues related to China's large grid system.
- Key scientific programs related to large-scale and pollution-free production, storage and transmission of hydrogen fuel.
- Exploration of utility-scale renewable energy and new energy development.
- Exploration of large-scale nuclear fission and fusion development.
- Key scientific issues related to energy efficiency improvement.

Both the 863 & 973 programs are funded and managed by the MOST. At the local level, provincial and municipal governments are also actively involved in funding R&D. In the past 10 years local Chinese governments' S&T appropriation has steadily increased (Figure 3). In 2006, Shanghai topped the nation in R&D appropriation, with a total investment of 9.5 billion yuan ($1.5 billion). This accounted for 5.2% of Shanghai's GDP in the same year.

Figure 3 | **Central and Local Government R&D Appropriation in China**



Data source: China Science & Technology Statistics Data Book, 2007

4. PROMOTING INTERNATIONAL COLLABORATION ON CLEAN TECHNOLOGY

In November 2007, the MOST and National Development and Reform Commission (NDRC) jointly launched the International Science and Technology Cooperation Program (Cooperation Program) on New and Renewable Energy. The program's goals are twofold: diversifying the sources of technology imports, and expediting technology transfer processes between China and other countries. The program has identified five priority technologies for international collaboration (Table 5).

The program has greatly enhanced China's efforts in international collaboration. Already, China has signed 103 cooperation agreements with 97 countries (Wan Gang 2009). A significant number of these agreements have a focus on new energy and renewable energy development. The EU, the US and Japan are the top three partners China seeks collaborative opportunities from. In July of 2009, US Secretary of Energy Steven Chu together with Chinese Minister of Science and Technology Wan Gang announced plans for a joint US-China Clean Energy Research Center.

Table 5 | **Priority Fields for International Collaboration**

Technology	Details
Integration of solar power generation and building integrated solar technology systems	Solar and PV power generation system, thin-film solar cells, building integrated solar, low-cost, low-pollution and high-purity silicon material production, solar thermal utilization for industrial applications.
Biomass fuels and biomass power generation	Non-food energy crops and ethanol from cellulosic materials, energy forestry, bio-diesel, biomass briquettes and biomass gasification, biogas power generation and more.
Wind power generation	Wind energy resources assessment, large high-efficiency wind turbines, offshore turbines and wind farms.
Hydrogen energy and fuel cell	Technologies for the production, storage and transportation of hydrogen, technologies for new types of fuel cells and fuel cell automobiles.
Natural gas hydrates	Technologies for the exploration, development, storage, transportation, and utilization of gas hydrates.
Source: International Science and Technology Cooperation Program on New and Renewable Energy, 2007	

With initial financing of $15 million and headquarters in both countries, the center will focus on clean coal and clean buildings and vehicles. The plan highlights China's commitment to tackling climate change through enhanced international cooperation.

5. PROMOTING INDUSTRY-ACADEMIA RESEARCH COLLABORATION

In pursuing global leadership in clean technology development, China has identified partnerships between private industry, research sectors, and academia as a key approach.

The Ministry of Finance has formulated an array of favorable policies to encourage private sector investment in R&D and innovation via partnerships with educational institutions (Box 1), and the Ministry of Education has provided incentives to universities to turn their research into practical products. In addition, the MOST published Guidelines for Promoting Strategic Consortium for Industrial S&T Innovation whose purpose is to steer the direction of the partnerships, and enable their effectiveness. Many Chinese provinces have also set up demonstration bases for such consortiums. Guangdong Province, for example has a total of 64 bases, a number of which are devoted to clean technologies. The Yanming Wind Energy Technology Corporation, for example, teamed up with Tsinghua University, Beijing Aeronautics and Astronautics University and the New Energy Technology Research Center to form a demonstration base for large-scale wind power generation systems. Such synergies have facilitated clean technology deployment processes.

6. PROMOTING TECHNOLOGY EXPORTS

In common with other major economies, China has taken a series of measures to motivate enterprises, research institutes and universities to "go global." Since the publication of the Cooperation Program, China has hosted four high-profile international forums on new and renewable energy to exchange ideas and identify partners. Through various channels (including forums, dialogues, seminars and workshops), China's universities and research institutes are beginning to play active roles in

Box 1 | Policies to Stimulate Private Sector R&D Investment

Preferential tax treatments:
· Accelerated implementation of consumption VAT to allow for capital expenditure deduction
· Accelerated depreciation of R&D apparatus and facilities
· Increased deduction of R&D expenses from taxable income
· Favorable tax policies, including favorable taxation terms for venture capital to promote development of new products, technologies, and high-tech enterprises
· Preferential tax policies for R&D-focused small and medium enterprises
· Further support the establishment of overseas R&D centers
Favorable financing policies
· Provide loans to R&D-focused enterprises, and finance their imports and exports
· Encourage commercial banks to provide loads based on government guarantees and discounted interest rates
· Encourage venture capital investment with government funding and commercial loans
· Create a favorable environment for R&D enterprises to go public in overseas stock exchange
· Establish technology-oriented financing platforms
· Special funding for the absorption, digestion, and re-innovation of imported technologies
Government procurement policies
· Governments purchase domestically-innovated products and technologies
· Financial support to enterprises that purchase domestically-innovated products and technologies
· Establish technical standards through government purchases of domestically-innovated products and technologies
Protection of IPR and implementation of technology standards
· Further improve the national IPR system
· Create a legal system that respects IPR
· Prioritize the development of technology standards
· Actively participate in international standard-setting
Designation of high-tech development zones
· Build infrastructure for high-tech development zones
· Create a favorable policy environment for enterprises based in high-tech development zones
· Provide policy support to technology transfer center and other technology-focused intermediary service institutions
Data source: China S&T National Plan, 2006

major collaborative projects in the fields of energy efficiency and renewable energy.

With the ambition of becoming a global power in energy efficiency and renewable energy technology, China's major enterprises are actively pursuing opportunities around the world, especially in developing countries. To assist with the private sector's efforts, the Ministry of Commerce established the Department of Scientific and Technological Development and Trade in Technology. Under its auspices, governments at different levels have been deeply involved in technology transfer to other developing countries. This outreach includes helping Chinese firms to build a presence overseas; helping to train local staff in partner countries, and mandating "all-in-one service" (described below) as the way to transfer technology to local partners. The China Council for the Promotion of International Trade, for example, has hosted training workshops for government employees and workers from 91 developing countries in the past decade (CCPIT 2009).

The Ministry of Commerce's requirement of providing "all-in-one service" to technology users (MOC 2002) has simplified export procedures and helped provide both "hard" (equipment and facilities) and "soft" (expertise and know-how) technology transfer. For example, in September 2009 China's Dongfang Electric Corporation signed a contract with the Indian East Coast Electric Power Corporation to build a coal-fired power plant equipped with two 660MW supercritical units. The contract includes not only equipment and facilities but also expertise and services. Due to such package services, China's clean technology exports have greatly increased in the past five years. For example, Shanghai Electric Power Corporation's overseas sales have accounted for 45% of total revenue, up from 13% in 2006 (Autonet 2009). A majority of the increase comes from the export of supercritical and sub-supercritical technologies to developing countries.

CONCLUSIONS

This paper has examined an array of complementary policy measures that China utilizes to spur domestic R&D and innovation in clean technology. These measures include:

- designing a national-level S&T strategy prioritizing clean energy;
- establishing direct funding programs to support clean energy R&D;
- capitalizing on public-private synergies to bring together multi-sector expertise;
- pursuing a "going-out" policy of global engagement on clean energy development; and
- incentivizing (via a favorable policy environment) the involvement of the private sector in clean tech innovation.

The paper did not seek to provide a critique of these measures. Rather, it described the totality of China's clean technology development efforts as an example of the approaches that can taken in crafting effective, country-specific clean technology policy and development.

For developing countries, the bulk of technological progress comes from the adoption and adaptation of pre-existing but new-to-market technologies; and through the spread of such technologies across sectors, within a country (World Bank 2008). In the decades ahead, most of the growth in global energy demand – 90% by 2030 – will come from emerging countries. If greenhouse gas emissions are to be constrained, and a low carbon economy achieved, large-scale clean technology deployment is therefore especially vital in the developing world. Also critical is crafting an innovation model that fits the particular conditions and needs of developing countries.

China's comprehensive efforts to lay the groundwork both to achieve a domestic clean energy economy, and to assist other developing countries to do so, indicate its commitment to becoming a global player in the clean technology revolution. They also provide policy approaches and funding and partnership models from which other developing countries can learn.

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