Promotion of New Clean Energy Technologies and the World Bank Group

Background Paper for the World Bank Group Energy Sector Strategy

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Contents

Boxes

Figures

Tables

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Abbreviations

AMC	Advanced Market Commitment
CCS	carbon capture and storage
CDM	Clean Development Mechanism
CFL	compact fluorescent light bulb
CGIAR	Consultative Group on International Agricultural Research
CIF	Climate Investment Funds
CNG	compressed natural gas
CO_2	carbon dioxide
CSP	concentrating solar power
CTF	Clean Technology Fund
EE	energy efficiency
ESMAP	Energy Sector Management Assistance Program
G8	Group of Eight (industrialized nations, comprising Canada, France, Germany, Italy, Japan, the Russian Federation, the United Kingdom, and the United States)
GEF	Global Environment Facility
GHG	greenhouse gas
GW	Gigawatt
HVAC	heating, ventilating, and air conditionin
IBRD	International Bank for Reconstruction and Development
IDA	International Development Association
IEA	International Energy Agency
IFC	International Finance Corporation
IGCC	integrated gasification combined cycle
IPCC	Inter-governmental Panel on Climate Change
IPR	intellectual property rights
kWh	kilowatt-hour
LED	light emitting diode
LIC	low-income country
MEF	Major Economies Forum on Energy and Climate
MIC	middle-income country
MW	megawatt
MWh	megawatt-hour
Mtce	million tonnes of coal equivalent
OECD	Organisation for Economic Co-operation and Development
PPIAF	Public-Private Infrastructure Advisory Facility
ppm	parts per million
R&D	research and dvevelopment
RD&D	Research, development, and demonstration
RE	renewable energy
SMEs	small and medium-sized enterprises
SREP	Scaling Up Renewable Energy Program in Low-Income Countries
STAP	Scientific and Technical Advisory Panel
STI	science, technology, and innovation

UNFCCC	United Nations Framework Convention on Climate Change
WBG	World Bank Group

All dollar amounts are U.S. dollars and cents unless otherwise indicated.

Executive Summary

Progress in development and deployment of new clean technologies can help meet the World Bank Group's two objectives in the energy sector: to improve access to, and reliability of, modern energy services, and help shift to environmentally sustainable energy sector development. New technologies have the potential to increase the availability and the environmental sustainability of modern energy services through lowering the cost of securing cleaner energy and reducing the intensity of energy use.

Concerns about the threats posed by climate change have amplified interest in new energy technologies for low-carbon development. Analysis by the International Energy Agency (IEA), the Intergovernmental Panel on Climate Change (IPCC), and other leading policy and scientific organizations shows that keeping global climate warming below 2 degrees Celcius (^{o}C) most likely cannot be met without a revolution in energy technology (IPCC 2007; IEA 2008a and 2010a).

Some technologies offer promise in addressing both climate change and energy access goals. For example, pollution from nearly half of the world's population burning solid fuels inefficiently in traditional stoves may be a large contributor to global warming, in addition to posing a major health threat. Where the fuel is a woodfuel, unsustainable harvesting may also lead to deforestation.

"New" technologies encompass a wide range of hardware and operational knowledge, from the very large, complex, and knowledge-intensive (e.g., carbon capture and storage) to incremental, relatively low-tech improvements such as advanced-combustion cookstoves and green buildings. Some, such as biodiesel from sugar cane or algae, are still emerging from laboratories while others, such as industrial efficiency technologies, are extensively used, although only in some markets. Some technologies are very widely applicable (e.g., efficiency in buildings and appliances), while others are highly specialized or location-specific.

Consistent with their diverse characteristics, the development and deployment of clean energy technologies face widely differing market barriers. *Economic* barriers include high development and capital costs; limits on access to financing, aside from cost considerations; shortages of technical expertise; technology risks that are difficult to mitigate in regular financial markets, leading, *inter alia,* to the "valley of death" in commercialization; lack of internalization of environmental externalities of competing, high-emission energy sources; policy barriers (such as fossil fuel subsidies) that artificially reduce the competitiveness of new technologies; and various types of inertia associated with incumbent technologies. *Institutional* barriers include weak institutional capacity to support adoption of new technologies and to monitor and enforce performance standards as well as environmental regulations, information shortages, and cultural and social barriers to doing things differently. The role of *intellectual property rights* is a particularly contentious issue, although there is evidence that for many purposes this concern may be less serious for new energy technologies than in some other fields such as pharmaceuticals.

The World Bank Group's client countries are increasingly seeking support for developing, adapting, and deploying clean energy technology solutions to address a wide array of developmental, environmental, and energy-cost goals. China, India, and Kenya are among countries currently working with the World Bank Group (WBG) on technology assessment and support programs. More than a dozen countries are participating in the Clean Technology Fund (CTF), which finances scaled up demonstration, deployment, and transfer of low-carbon technologies. The focus on technology development and transfer in the climate negotiations is also indicative of increasing international interest in this topic.

The IEA, United Nations Industrial Development Organization, and many other international and bilateral agencies have programs supporting technology development and deployment in developing countries. These agencies are already collaborating with the WBG in some cases or have indicated their interest in cooperative relationships.

World Bank Group's Strategic Direction

The WBG has established support for new technology as one of the six action areas in its Strategic Framework on Development and Climate Change. The WBG also participates actively in a number of international programs as project developer, source of technical assistance, and donor fund trustee.

In carrying out these roles, the WBG has drawn upon extensive experience in finance, technical assistance, technology and innovation capacity building, coordination of global research and development and information sharing, and technology demonstration and deployment. Its strengths include 1) anchoring complex and large-scale developmental project finance; 2) providing high-quality technical assistance and policy expertise to governments, non-governmental organizations, and the private sector; 3) a modest but growing presence in early-stage, clean tech investing; 4) convening relevant stakeholders to forge coalitions and address cross-cutting challenges; 5) an established program of outreach and capacity building for staff on developments related to new energy technologies; and 6) broad global reach, experience, and expertise implementing development initiatives. The WBG's greater experience with new technology in other fields (particularly agriculture) offers valuable lessons.

In establishing its strategic direction for promoting clean energy technologies, going forward, the WBG needs to identify and select areas where its core competencies most substantially intersect with growing interests in low-carbon development and provision of reliable modern energy services. In so doing, the WBG can help devise interventions with high-impact outcomes that also contribute to the effectiveness of resources and efforts of governments and the private sector. There are several areas where the WBG can have such a role, including some activities already being undertaken. Opportunities arise in provision of financing, technical assistance, technology dissemination and innovation capacity building, and knowledge management.

The WBG has considerable knowledge and experience to draw upon in providing financing for clean energy projects. Clean energy finance already has been applied to market-ready technology deployment, adaptation to energy service markets in developing countries of technologies that have commercial applications in other countries or sectors, and, although to a very limited extent, late-stage development and demonstration of pre-commercial technologies. The WBG has been at the forefront of several realms of clean energy finance, including carbon finance, Global Environment Facility (GEF) grants, and blending concessional and commercial loans. These efforts can be refined and expanded.

The WBG also has considerable knowledge and experience in providing policy advice and technical assistance necessary for successful and efficient provision of new energy technologies. Examples include promotion of supportive regulatory frameworks for clean energy and reduction of subsidies for fossil fuels. These efforts are indispensible complements to the finance the WBG provides for successful, efficient, and sustainable provision of clean energy.

The WBG's strengths also include building capacity and exchange of information to accelerate deployment of new energy technologies in client countries. The exchange of information and creation of incentives for technical advance are important roles for which the WBG can draw upon successful experiences in non-energy areas. Global research consortia, exchanges, conferences, databases, technology competitions, and targeted institution-building can contribute to this goal. Such activities are also being promoted by many other national and international public and private organizations, and collaboration with others is essential for effectiveness and to avoid duplication.

Options for Consideration

The WBG can prioritize efforts to advance clean energy technologies as a contribution to supporting the goals of its energy sector strategy. This effort should start with a more detailed identification of the WBG's capacities in clean energy technology, as well as those of other key partners, and a deeper investigation of financial and other resources potentially available. Such a review would help identify those activities where the WBG's limited resources are best deployed. The menu of options from which selection could be made includes supporting and coordinating assistance to pilot commercial-scale demonstration projects; development and expansion of innovative financing vehicles to link conventional lending by multilateral development banks, concessional resources, and private sector funds; greater access to finance for smaller-scale clean energy services, including at the small business and household level; and carefully targeted efforts to provide early-stage capital for new technology enterprises, building on initiatives already underway at the International Finance Corporation (IFC). National technology needs assessments, low-carbon growth studies, and economic analysis of different clean energy options and new investment plans could help identify country-specific strategic investment needs and priorities.

The WBG could consider innovative financial products and technical assistance activities tailored to country- and application-specific needs. Financing is a key ingredient. Development of a market presence for new energy technologies also requires policy reforms, risk management including efforts to win consumer confidence, and other interventions. Smaller amounts of funding early in market development may sometimes have greater value than larger amounts later. In this context the WBG also must address the widely expressed concern about picking winners, drawing on models for competitive and market-based approaches that can mitigate the associated risks.

The WBG could also consider broader initiatives for knowledge sharing, increased outreach, and collaboration with other institutions. These initiatives could include those already being explored by the Science, Technology and Innovation Global Expert Team and other entities within the WBG, as well as the ongoing efforts of GEF. New internal capacities and institutional structures may be required to support such initiatives, and significant new resources would be required to scale up such efforts, although some efforts and organizational changes would have modest costs.

The WBG can help by improving its own and others' understanding of what areas require further research. These areas might include the comparative public, social, and private-sector costs, benefits, and returns of different energy technologies; advantages and disadvantages of technology importation and adoption versus technology development domestically; centralized versus decentralized energy systems; and the preferences of base-of-the-pyramid consumers, best practices for developing and disseminating pro-poor technologies, and sustainable, best-value financing mechanisms for demand-driven base-of-the-pyramid technologies.

Given the limitations on its resources, the WBG needs to expand and deepen partnerships with other entities to draw on their expertise and resources, while in turn being able to bring to the table its own comparative advantages. In particular, the WBG can partner with entities better equipped to provide research and development, energy technology expertise, and private capital, government energy ministries, leading foundations and universities, and private sector developers and financiers.

Table E.1 summarizes a range of specific WBG action options related to new energy technologies, along with comments on their market niches, and their challenges. The actions listed span the areas of possible further WBG involvement identified above.

Table E.1: Proposed Options

Option	Strengths and opportunities	Barriers and other concerns	Potential market niches
FINANCING			
1. WB loans and credits for new technology	• Demand-driven, easily tailored to country needs • Can be complemented by policy and regulatory support • Can accelerate commercial-scale deployment of new technologies in new markets • Can use to leverage private investment • Area of WBG core competency	• Buying down of the incremental cost using scarce International Development Association (IDA) resources would be considered unacceptable • Weak country capacity for planning and implementing investment • Limited access to private capital, in particular with underdeveloped capital and risk markets • Likely to require large investments and some concessional finance	• In middle-income countries (MICs) with willing governments, financing of commercial but expensive or capital-intensive energy efficiency (EE) and renewable energy (RE) technology • Enabling infrastructure for new technologies (e.g., public transit, alternative fuel supply chain development, grid transmission and distribution extension and improvement) • Demonstration of pre-commercial or growth-stage technologies
2. WB loans and credits for technology capacity building	• Country ownership • Responds to the technology transfer agenda for the UN Framework Convention on Climate Change • Some WBG experience • Potential indirect benefit if domestic energy technology industries develop	• Weak country capacity to utilize • Results often difficult to measure	• Innovation infrastructure—research and development (R&D), academic capacity, seed and venture capital institution building—in MICs • Country-specific low-cost technology and entrepreneurship development in developing countries
3. Grant financing	• Can help finance incremental costs of new low-carbon technologies • Can finance necessary capacity building (policies and markets) • Particularly suited for low-income countries (LICs)	• Interests of donors and recipients may not align • Risk of distorted incentives from concessional investment financing	• Demonstration of pre-commercial or growth-stage technologies in MICs • Deployment of new energy technologies in developing countries
4. IFC investment	• Can help stimulate private sector participation in commercially viable but underutilized EE and RE technology • Does not compete for a share in scarce IDA resources	• Often requires long-term and potentially costly support by WBG and client countries for success	• Domestic companies in client countries

Option	Strengths and opportunities	Barriers and other concerns	Potential market niches
5. Public sector procurement mechanisms	• Procurement initiatives attract public and non-profit sector funding if well-designed • Competitive-based procurement (prizes) may stimulate emergence of cost-effective winner • Competitions also can raise global profile of challenges in developing countries, stimulating additional search for new technologies • The WBG has some experience with such approaches	• Given the size of financing gap, incentives may be too small • Procurements may end up "picking winners" with disappointing results • Concerns about intellectual property rights (IPR)	• Developing countries with low market demand and/or domestic innovation investment capacity • Well-identified energy service needs of the poor and new technologies with potential low-cost, village-level applications • Leading high-tech companies not yet investing in developing-country-market solutions
6. Targeted capital for the poor, rural areas, consumers, and small- and medium-sized enterprises	• Addresses barriers from limited access to financing for initial costs, lack of awareness, and limited private sector interest in service provision • As part of a larger program for expanding energy access and clean energy use, can supplement low-income individual users' limited ability to pay—the result can be significant, positive impact on inclusive growth, poverty reduction	• Dealing with numerous small consumers with limited ability to pay is difficult • Designing appropriate co-financing and other assistance arrangements to cost-effectively extend service and limit market distortions is difficult	• Micro-finance institutions • Locally-owned small- and medium-sized enterprises • Experienced seed-capital financiers • Small-scale Clean Development Mechanism project developers • Commercial and state banks providing leasing and other finance instruments for small- and medium-sized enterprises
TECHNICAL ASSISTANCE			
7. Policy and regulatory support	• Assists clients to expand opportunities for clean energy investment by reducing policy and regulatory distortions, distorted incentives • Reinforces traditional work of the World Bank, such as price subsidy reform and economic regulation—an area of strength for the Bank	• Political economy can be very challenging	• Governments, regulatory agencies responsible for creating technical capacity and policy conditions necessary for EE and RE private-sector investment in client countries
8. Amend as needed	• Can pull private sector actors into	• Potentially high risk; for example,	• Joint ventures and competitive domestic

Option	Strengths and opportunities	Barriers and other concerns	Potential market niches
operational procedures for grants, contracts, joint ventures, procurement procedures, and other partnership agreements with private sector	new markets; enable stronger collaboration with private sector in new technology including first-stage procurement • Can support domestic technology entities in MICs • Can increase the WBG's understanding of new energy technologies and markets • Could substitute for some WBG in-house technical expertise	difficulties in procuring new technology from a sole supplier • Challenge to align public and private incentives	companies in MICs • Developed-country technology companies and investors exploring operations in developing countries • Developing countries with low market demand and/or innovation investment capacity • Well-identified energy service needs of the poor and new technologies with potential low-cost, village-level applications • Companies, industry associations, international organizations, and research institutes with energy technology expertise keen to tap into WBG resources, market presence and expertise in developing countries
9. Asset management and investment advisory services	• Can help ameliorate transaction costs, risks in emerging markets • Useful particularly for countries with weak capacity and capital markets • IFC has some experience with both investment advisory support, and asset management (Green Bonds and new Asset Management Company)	• WBG's lack of experience, possible operational obstacles or conflicts of interest	• Large institutional investors (pension funds and insurance companies) • More risk-tolerant venture investors seeking high developing-country returns • Social investors willing to take lower returns • Possible non-concessional vehicle for developed country contributions to Copenhagen Fast-Start climate finance commitments
TECHNOLOGY, RESEARCH AND INNOVATION CAPACITY BUILDING AND INFORMATION DISSEMINATION			
10. Aggregation and dissemination of energy technology knowledge on a global scale	• WBG has unique capacity to support knowledge diffusion to developing countries at a global scale	• WBG does not have a comparative advantage for ex ante technology assessment • Can be resource-intensive	• Facilitating IPR and knowledge dissemination in MICs and especially LICs • WBG client country governments, research institutions, and universities • Growth-stage investors interested in new markets

Option	Strengths and opportunities	Barriers and other concerns	Potential market niches
11. Independent evaluation of new technology performance, economics, and environmental effects	• Can help reduce uncertainties about merits of new technology adoption—for example, for technology that is new to a country but commercially proven elsewhere • Can contribute to information and technology dissemination to client countries, along with other expansion of WBG information portals and potential establishment of a "technology office" • Can contribute to global dialogue on alternative energy technologies costs, benefits, risks, and rewards	• The WBG does not have a comparative advantage for ex ante technology performance assessment	• Evaluations of GEF and other WBG energy technology programs • Bridge from small-scale and demonstration grants to large-scale client country adoption, IBRD (International Bank for Reconstruction and Development), IDA and IFC, and private-sector mainstream finance • South-South and North-South collaboration
12. Global energy research fund	Financing; institutional design and governance	• Depending on how it is structured and managed, would help researchers, especially in countries with limited or no funding for R&D • Setting up the right administrative structure could be difficult • Opportunity to promote global search for most promising global technologies • Unclear that research proposals can be evaluated in a way that would lead to cost-effective research • Could become bureaucratic and donor-driven • Politics of selecting projects and technologies for financing may be challenging	• South-South and North-South collaboration • Domestic research institutions in MICs • Linking research to growth-stage finance and large mainstream energy companies • Leverage and amplify domestically-led energy R&D funding in MICs and internationally-led energy R&D funding for LICs

Option	Strengths and opportunities	Barriers and other concerns	Potential market niches
13. Umbrella technology and research organization	Synergies, potential collaboration, and information exchange not currently fully exploited	• Exploit cross-pollination and collaboration • Without clearly defined objectives, could become diffuse and unfocused • If virtual, unclear administrative burden may outweigh benefits • If a physically located institution, could run into the same problems as the research centers financed by the Consultative Group on International Agricultural Research	• South-South and North-South collaboration • Facilitating IPR and knowledge dissemination in MICs and LICs • Domestic research institutions in MICs • Clients of business incubators and climate innovation centers • Linking research to growth-stage finance
14. Promotion of open-sourcing, databases, and portals	Decreases cost of information	• Would stimulate R&D, particularly those activities that are not well funded • Resource-intensive to be of meaningful value to those engaged in cutting-edge technology development • Unclear that the WBG has a comparative advantage	• South-South and North-South collaboration • Facilitating IPR and knowledge dissemination in MICs and LICs • Domestic research institutions in MICs • Clients of business incubators and climate innovation centers • Linking research to growth-stage finance
15. Regional or global science fund for pro-poor technology	Tackles financing, institutional obstacles	• Specifically targets the poor, possibly addressing a market failure • In line with the WBG's mission • Limited experience exists • Setting up the right administrative structure could be difficult • Unclear that research proposals can be evaluated in a way that would lead to cost-effective research • Could become bureaucratic and donor-interest-driven • Unclear if a regional fund has clear advantages over a global fund	• South-South and North-South collaboration • Researchers addressing energy-related economic, social, and environmental problems in under-served markets in developing countries • Demonstration of laboratory-scale R&D for technologies targeting markets in developing countries

Option	Strengths and opportunities	Barriers and other concerns	Potential market niches
16. Creation of a technology office	Addresses lack of internal technical capacity	• Dedicated resources made available for strengthening technical skills • Facilitates strategic, systematic approach to technology promotion within the WBG • Potentially resource intensive • To date not a priority in the overall context of the WBG's work in energy	• Regional- and country-specific technology strategies • New products aggregating and disseminating the WBG's institutional knowledge to client countries

Promotion of New Clean Energy Technologies and the World Bank Group

Importance of Technological Advance in Energy

There has been an increasing focus inside and outside the World Bank Group (WBG) on supporting *new technology development, transfer,* and *deployment* in the energy sector. This has been a response to a number of longstanding and emerging challenges associated with current patterns of energy production and use.

This paper examines the opportunities and challenges for promoting clean energy technologies, and highlights options for the WBG in this area going forward. The definition of clean technology used here is taken from the Climate Investment Funds (CIF): a clean technology is one that reduces greenhouse gas (GHG) emissions; air, water, and soil pollution; and/or habitat degradation and destruction (see www.climateinvestmentfunds.org/cif/node/2). The focus is on new technologies—those that have yet to achieve widespread commercial acceptance due to policy, cost, performance risk, or lack of familiarity. New technologies frequently, but not always, involve patents,[1] and include technologies that have been available only in specific markets previously as well as products and services that are becoming available for the first time anywhere. It is important to note that there is no sharp boundary between new and commercial technologies, but there exists a continuum of technologies with a range of technical and non-technical factors that impede their widespread deployment.

Context

The most prominent of the emerging challenges has been climate change. As the International Energy Agency (IEA) recently stated, "The most important message remains unchanged: current [energy use] trends… are patently unsustainable in relation to the environment, energy security and economic development. Ongoing dependence on fossil fuels (especially coal) continues to drive up … CO_2 emissions…" (IEA 2010a). There is also concern about growing emissions of methane (CH_4) and other greenhouse gases, as well as release of biomass and soil carbon from changes in land use and deforestation.[2]

At the same time, currently available alternative technologies with lower carbon-intensity are noteworthy for their shortcomings as large-scale substitutes for petroleum fuel and fossil fuel-powered electricity. Challenges relate to scalability, the time required for scale-up, energy

[1] IFC's pilot program for investments in early-stage clean technologies has invested in technology companies without patents.

[2] More recently, "black carbon" emissions have drawn attention as a significant contributor to global warming. Combustion of fossil fuels and various forms of biomass are the sources of black carbon emissions, which are very fine particles that remain suspended in the atmosphere and increase its heat-trapping effect. There are large uncertainties concerning the net impact on global warming of reducing black carbon emissions from biomass combustion, but there is broad agreement that reducing emissions from sources that are particularly intensive sources of black carbon, and have a high proportion of very small particle size, is likely to reduce the pace of global warming (Shindell and Faluvegi 2009; Wallack and Ramanathan 2009; Pew Center on Global Climate Change 2009; Bauer et al. 2010; Koch et al. 2010). Examples of these sources are particulate emissions from diesel combustion, industrial sources, and thermal power generation.

density, substitutability into current infrastructure, availability of input resources such as water and rare earth minerals, and independence from fossil fuel inputs (Fridley 2010). The IEA has noted for several years that an energy revolution, based on widespread deployment of both existing and new technologies, is needed to cut GHG emissions by 50 percent or more below current levels and keep atmospheric CO_2 concentrations below 450 parts per million (ppm) (IEA 2010a). To overcome these challenges, sustained technological research, development, demonstration and deployment are required.

Aside from climate change, clean energy technologies offer a number of opportunities to address other development needs:

- Meeting *the needs of the poor for modern energy services* at relatively low cost, while also satisfying *the imperative to address public health by improving air quality.*

  Many efforts to find technological solutions to the needs of the poor have been impeded by fuel and/or technology cost and financing constraints, supply chain and distribution challenges in rural areas, and cultural barriers to adoption. However, lack of capacity to maintain the systems and budgetary limitations often limit the use and efficacy of such technologies.

  Studies also have shown that emissions from traditional use of solid fuels for cooking and heating, as well as flue gas and tailpipe emissions that remain high in some urban areas, can increase illness as well cause approximately 2 million premature deaths annually (WHO 2002;[3] WHO and UNDP 2009; Saikawa et al. 2009).

- Addressing concerns regarding the *reliability and affordability of future energy supplies.* Developing economies relatively dependent on fossil fuels, especially petroleum products, have ongoing risks of fuel price shocks. Absent significant changes in energy technologies, these risks from dependency on fossil fuels are expected to worsen considerably by 2030 (IEA 2010b). In some cases, moreover, high dependence on an outside source of piped natural gas or electricity, for which there are very limited short-run substitutes, raises concerns about potential supply disruptions. Increasing the diversity of energy sources, which may include domestic renewable energy, and increasing energy efficiency can reduce exposure to these risks.

- Opportunities to take advantage of growing global demand for renewable energy forms by *fostering high value-added local manufacturing and export industries.* In middle-income developing nations with a well-educated labor force and the infrastructure for high-tech manufacturing, investment in new energy technologies and associated systems and services have been among the most rapidly growing sectors in recent years, even allowing for the recent declines in demand associated with the fiscal

[3] For *The World Health Report 2002: Reducing Risks, Promoting Healthy Life,*" the WHO carried out detailed estimates of premature mortality from outdoor and indoor air pollution, and estimated that the two forms of air pollution were responsible for 650 million and 1.6 billion deaths, respectively, in 2000 (WHO 2002). Saikawa et al. (2009) calculate 500,000 premature deaths per year from aerosols, including black carbon and sulfates, of which 470,000 are in China.

crisis. Many middle-income countries are aggressively promoting exports of clean technologies to increase economic returns from a growing market, and in some cases to stimulate employment.[4]

International financing to enable adoption of new clean energy technologies is embodied in the United Nations Framework Convention on Climate Change (UNFCCC), which requests developed countries to "take all practicable steps to promote, facilitate and finance, as appropriate, the transfer of, or access to, environmentally sound technologies and know-how to, … [and] support the development and enhancement of endogenous capacities and technologies of," developing countries (United Nations 1992). This has led over time to variety of clean energy efforts by the Global Environment Facility (GEF), which has a mandate from the UNFCCC to provide financial resources to support the development, diffusion, and transfer of such technologies to developing countries. GEF has identified technology transfer as a key priority in its climate change focal area including assisting countries to develop National Technology Action Plans. A particular focus is to promote "innovative, emerging low-carbon technologies at the stage of market demonstration or commercialization where technology push is still critical" (GEF 2010).

More recently, at the United Nations Climate Change Conference in Cancún in December 2010, the international community committed to establishing a Technology Mechanism to accelerate technology development and transfer in support of action on mitigation and adaptation. Priority areas included increased investment, development and enhancement of endogenous capacities and technologies of developing country Parties, strengthening of national systems of innovation and technology innovation centers, and development and implementation of national technology plans for mitigation and adaptation. By establishing the Green Climate Fund, the parties in Cancún strengthened the commitment made in Copenhagen to work toward a goal of jointly mobilizing $100 billion a year by 2020 (UNFCCC 2010).

WBG client countries are in many instances having a considerable influence on the agenda of international organizations responding to these imperatives. In addition to the UNFCCC, the Major Economies Forum on Energy and Climate (MEF) and the Group of Twenty (G-20) are well-represented by developing countries, including Brazil, China, India, Indonesia, Mexico, and South Africa. The MEF has issued a "Technology Action Plan" with Brazil, India and the Republic of Korea taking on key leadership roles (MEF 2009). In the fall of 2009 the G-20, which includes 11 WBG client countries, pledged to phase out inefficient fossil fuel subsidies, a key step in promoting alternative energy sources. Moreover, while not common to all countries, the drivers of energy technology development and deployment have stimulated a dramatic rise in investments related to clean technologies in recent years—from $35 billion in 2004 to $162

[4] According to a Pew Charitable Trust survey, clean energy investment in China grew 54 percent in 2009 and now substantially exceeds investment in the United States, although the latter still dominates in venture capital financing (Pew Charitable Trusts 2010). Some new renewable technologies, such as solar photovoltaic (PV) panels, are now commodities for which scale economy and low production costs, including access to capital, are important. Some developing countries—notably China—are in a position to exploit these features needed for industry expansion (*Economist* 2010). In 2008 China surpassed Japan to become the world leader in PV cell production, mostly for export. In 2008 India also emerged as a major center of PV investment, thanks to favorable policy announcements leading to announced plans or proposals for $18 billion in financings (REN21 2009). Both countries are also major players in the global wind market. Electric vehicle manufacture is increasing in both China and India.

billion in 2009 by one widely cited estimate—although relatively little as yet in developing countries outside of China (Pew Charitable Trusts 2010).

Objectives of the WBG's Energy Sector Strategy

There is increasing interest within the WBG in supporting the development and diffusion of new clean energy technologies. Such a role can support the twin objectives of increasing access and reliability of energy supply, and facilitating the shift to a more environmentally sustainable energy development path (WBG 2009a). Over the past several years, dating at least to the 2005 G8 meeting in Gleneagles, the WBG has been called on by a number of international entities to show leadership in facilitating and financing the deployment of clean energy technologies.

The 2008 document *Development and Climate Change: a Strategic Framework for the World Bank Group* included as one of the six pillars support for accelerated development and deployment of new technologies able to provide both development and climate-change-related benefits. The document describes the role of the WBG in four stages (WBG 2008):

- The WBG will promote technologies in the commercial stage through its policy and advisory functions and regular lending operations.
- For technologies in the scale-up stage, the WBG's role will be to find innovative and creative ways to encourage the early adopters of the technology, to work to grow the market, and to increase the number of installations where the new, clean technology is deployed.
- The WBG's support to the deployment of clean technologies in the demonstration stage will focus on creating the knowledge base to facilitate countries-based decision making.
- While the WBG is not a research and development (R&D) institution, it will explore its appropriate role in supporting technology research and development.

This was followed in January 2009 by three specific proposals from the World Bank and the International Finance Corporation (IFC) (Avato and Coony 2008):

1. *Technology policy support program* to deliver timely, tailored policy advice in response to country requests for specific advanced energy technologies and situations
2. *Advanced energy innovation program* to provide more funding to build infrastructure for science, technology, and innovation in developing countries and promote international cooperation
3. *Energy technology innovation facility* to create in-country focal points to provide selected local and international companies with tools and assistance to overcome barriers to new energy technology commercialization and scale-up

Report Outline

This paper endeavors, first, to review the opportunities and challenges facing clean energy technology development: why it is needed, and what barriers exist. Second, the paper considers the experience of the WBG and other international and multilateral organizations in the sphere of clean energy technology. Third, the paper examines the particular comparative advantages as well as limitations of the WBG in engaging in the advancement of clean energy technology.

Fourth, the paper reviews a number of strategies to expand WBG engagement in clean energy technology. The paper closes with conclusions.[5]

[5] This paper reviews operational experience and options for the WBG with respect to new energy technologies but does not review the broader economic literature regarding the role of such efforts as a contributor to economic growth and development. This issue has generated an extensive, ongoing debate. See, for example, Nelson (2005) (economic growth is linked to the co-evolution of technologies, institutions, and industry structure in ways not amenable to aggregate quantitative measures). While not within the scope of this paper, a better understanding of these larger issues is also potentially highly relevant to WBG policy and priorities insofar as it could inform strategies for promoting and measuring economic development with implications for the design of new technology projects and programs.

Opportunities and Challenges

What constitutes a *new* energy technology is not always simple or obvious. Potential new technologies with environmental and efficiency benefits can be found in almost every sector at various stages of development, but much of the focus in energy is on renewable sources of energy and efficiency.[6] In many cases a new technology is an adaptation of an established technology for a substantially different application, rather than a fundamentally new idea (Table 1, Figure 1). Pathways for technological development consequently vary with important implications for the form of assistance needed to accelerate technology diffusion.

Table 1: Categories and Examples of Advanced Energy Technologies

Renewable energy	*End-use energy efficiency*	*CO_2 capture and storage and high efficiency use of fossil fuels*	*Off-grid and mini-grid distributed generation*	*Other*
• On-shore and off-shore wind • Geothermal • Modern biomass • Concentrating solar power • Solar PV • Wave energy	• Building heating and cooling (heat pumps) • Industrial motors • Light-emitting diodes • Home appliances	• Carbon capture and storage in industry and power generation • Integrated gasification combined-cycle • Ultra-supercritical pulverized coal • Fuel gasification technologies (underground coal gasification; coal and biomass to gas or liquids; hydrogen production)	• Wind-solar systems • Micro-hydro • Advanced wind-driven water pumping • Fuel cells	• Smart grids (smart metering, demand response) • Electric and plug-in vehicles • Engine and other automotive vehicle technology improvements • High-voltage direct current transmission • Advanced energy storage systems

Source: Adapted from IEA 2008.

[6] Analyses of the prospects for new and clean technologies often use criteria based on social objectives (such as sustainability) or similar metrics of public policy (regulatory drivers). For example, a recent report by the investment research firm Jeffries International defined clean technology companies as encompassing "a wide range of industries and business models that stand to benefit from powerful secular trends in favor of more efficient use of resources in the face of rapid demand growth in the emerging economies that is stressing energy and water supplies." The authors focus on companies "that address constraints in feedstocks, energy inputs and water supplies, among others. In a world increasingly sensitive to carbon emissions, in some contexts efficiency can capture more value than new production. Make haste, not waste" (McNamara, Clegg, and Alexander 2009).

Figure 1: Clean Technology in Emerging Market

Decrease fossil fuel usage

	Adaptation of existing technologies	**Breakthrough technologies**
Characteristics	• Adapt existing (1st generation) technologies to local needs, often involving innovation (2nd generation) • Change driven by regulations • Often achieved through energy efficiency or direct CO_2 reduction	• Brand new technologies and inventions to address climate change challenges • Often targeted at increasing sources and uses of renewable and alternative energy • Intellectual properties often from developed countries
Risks	• Market risk • Execution risk	• Technology, business model and market risks • Execution risk
Examples	• Waste water treatment • Solid waste treatment • Enhanced efficiency boilers and furnaces • Battery/power management	• Solid oxide fuel cells • Second-generation biofuels • Hydrogen technologies • Lithium ion battery storage • Electric cars

Increase clean energy use

For IFC, emerging market opportunities lie mainly in <u>technology adaptation</u>

Source: World Bank staff.

Key Distinctions Among New Energy Technologies

Some key characteristics distinguish types of new energy technologies that are relevant for understanding the significance of market barriers and options for WBG intervention:

- ***Supply side versus demand side.*** Much of the focus on energy technologies is on increasing supply, for example new renewable energy technologies such as wind and solar. However, there are also significant opportunities for new technologies to reduce the demand for energy by improving consumption efficiency (see case studies on high-performance cookstoves and efficient lighting in annex 1). For example, the IEA estimates that there is scope for increasing appliance efficiency by 30 to 60 percent, much of which would not require major technological development (IEA 2008, p.544). Innovation pathways for supply- and demand-side technologies could be different, given the latter are embodied in diverse manufactured products
- ***Relative maturity.*** From an investment perspective, perceived risk typically declines as commercial acceptance in a particular market increases. However, a technology proven in one region or for one application may be considered high-risk and unproven for use in

another location or in a different application. For example, integrated gasification combined cycle (IGCC) requires pilot tests and additional work for coals of varying qualities and compositions.

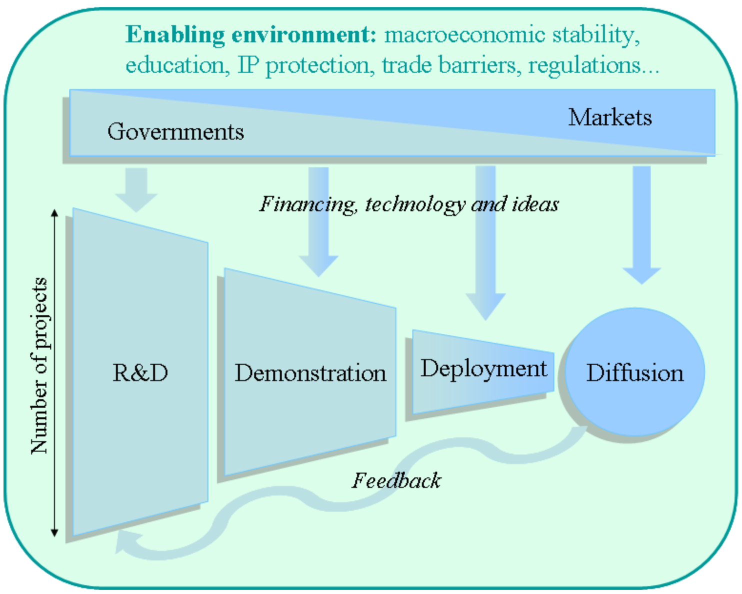
- ***Small scale/modular versus large scale.*** Utilities typically think in terms of large-scale power plants consistent with the economies of scale associated with thermal or nuclear power generation. Increasingly, smaller distributed systems that can be built in shorter times, within manufacturing facilities, with smaller land requirements, and closer to demand are receiving attention.[7] Distributed energy efficiency technologies can also create "negawatts" that replace generation capacity and peak load demands. Some technologies that are economic on a very large scale, such as the current generation of nuclear power plants, have special requirements for financing and typically require public sector involvement because cost recovery is closely linked to regulatory decisions regarding permitting and tariffs.
- ***Capital intensity***. Large, capital-intensive energy technologies (e.g., nuclear power) are often seen as particularly important as a source of baseload power. However, financing such projects in developing countries is often difficult due to country investment risks and may require forging of complex public-private partnerships. Conversely, technologies that are smaller and modular do not face comparable financing challenges but may have higher transaction and operating costs.
- ***Baseload versus variable***. A particular challenge for many sources of renewable electricity generation is the ability to provide power in a predictable and stable manner. The variable output from most solar and wind-based energy sources is a critical performance weakness and remains a hindrance to their substitution for baseload thermal (coal, oil, gas, or nuclear) generation capacity. Demand-side energy efficiency, smart grid, and energy storage technologies can themselves address many of the challenges associated with variable energy sources.
- ***Incremental versus. breakthrough technologies***. Incremental versus breakthrough connotes differences in the degree of change from the current technology, with breakthrough implying a step change. Steady improvement in the operating efficiency of equipment and appliances (boilers, motors, refrigeration units, heaters) is typically achieved through incremental change. Technologies are often categorized as being breakthrough after they become economic and deployed on a commercial scale. For example, large-scale adoption of electric hub motor vehicles would be considered a breakthrough today, but the Lohner-Porsche, embodying this technology, actually made its debut a century ago at the 1900 World's Fair in Paris. Breakthrough technologies that are widely adopted may even be called revolutionary, as the Green Revolution fundamentally changed agriculture in the 1960s and 1970s, and, more recently, cell phones have transformed the telecom industry in many developing countries.
- ***Policy dependence***. Investment in many energy technologies is highly dependent on regulatory decisions to allow, mandate, or facilitate their use with financial support. The financial attractiveness of wind turbines, solar power, and other forms of distributed

[7] The concept and merits of distributed generation is now recognized in numerous government programs and international initiatives, including the Asia Pacific Partnership on Clean Development and Climate Change (www.asiapacificpartnership.org/english/tf_renewable_energy.aspx). In many parts of the world utilities are increasingly being asked to act as integrators and distributors of smaller, more diverse, and highly dispersed sources of power, which may add to the complexity of assuring adequacy and reliability of power supply.

generation requires favorable policies for access to utility grids and, very often, direct government subsidization.

The process of innovation is, as noted above, typically described as stages of development, transfer, and deployment (or diffusion). As pointed out in the *World Development Report 2010: Development and Climate Change*, however, the process contains a number of feedback loops. Feedback from manufacturers in the deployment stage, and from retailers and consumers in the diffusion stage, trickles back to the other stages, modifying the course of innovation, leading to new unexpected ideas and products, or unforeseen costs. Learning curves, which describe how unit costs decline as a function of cumulative production, are a way in which deployment can feed back on ongoing technology development, though this process remains poorly understood (WBG 2010). As shown in Figure 2, public policies have impacts across the stages of the process. International cooperation in development, transfer, and diffusion in turn can involve a number of different stages and procedures, as summarized in Table 2.

Figure 2: Policy Affects Every Link of the Innovation Chain



Source: WBG 2010.

Table 2: International Technology-Oriented Agreements Specific to Climate Change

Type of agreements	Sub-category	Existing agreements	Potential impact	Risk	Implementation	Target
Legislative and regulatory harmonization	**Technology deployment and performance mandates**	Very few (European Union)	High impact	Wrong technological choices made by government	Difficult	Energy technologies with strong lock-in effects (transport) and that are highly decentralized (energy efficiency)
Knowledge sharing and coordination	**Knowledge exchange and research coordination**	Many (IEA)	Low impact	No major risk	Easy	All sectors
	Voluntary standards and labels	Several (EnergyStar, ISO 14001)	Low impact	Limited adoption of standards and labeling by private sector	Easy	Industrial and consumer products; communication systems
Cost-sharing innovation	**Subsidy-based "technology push" instruments**	Very few (ITER)	High impact	Uncertainty of research outcomes	Difficult	Pre-competitive RD&D with important economies of scale (CCS, deep offshore wind)
	Reward-based "market pull" instruments	Very few (Ansari X-prize)	Medium impact	Compensation and required effort may result in inappropriate levels of innovation	Moderate	Specific medium-scale problems; solutions for developing country markets; solutions not requiring fundamental R&D
	Bridge-the-gap instruments	Very few (Qatar-UK Clean Technology Investment Fund)	High impact	Funding remains unused due to lack of deal flow	Moderate	Technologies at the demonstration and deployment stage
Technology transfer	**Technology transfer**	Several (CDM, GEF)	High impact	Low absorptive capacities of recipient countries	Moderate	Established (wind, energy efficiency), region-specific (agriculture) and public sector (early-warning, coastal protection) technologies

Source: WBG 2010.
ITER = originally the International Thermonuclear Experimental Reactor, CDM = Clean Development Mechanism, RD&D = research, development, and demonstration, CSS = carbon capture and storage

Barriers to Clean Energy Technologies

Developing, demonstrating, and commercializing new clean energy technologies can be particularly difficult in developing countries, where policy risks and complex-to-manage technology risks can increase financing costs to a greater extent than in more developed countries. Other barriers, however, are common to all countries. These involve circumstances in which the new technology is not able to be commercialized given current economic and policy circumstances.

In this section we review these barriers, dividing them into two categories. The first category consists of *economic barriers* that can only be mitigated by significant further advances in the technology, or the adoption of policies that could impose significant costs on the larger economy. The second category consists of what are commonly called *institutional barriers* that impede the diffusion and commercialization of technologies but are at least potentially amenable to significantly lower-cost barrier reduction measures. The line between these categories is not cut and dried, but it is still a useful organizing device for considering later the options for the WBG in the clean technology arena.

Economic barriers

Levelized cost of the new technology

While some emerging technologies can become commercially viable once some of the institutional barriers are lowered, in a great many cases the technology simply has not matured to the point where it can successfully compete in the market. Overcoming this requires some combination of (a) further development and pilot deployment to assess if and how levelized unit-cost can be sufficiently lowered, or (b) policies that mandate or subsidize the use of the technology in its current state. While the latter approach can provide benefits of learning by doing and scale economies, as noted below, it also can impose significant economic costs. In many cases these costs are not immediately visible because of the indirect ways that subsidies or mandates can operate, but they exist nonetheless.

Another challenge to affordability is that incumbent competitors using established technologies often have amortized significant portions of their capital investments. Moreover, the legacy of past policies governing the development of infrastructure can leave new energy technologies at an economic disadvantage. A primary example is a power transmission grid designed for connecting large central-station power plants. Even if any lingering barriers to access were overcome by new regulations, it is inherently more costly to supply more decentralized, small-scale, and intermittent renewable energy technologies at a large scale with the existing grid. This in itself does not constitute a bias against these renewable energy sources; it simply reflects that the opportunity cost to overhaul the grid for greater connectivity of small-scale renewable energy would be very costly. And even without these advantages, the lifecycle *financial* costs of existing technologies could still be lower than those of the emerging new technologies (see annex 2 for comparison of costs).

For technologies that are simply too costly, financing necessarily will not be available unless mandates or subsidies are applied. This brings into sharp focus the need for greatly stepped up research, development, and demonstration (RD&D). To highlight the challenge, the IEA calculates that there is a global annual shortfall of $50–100 billion in low-carbon energy technology RD&D in order to reach an energy-related GHG emissions reduction of 50 percent by 2050 (IEA 2010a).

Barriers to availability of financing

The single most important barrier to obtaining adequate financing relates to the *size of investment risks and inabilities to insure against them.* This is important in the transition from basic technology development to pilot commercial deployment and for subsequent scale-up. The initial capital costs for a new technology are likely to remain quite uncertain until several full commercial-scale plants have been built. Site-specific characteristics can lead costs to be much higher than "lab bench" estimates, imparting a persistent "optimism bias." Against that is the prospect of unit capital cost decline as knowledge is gained from construction of successive capacity; but it is difficult to estimate before the fact how substantial the cost decline might be, and for how long. For technologies that remain under development, such as carbon capture and storage (CCS), the uncertainty is especially acute.

Operating cost is also subject to a sharp decline, which can be important for plants in which materials are an important cost component (e.g., biofuel feedstocks). In addition, uncertainty about the future price levels and price volatility of incumbent energy sources can impede investment. For example, uncertainty in oil and other fuel prices may inhibit investment in energy efficiency improvement and competing renewable energy technologies. Uncertainty about fuel costs and capital costs for fossil electricity plants can be an important impediment to making large sunk-cost investments in renewable energy technologies that are very capital-intensive, given their primary cost advantage lies in using no purchased fuel. On the other hand, the capacity of such technologies to provide a hedge against price shocks in fossil fuel markets is a benefit, at least at a national level (Awerbuch and Berger 2003).

Clean energy technologies are often particularly challenged seeking private capital due to a cascade of risks and uncertainties from the perspective of some of the largest sources of financing -- large, risk-averse institutional investors (UNEP and partners 2009). Technology development risk is compounded by performance risks in low-income developing countries, where most new technologies must be adapted from developed-country prototypes, and where implementation capacity is often low. Yet another factor has been the financial crisis. Before the financial crisis, risk capital had become increasingly available for clean-energy related investments. As the larger emerging markets have attracted more risk capital, the availability of financing for clean energy in these countries had also increased.[8] The industry, however, fared poorly in the fiscal crisis beginning in the latter part of 2008, given in particular the high sensitivity to financing costs.

The problem summarized here is often referred to as the "valley of death," as illustrated in Figure 3. In the model shown, a new invention is initially conceived in a public-sector-financed laboratory and eventually commercialized by the private sector.[9] The difficulty arises in the

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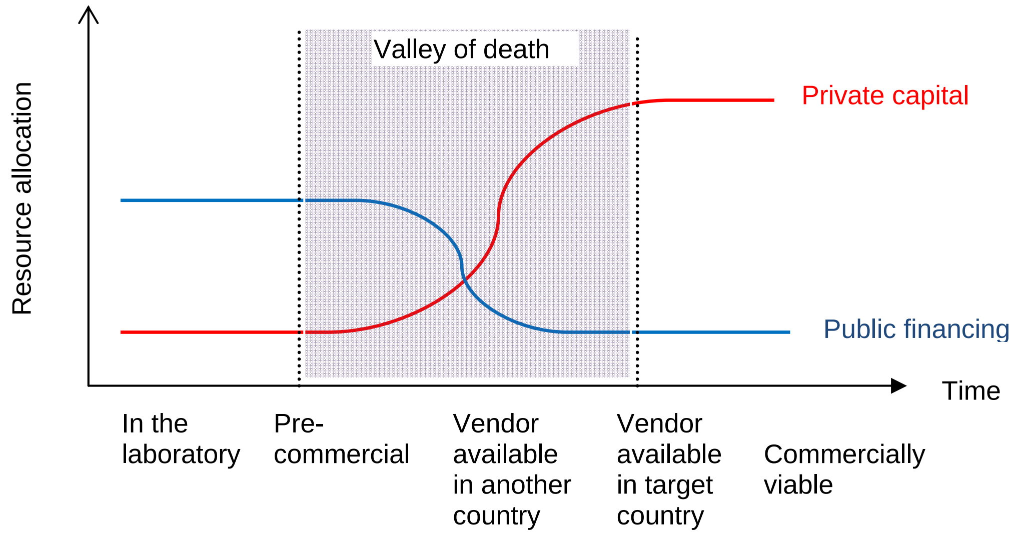
[8] Clean energy investment in 2009 was estimated to be $34.6 billion in China, $7.4 billion in Brazil, $2.3 billion in India. For the period 2004–2008, the compound average annual growth rate was 147.8 percent in Brazil, 147.5 percent in China, and 72 percent in India (Pew Charitable Trusts 2010).

[9] Aero-derivative turbines, solar cells, and fuel cells fit this model to varying degrees, as commercial products built on years of public support for technologies to meet the needs of the defense and space industries (Pegram 1991; Williams and Larson 1988). There are other business models. In contrast to biotechnology and information technology, large, established firms carry out a considerable share of overall R&D in the energy sector as part of their growth strategy. A recent review of intellectual property in six important new energy technology sectors found

middle stage where public financing usually is dropping off because the pre-commercial work is finished, yet private financing has not picked up rapidly enough to transitional toward commercialization due to the various risks noted above.

Figure 3: An Example of the Valley of Death



Source: Schematic diagram drawn by World Bank staff based on publications such as UNEP/SEFI Alliance 2008 and Bendis and Byler 2009.

One reasonable argument is that this is an inherent risk associated with technology development and commercialization, to be overcome by competing for high-risk-taking venture capital. Another response is the suggestion to seek out financing from sources holding larger-scale portfolios of different renewable technologies, which can hedge against technology-specific risks (but this does not hedge against economic risks common to a number of the renewable technologies, which requires much broader portfolio diversification). One serious difficulty in obtaining such financing, however, is that at a stage when sources of new technologies are few and potentially small, gauging the level of risk can be quite difficult.

A stronger argument, but that requiring great care, is that the information gained from the first few commercial-scale investments in a new technology provide an important *public good*, in the form of the information conveyed, for which they cannot be compensated. On this reasoning, government support should not fall off so sharply after the pre-commercial phase. Nevertheless, policies to support the initial investments need to be built with care not to create perverse incentives—for example, over-generous direct subsidies of capital or operating costs or risk guarantees that do not weed out the less solid potential recipients of the subsidy. It is also necessary to confront the difficult challenge of how to stop financing the development of technologies that show increasing signs of being unlikely ever to be commercially competitive.

One other financing-related barrier to note here is that financial markets for capital-intensive and relatively risky new technologies remain severely underdeveloped in many WBG client countries. For example, in China, commercial debt markets are extremely small, and interest-rate

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that large established companies are the main players, with small- and medium-sized enterprises accounting for a relatively small share of overall patents (Lee, Iliev, and Preston 2009).

ceilings discourage high-risk debt finance, affecting new technologies and energy efficiency loans in particular (Chandler and Gwin 2008). IFC efforts to promote energy efficiency finance capacity in local finance institutions, notably in the Russian Federation and China, have borne fruit, but have underscored the need for strong and sophisticated banks in energy efficiency finance (Taylor et al. 2008; see also www.ifc.org/chuee). Capital markets (both equity and debt) in developing countries are often illiquid and deficient in risk-pooling funds, which disadvantage small companies and those in new industries that may not have access to international finance. Undercapitalized banks in lower-income countries with low capacity for risk assessment avoid complex and risky technology investments (UNEP/SEFI Alliance 2010).

Under-pricing of carbon emissions and other pollutants

Pricing of carbon into energy supplies offers incentives not only to renewable energy but also to energy conservation and efficiency improvement. As yet, carbon pricing is limited by the nature of country commitments to limit GHG emissions. Limited commitments relative to the scale of the long-term problem and only modest international participation in setting ceilings on emissions implies a lower price of carbon, thus giving an inefficient continued cost advantage to high-carbon over low-carbon sources. Uncertainties about future UNFCCC negotiations, particularly for a post-2012 framework, and about climate legislation in certain large high-income countries make it difficult to predict when a stronger internationally accepted price of carbon could emerge. Cutting local air pollution also is hampered when national policies are not that stringent.

Access to finance is a particularly serious problem for small-capitalization and start-up energy technology enterprises. Informational, institutional, and transaction barriers inherent to small business finance in the developing world are well-known challenges to financing bottom-up clean energy innovation (Zavatta 2008). Anecdotal evidence from business incubator clients and small entrepreneurs suggests that financial markets in developing countries have made only a small dent in the problem and have, in many cases, been dealt setbacks by the global financial crisis. Capital markets in low-income developing countries are ill-prepared to assess and absorb the risks of technology companies seeking seed and initial investments ranging from tens of thousands to several million dollars—the niche between microfinance and venture capital. International financial institutions are equally hamstrung by limited expertise in new energy technologies, the risk profiles of start-ups, and the high transaction costs of identifying and conducting small investments. There is currently a paucity of international firms capable of project development and project bundling that could help overcome some transaction cost, project bottlenecks, and capacity barriers for institutional investors (UNEP and partners 2009; UNEP/SEFI Alliance 2010).

Inadequate access to finance can be equally crippling for users of energy technology. Business and household consumers of photovoltaic (PV) solar panels, weatherization and energy-efficient retrofits, and energy-saving appliances and equipment are often unable to secure loans or leases to defray the up-front costs. The absence of proven consumer finance mechanisms such as leasing may seriously hamper the uptake of retail energy technology (Miller 2009, p. 63). In some cases, local banks may simply be unwilling to take the plunge into consumer lending in a new sector. In others, difficulties assessing creditworthiness and the complexity of special finance vehicles such as energy services and leasing, often involving a third party, may exceed the capacity of banks' human resources. That said, these barriers should be viewed against the backdrop of grid connection being prohibitively expensive for many rural communities in developing countries, for whom solar panels, small-scale wind and hydro power systems, and solar lamps may be less costly, although raising financing for those communities that tend to be among the poorest faces other challenges.

Suitable financial products depend on the needs of different technologies. Carbon markets provide one critical source of funding for technology needs in developing countries. The Clean Development Mechanism (CDM), in addition to providing billions of dollars for investment capital, also contributes to technology transfer and diffusion. An analysis of the CDM project portfolio revealed that 36 percent of the projects claim to involve technology transfer, particularly those involving larger projects and foreign participants (Seres 2008). The prospects for the CDM to serve as a primary agent for new technologies are limited by transaction costs and other barriers, as discussed in Box 1 below.

Institutional barriers – "transaction costs"

One set of demand-side institutional barriers commonly discussed in the context of energy efficiency, but relevant also to some forms of renewable energy, has to do with information and attitudes of buyers. The standard argument is that individuals have difficulty with new products to judge their reliability and quality of service in order to have a solid basis for weighing the advantages against up-front costs. The stock example of this phenomenon is compact fluorescent bulbs, but as noted above, it can also apply to cook stoves for the rural poor in developing countries. Still another well-recognized challenge to penetration is the ability to recover all the costs of the initial capital when a property turns over. Tenants will have less incentive to install energy-saving devices that pay off over a longer period than their expected occupancy. The same could be true for large-scale investments in alternative energy in homes and other buildings, to the extent that the improvements are unlikely to be fully capitalized into the price of the structure.

Access to intellectual property is a frequently cited concern by developing countries in their submissions related to technology in the context of the ongoing climate negotiations.[10] In recent UNFCCC discussions, countries such as Brazil, China, and India have made proposals that would enable acquisition of licenses for climate-friendly technologies to make them available to developing countries at low cost (Bazilian et al. 2008). Not surprisingly, the prospect of negotiations related to concessions for intellectual property rights (IPR) has generated political resistance in some developed countries and business communities.

Bilateral and multilateral environmental agreements can create a climate for technology cooperation such that otherwise patentable knowledge is freely shared—for example, the United States and China recently agreed to the creation of a Joint Clean Energy Research Center, with a commitment of $150 million over five years shared evenly between the two countries (Collier 2009). On the other hand, companies holding clean energy technology IPR may not face the same threats from knockoff technologies that, for example, pharmaceuticals do, because R&D is

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[10] Country submissions to the negotiations are posted at www.unfccc.int. The World Resources Institute tracks country submissions and has posted a summary covering the period August 2008 through May 2009 (http://pdf.wri.org/working_papers/unfccc_wri_submissions.pdf).

Box 1: The Clean Development Mechanism as an Instrument for New Technology Development and Diffusion

The CDM of the UNFCCC illustrates the impact of transaction costs on the type of projects that go forward in developing countries. Because project development, review, monitoring, and verification are onerous, large or industrial projects following standard technical procedures are easiest and most cost-effective to implement. Not surprisingly, the most industrialized middle-income countries dominate this market: Brazil, China, India, and Mexico account for more than 70 percent of the 1,800-odd CDM projects. By contrast, all of Sub-Saharan Africa, excluding South Africa, has registered only 8 projects, or about 0.4 percent of total project volume. Furthermore, monitoring, reporting, and verification costs are high and rising—particularly for small-scale projects— and registration and validation of new projects now typically takes upwards of 18 months (World Bank 2010a). Recognizing these problems, the CDM has simplified baseline and monitoring methodologies for small-scale projects, for example renewable energy equipment with an equivalent output capacity of up to 15 megawatts (MW). Additionally, the CDM executive board in 2007 approved new methodologies, collectively known as programs of activities, that allow for bundling diffuse, site-specific emissions reductions efforts under a single CDM activity. Programs of activities have opened the door to many small-scale, diffuse energy efficiency and rural energy projects.

These developments as well as other anticipated future simplifications of methodologies are creating opportunities for the World Bank’s Carbon Finance Unit to expand activities in least-developed countries and in local-level technology transfer and diffusion (World Bank 2010a). Dedicated funds, such as the Community Development Carbon Fund and the BioCarbon Fund in particular, have demonstrated operating platforms that are particularly effective in reaching beyond the most common CDM credit-recipient industries and countries. The BioCarbon Fund focuses on bringing social and economic benefits to many rural communities through land-use management projects, which may include efficient use of household biomass and plantation biomass cultivation for energy. The fund recommends a review of CDM rules to consider wider land-use management crediting (World Bank 2008). Programs of activities also lay the groundwork for designing a wider array of projects—especially in energy efficiency and low-carbon growth in urban areas—and greater integration of carbon finance into the WBG’s mainstream lending (World Bank 2010b).

a much smaller share of overall costs, product markup is much lower for most energy companies. Stern reviews a range of studies and concludes that “[i]n many cases intellectual property rights are not the key barrier to transfer of technology” (Stern 2007). One reason is that patents are the most important means of intellectual property protection in only a few industries, for the most part not environmental technologies.

Finally, incumbent technologies may profit from strong political constituencies that advocate for subsidies and against preferential policies for alternative technologies. The incumbents may also enjoy social and cultural acceptance—powerful inertial forces of the status quo that counteract the “creative destruction” resulting from technological innovation.

Challenges and Options for Public Sector Action to Lower Barriers

General challenges

Picking winners

Policymakers must assess whether the goals of technology promotion merit bearing the risks and public-sector expenditures associated with concentrating support on a few technologies, as distinct from supporting a broader portfolio of promising options. Mandating or subsidizing specific types of renewable energy is an example of picking winners. Renewable energy portfolio standards in several U.S. states mandate specific technologies, such as solar power. Feed-in tariffs in a number of countries have differentiated subsidies for different energy sources, project size, place of installation (on the ground or rooftop), and technologies.[11]

Public support of a specific new technology runs a risk associated with picking winners in general—the need to select some limited set of technologies at the expense of those not chosen, thus limiting options for mitigating specific failures. This concern is particularly acute at the earliest stage when injection of funds is critical, but it can also be an issue for more advanced technologies seeking credibility and public acceptance. Public officials are also seen as less capable of making such judgments due to their lack of risk exposure and direct engagement in technology development.

To mitigate this concern, the overall risk can be shared through financing based on public-private partnerships. Such risk-sharing is beneficial where the private sector cannot manage the risk alone, public programs can help finance gaps during the development process where private sector investment is weak, or the broad societal impact of successful energy innovation justifies public support. However, while public-private partnerships can spread the risk of picking winners, it cannot lower it except insofar as more informed private sector participants can drive decisions.

Public private cooperation and risk sharing

Even with support, it may be difficult to attract private funds in the early stages of technology development. A public-private partnership might be able to promote pre-commercial technologies, although likely could attract private participation only for later-stage research for technologies close to commercialization. The use of prize funds and advanced market commitments might be better suited to attracting private funders, although the sizes of prize funds are small compared to the costs involved in development and deployment of many energy technologies. If private funds are not forthcoming but technology is seen to be important, one approach to public-sector support of pre-selected technologies that has been used to solve specific problems and enter specific markets is the government-owned corporation. If set up

[11] For example, the feed-in tariff law in Germany, which went into effect in 2000, based compensation on the cost of generation, resulting in different prices for different sources and further differentiated by size to account for economies of scale—hydroelectric power, gas from landfills, mines, and sewage treatment plants; biomass; geothermal; wind; and solar (Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety 2000). The CTF excludes CCS from consideration on the grounds that, among other reasons, the CTF will not pick a winner when there are multiple technology candidates for power generation with CCS and only limited funds for demonstration (CIF 2009a).

properly, the corporation can pursue public mandates while responding to market conditions and operating relatively independently from political concerns. The U.S. Defense Department's Defense Advanced Research Projects Agency traditionally has focused on research of this nature in the United States (Weiss and Bonvillian 2009).

Issues of economic nationalism

Preferential policy regimes for clean energy technologies can become a tool for promoting economic nationalism. Overly-restrictive tariffs, persistent subsidies, and stringent local content requirements instituted in the name of developing domestic industry may undermine efforts at free trade and raise international tensions. These distortions, combined with other restrictive practice that hinder foreign direct investment, can be major impediments to the transfer of new technology.

Pre-patent technologies and technology transfer

There are many calls for public financing of pre-patented technologies. One way to do this is to invest in broader programs of technology sharing, transfer, and joint research. The IEA has been facilitating international technology cooperation for 35 years. A key feature of this program is a legal contract, or Implementing Agreement, that allows interested member and non-member governments (including developing countries) to pool resources for research, development, and deployment of technologies (Box 2). As of 2007, there were 41 collaborative projects from 72 countries, organizations, and companies. Agreements include end-use as well as supply technologies, early-stage research such as ocean energy and advanced fuel cells, and deployment issues such as accelerating the use of renewable energy as well as data exchange and systems analysis (IEA 2007).[12]

Particular challenges in developing country markets

Many of the difficulties encountered in technology innovation, development, and commercialization are exacerbated in developing countries—particularly low-income countries where financial, institutional, and human resources tend to be more limited. Even innovations originating in developing countries may fail to be commercialized due to weak institutional pathways linking and engendering research, finance, and market development.

Policy frameworks

Appropriate policy frameworks are one of the cornerstones of energy technology promotion. Policies concerning on-grid power generation, taxation and regulation of small businesses, and subsidies for fossil fuels are particularly pertinent. For large on-grid electricity generation projects, guaranteed transmission hookups, and clear regulatory and compensation rules are critical to attracting private capital investment (Miller 2007). Net metering provisions and other such measures can provide additional opportunities for renewable production. Smart grids and meters, deployment of data collection devices and load balancing software by utilities, uptake of electric cars, and widespread use of programmable appliances that run automatically when demand is low or when the wind is blowing strongly can all promote the efficient use of

[12] A forthcoming update of a 2007 IEA publication, *Energy Technologies at the Cutting Edge*, will review outcomes and achievements of IEA implementing agreements.

Box 2: International Energy Agency Technology Implementing Agreements Framework

Article 2 of the IEA framework for international energy cooperation gives examples of activities under an Implementing Agreement:

- Coordination and planning of specific energy technology research, development, and deployment studies, works or experiments carried out at a national or international level, with subsequent exchange, joint evaluation and pooling of the scientific and technical results acquired through such activities
- Participation in the operation of special research or pilot facilities and equipment provided by a participant, or the joint design, construction and operation of such facilities and equipment
- Exchange of information on national programs and policies, scientific and technological developments, and energy legislation, regulations and practices
- Exchanges of scientists, technicians or other experts
- Joint development of energy related technologies

Other examples include technology evaluations, developing and monitoring expert networks, data collection and analysis, modeling, and publications. More recently, projects on energy-efficient electrical equipment have been focusing on benchmarking performance and harmonization of standards. A number of the implementing agreements focus on policy-relevant questions related to technology adoption. One example is the agreement on district cooling and heating, including integration of combined heat and power. The program conducts R&D as well as policy analysis of district heating and cooling systems with low environmental effects.

Source: IEA 2010c.

renewable energy technologies, adding to its effective value. Fixed power purchase agreements, feed-in tariffs, and energy portfolio standards and targets can all help stimulate deployment of grid-connected distributed generation and energy storage systems by lowering the risk of under-recovery borne by the investor. However, insofar as these policies transfer that risk to the purchasers, the more so the greater is the cost of the renewable relative to conventional sources.

Infrastructure constraints

Inadequate infrastructure is a significant constraint on the ability to deliver energy supplies in a reliable manner, and hinders implementation of many energy technologies. World over, there are constraints on the ability to transmit electricity from renewable sources in remote areas to consumption centers in urban areas. In developing countries, the situation is made worse by the limited transmission and distribution capacity even for electricity generated from conventional sources.

The inability to store generated power is a major technological barrier. Battery technology has seen limited improvements in recent years, and high-performance batteries still remain expensive. Energy-storage technologies using, for example, compressed air, molten salts, chilled water, or water pumping to optimize use of intermittent sources and cheaper, off-peak generation are generally high-cost, little utilized, and at a nascent level of technological development.

Certain technologies require a supply network. A classic case is fuel switching in the automotive sector to compressed natural gas (CNG), for which a new and costly network of refueling stations is needed. Vehicle owners will not switch to CNG unless they are assured that they can refuel wherever and whenever they run out of the fuel, but investors will not invest in refueling stations unless they can be sure that there will be enough CNG vehicles to refuel. In the early days of a CNG program, the infant industry argument may justify subsidies. Similar problems will be faced in the future if and when vehicles switch to all electric powering or hydrogen fuel. The depth, source, and lifespan of these types of subsidies require policy analysis where the WBG may play a constructive role.

Human and institutional capacity, dissemination of information, and social acceptance

Having access to key research information provides analysts with the tools necessary to draft appropriate policy documents. Insufficient institutional and human resource capacity in energy production, regulation, finance, energy services, energy product entrepreneurship, and among consumers creates challenges to energy technology innovation across the value chain. McKinsey estimates that many emissions abatement technologies—primarily in energy sectors—have negative incremental costs, but they are not adopted because of insufficient incentives and capacity to install and manage the technologies (McKinsey & Company 2010). Many opportunities for increased efficiency languish as a result of lack of attention, information, and creative thinking. Capacity building is the universal development challenge, and one relevant to the success of all energy projects, whether requiring engineers, builders, managers, bankers, government officials, or marketers.

Social norms are another network-related barrier, particularly applicable to consumer retail technologies. There is some resistance to shifting to a new technology under all circumstances, but the level of resistance rises if the technology has higher upfront costs to the user—even if they can be recovered over time—than existing technologies, entails some degree of learning before it can be used, requires behavioral change, or its reliability and repair costs are unknown in the market. New technologies sometimes have to dispel misconceptions and ingrained biases. Efficient biomass cookstoves and domestic lighting sources are examples of technologies that often must contend with social acceptance factors to penetrate rural areas of developing countries. Ultimately, effecting a change in social norms and consumer desires in order to spur uptake of environmentally-friendly products has proven a difficult proposition, particularly within groups with limited financial resources or where the environmental benefits are not directly felt. As such, for new energy technologies to make a significant impact on energy markets, whether deployed in the developed or developing world, they must provide similar or improved quality of service and value relative to existing products.

Alternative Roles for the World Bank Group

The requirement for massive scale-up of efforts at the global level in order to meet development and environmental objectives with deployment of new clean technologies has been widely recognized.[13] The WBG has a number of institutional strengths that it may be able to use as it examines options to broaden and deepen its engagement in clean energy technology. Its core competencies point to how the WBG may add value in this context by providing targeted investment, analysis, coordination, and advice.

- *Global reach*. The WBG has strong representation in all regions of the developing world, particularly in underserved areas, and can assess if good practices can be transferred and replicated across markets.
- *Convening power*. The WBG has the reach and authority to bring together key players in government, business, and civil society to identify and address international problems and forge partnerships in pursuit of solutions.
- *Understanding of developing markets*. The WBG has many years of experience in emerging markets, including those where foreign direct investment is limited. The WBG is positioned to help facilitate those investor and developer engagement in new markets.
- *Implementing experience*. The WBG combines analysis with decades of project implementation experience and extensive technical assistance capacity. This repository of capacity and experience provides a base on which to build further initiatives.
- *Ability to facilitate investor collaboration, particularly in the private sector*. In developing markets, the WBG's investments often pave the way for the private sector. In project finance deals, a WBG stake provides security against policy uncertainties. WBG investment in a sector also establishes social, environmental, and quality standards that make investments for global finance institutions more accessible and palatable. Consequently, the WBG is in a position to provide a bridge between development funding and technical assistance with private sector investment.
- *Ability to identify problems at the global level that may have technical solutions*. The WBG can conduct global and sector-based cross-cutting analysis and technical assistance on critical development issues, particularly in developing markets or the commons, where the private sector may not have an incentive to engage properly.

Box 3 provides criteria for determining when IFC might consider investing in a project. These points notwithstanding, the WBG and other international financial institutions have not historically been leaders in promoting new energy technology. Procurement rules generally have required competitive bidding for lowest-cost provision of investment works and analytical services (Stern 2007). This least-cost project approach is not always well aligned with support for new energy technology investments in developing countries that are more costly, but meet other country-level or international goals.[14] Limited capacity to gauge the potential of new

[13] Annex 3 provides key messages in this regard found in recent publications.
[14] Investments with higher direct costs can be justified by showing that, for example, they help provide important social benefits such as rural access to modern energy or reduced health impacts of air pollution. In addition, technical assistance and analytical work designed to explore the opportunities of new clean energy technologies, or to build client capacity in evaluating and implementing them, is not thus constrained.

technologies, aversion to technological risk in investments, and focus on large-scale projects with proven technologies are other factors that have contributed to the limited involvement of the WBG in new energy technology.

Box 3: IFC Distinctive Competence Criteria

IFC uses four key criteria for distinctive competence of products, which provides a useful framework for evaluating the potential for effective intervention:

- *Addressing market failure*. Can we define point A and point B for market transformation that will have a measurable and significant impact? Can we demonstrate that a catalytic intervention will pay off in terms of cost/benefit?
- *Investment perspective*. Is there a clear opportunity for IFC investment response directly related to the product?
- *WBG convening power*. Is there a clear need for IFC to use its "honest broker role" to launch changes in the market?
- *Global knowledge/experience.* Are there transferable / replicable good practices across markets?

As noted, a key concern has been that, given all their other pressing needs, developing nations are not in a strong position to assume the additional risks associated with emerging new technologies (Williams 2001). This concern has received greater attention of late, as developed countries have recognized the need to provide financial and technical support both to accelerate technology transfer to developing countries, and to provide concessional co-financing to cover the higher costs of emerging new energy technologies. In this context, some non-governmental organizations and developing countries have become increasingly vocal advocates of WBG leadership in promoting new technologies. Advocates of an expanded WBG role also point to experience promoting new technology in other sectors, particularly agriculture and pharmaceuticals (Box 4).

Box 4: Lessons from WBG Experience with New Technologies in Non-Energy Sectors

Three cases of WBG involvement in promoting technology transfer innovation in *non*-energy sectors—the CGIAR, Advanced Market Commitment (AMC) for vaccines, and the Montreal Protocol—offer useful lessons.

Founded in 1971, the CGIAR was the first global public-goods program to receive grants from the World Bank's net income. Its original mission was to increase food production and enhance food security by using the best science available and conducting high-return, global and regional public goods research. The CGIAR supports an alliance of 15 international research centers with more than 2,000 scientists in 100 countries. The World Bank houses the secretariat and has been providing $50 million annually, accounting for 8 percent of the CGIAR's expenditures in 2009.

The CGIAR pursued its strategic and narrowly focused mission successfully in the 1970s into the 1980s. During the 1980s and 1990s, the focus of the CGIAR was expanded to include donor-driven agendas that the group's technical advisory committee did not consider a high priority. By the early 2000s, an independent evaluation concluded that the evidence on the impacts of the CGIAR's "non-core" activities was lacking, the priorities were increasingly determined by individual donor preferences embodied in separate programs, often funded through contracts with individual centers. This mix of activities the CGIAR was engaged in reflected neither the group's comparative advantage nor its core competence (World Bank 2004). After two years of deliberation, the CGIAR adopted a new business model in 2010, pursuing large, multi-year development-outcome-oriented mega-programs jointly funded by donors (CGIAR 2010).

The history of the CGIAR offers useful lessons. Its earlier successes demonstrate the potential for collaborative international research. These successes include innovation that dramatically increase disease resistance and yields and reduced costs (Von Braun et al. 2008). However, more than a decade of work on reforming the CGIAR points to the governance challenges of a system of thousands of scientists in independent centers funded by several donors. The research agenda tends to fragment and system-level synergies cannot be fully captured.

The Stern Review sees possible relevance of the CGIAR model for research and dissemination of energy technologies in a shared commitment among the donors, building on an extensive existing set of research centers, funding programs as opposed to simply serving as a forum for advice and recommendations, diversity in institutions and crops, and the working links with users (farmers) assuring rapid diffusion of results (Stern 2007, p. 589). An OECD/IEA review of CGIAR suggests that "strong links between international R&D and national and local dissemination systems," as the CGIAR often achieved, can dramatically improve the effectiveness of technology deployment efforts as well as local R&D capacity building (Gagnon-Lebrun 2004).

There are important differences between the capital-intensive effort required for developing many energy technologies and the need for laboratory research and local adaptation and dissemination of knowledge characteristic of agriculture. CGIAR funding is on the order of several percent of global agricultural research, while an energy initiative of comparable size in absolute monetary terms would have a much smaller global impact. The similarities may be greatest for cookstoves and rural energy use where the challenge is local adaptation, knowledge sharing, and consumer finance rather than primarily capital investment. Site-specific energy solutions such as off-grid, village-level renewable energy installations may be amenable to labor-intensive local research. The more fundamental similarity, as noted by Stern, may be the potential value-added of a narrow focus on identifying research gaps and technologies with particular promise for development. The creation of a network for information sharing and donor coordination could be key elements of a heightened WBG focus on new energy technologies.

In another approach developed outside the energy sector, AMC, donors agree in advance of development to pay conditional upon delivery of a specific number of effective vaccine units at a volume and price sufficient to justify the necessary investment. The GAVI Alliance, in which the World Bank is a partner, launched a pilot AMC in June 2009 for pneumococcal vaccines, with a total pledge of $1.5 billion expected to be paid over seven to ten years (none of it from the World Bank). The use of AMCs is also being discussed in the context of developing low-carbon technologies (Bollyky 2009). Insofar as price and profitability guarantees are already used in energy policies, AMC-type mechanisms are well established. Examples include renewable purchase obligations, feed-in tariffs, and awards for pre-defined improvements in technology such as the super-efficient refrigerator competition organized in the United States and the $10 million X Prize for a commercially producible car with fuel economy of 100 miles per U.S. gallon (42 kilometers per liter) (WBG 2010).

Options and Instruments for WBG Financial Support of New Energy Technologies

This section provides an overview of two approaches—through financing and investment, and capacity building—that the WBG can consider for supporting new energy technology.

Increased financing of science and technology

The World Bank has financed activities far upstream of technology innovation that could lead to commercialization. However, a review of World Bank lending for science and technology between 1980 and 2004 (Crawford et al. 2006) raises several questions. The review found that, outside of agriculture, most support of science and technology projects went to a small number of countries. Most projects focused primarily on human resource or technology development. Several projects financed capacity building for researchers to produce scientific knowledge and firms to incorporate it into production. Those focused on human resources development occurred mainly within the university system, including support for science and technology education and basic research and institutional support for research infrastructure.

The review identified three types of technology projects:

1. *Restructuring public R&D institutes to make them more responsive to industry needs*. In China, for example, the Technology Development Project (1995) supported the privatization of research institutes and converted them to for-profit engineering research centers, with a deadline by which they would have to become commercially viable and self-sustaining, or else cease operation.
2. *Enhancing the level of technology development in industry*. An example is the Technology Development Project in Indonesia (1996), providing technology services to firms, especially small- and medium-sized enterprises (SMEs).
3. *Strengthening activities related to metrology, standards, testing, and quality*. An example is the Technical Assistance to Enhance Competitiveness Project in Mauritius (1994). The review noted that provision of infrastructure to scientists and researchers was often cited as an achievement, indicating that the focus tended to be more on inputs—though the review also noted that measuring outcomes for upstream projects of this nature would be difficult.

The review suggested that the World Bank's approach to supporting science and technology had been ad hoc, experimenting with different mechanisms depending on the country circumstances. Its recommendations included restructuring public R&D institutes to make them more responsive to industry needs, enhancing the level of technology development in industry, and strengthening activities related to metrology, standards, testing, and quality. Similar observations have been made about other national programs for supporting science and technology (National Academies 2009). It remains unclear how the WBG could effectively incorporate this advice into new financial support for new energy science and technology—the more so as decisions on funding would want to ensure the identification of a particular comparative advantage in the client country.

Grant financing of commercial technology development and deployment

For technology development, deployment, and market facilitation of relatively new technologies, various grant or grant-like funds have been the primary funding mechanisms. Until recently, GEF has been the primary source of funding new energy technology projects by the WBG. Results have been mixed but have provided important experience, with the co-benefit of supporting the internal capacity within the WBG in this area (Box 5). CTF funds aim to finance transformational action by scaling up development through funding programs embedded in national plans and strategies. The Scaling Up Renewable Energy Program in Low-Income Countries (SREP) aims to demonstrate, in a small number of low-income countries, how to initiate energy sector transformation by helping them take renewable energy solutions to a national programmatic level.

Box 5: GEF Support for Commercializing Climate Friendly Technologies
GEF adopted a strategy and approach to supporting commercialization of climate technologies with the potential to achieve substantial mitigation benefits in the mid-1990s on the basis of input from its Scientific and Technical Advisory Panel (STAP). Operational Program 7, one of ten initially adopted, outlines a rationale for using GEF resources to buy down the capital costs of new technologies with environmental benefits and higher-than-commercial costs, but with the potential to become fully commercial through demonstration and replication. STAP provided an important source of independent guidance and global expertise, with members primarily coming from academic institutions. STAP has advised on selection of particular technologies as well as on the overall strategy, at times recommending GEF support for concentrating solar power (CSP), fuel cell buses, ocean thermal energy conversion, and (narrowly) carbon capture and storage. The primary source of support is reduction in cost through a subsidy. However, most projects also include explicit elements of "barrier removal," recognizing that the introduction of a new technology usually requires capacity building, policy reforms, and other non-financial forms of support in addition to subsidies. This program was no longer considered a priority in the 4th GEF Replenishment and was not targeted for additional resources. The 5th GEF Replenishment, concluded in May 2010, includes technology transfer as a strategic priority and restores some commitment to support for innovative technologies but with a primary focus on scale-up and commercialization (GEF 2009a and 2010). A series of three wind power projects in Mexico, supported by GEF beginning in 2004, illustrate how GEF has contributed to creating an enabling environment for investment in climate-friendly technologies. The first of the three public projects (entitled "Action Plan for Removing Barriers to the Full-Scale Implementation of Wind Power in Mexico"), implemented by the United Nations Development Programne with a $4.7 million GEF grant, made proposals for the legal, regulatory, and institutional framework; started a green development fund; and established the Centro Regional de Tecnología Eólica (Regional Wind Technology Center). The 83.5 MW public-sector La Venta II wind power project in Oaxaca, supported by World Bank carbon financing, became operational in January 2007, and is a tangible outcome of the GEF project. The second project, under implementation by the World Bank, supported a higher tariff for the first private wind independent power producer, La Venta III project, through a $25 million GEF grant. The 103 MW wind farm is in the final stages of construction and is expected to be commissioned in 2011. The third project, to be implemented by the Inter-American Development Bank with a $5 million GEF grant approved in 2009, focuses on promotion and development of local wind technologies in Mexico (GEF 2009b). These GEF-supported investments provided the foundation for a vibrant wind development program in Mexico, which has grown from only 83.5 MW in December 2008 to more than 500 MW today, with another 550 MW under construction and approximately 1.5gigawatts (GW) in advanced stages of development.

Carbon finance

Funding accruing to WBG clients through their voluntary participation in carbon trading offers another source of financing for technology transfer. This occurs principally through the CDM. Trading, however, is not likely to be used much for new technologies, as the costs of emission reduction will be high relative to prevailing market prices for emission credits, and the extent of technology transfer in CDM projects remains limited, in part because the management of the CDM has labored to find methodologies appropriate but not fatally burdensome to proposals involving new technology (Hansen 2010; Box 1). By a broader measure of technology and knowledge transfer, however, diffusion of technologies that are available but not widely used may be more widespread in CDM projects than is explicitly acknowledged.[15]

The World Bank has been actively involved in carbon finance since 2000. As a financial manager for developed countries seeking to acquire emission credits, the World Bank currently operates 10 funds with capital totaling approximately $2.5 billion. It has a portfolio of 213 active projects, and leverages nearly half of the funding for its deals from the private sector (World Bank 2010a). As a source of technical assistance to client countries, the World Bank established the original pilot, the Prototype Carbon Fund, as well as a number of other funds to pilot CDM projects in more complex circumstances. A prime example is the Community Development Carbon Fund, which has had a portfolio of projects that exclusively benefit poor communities in least-developed countries. More recently it has created two additional assistance funds—the Carbon Partnership Facility and Forest Partnership Carbon Facility—which explicitly focus on carbon finance in the post-2012 period, after which the Kyoto framework expires.

IFC houses its own carbon finance unit, which develops new products for the carbon market including a carbon delivery guarantee and monetization of contracts for qualified sellers of carbon credits (www.ifc.org/ifcext/climatechange.nsf/Content/CarbonFinance). IFC provides advisory services on investments to provide flexible financing, including equity, to carbon-intensive projects, and is considering targeting debt facilities with local banks that will lend to sponsors of emission reduction projects.

On-balance sheet financing

The WBG has made a concentrated effort to rapidly increase its investment in the deployment of market-ready renewable energy and energy efficiency technologies in recent years. In 2004 the WBG made a commitment to "increase its financial commitments for new renewable energy and energy efficiency at a growth rate of 20 percent per annum between fiscal years 2005 and 2009." The WBG invested $9.8 billion in renewable energy and energy efficiency projects over that time span, rising to $3.3 billion in fiscal year 2009, and exceeded the target set in Bonne by more than threefold (WBG 2009b). Though one might argue that the technologies widely supported (usually wind and PV solar) are comparably less new than other fledgling technologies, most WBG lending efforts have focused on nascent product and geographic markets where such lending from the private sector is scarce or absent.

Due to the novelty of these concentrated lending efforts and the difficulty in attribution of successes and failures to WBG interventions, it is not yet apparent how successful the WBG's efforts to date have been. The challenge is illustrated in a recent comprehensive evaluation by the WBG Independent Evaluation Group of one such program focusing on new energy technology

[15] Seres (2008) pointed out that while not an explicit objective of the CDM, carbon trading could enable technology transfer by financing emission reduction projects that use technologies not yet deployed in the host countries. The author examined the claims of more than 3,200 CDM projects that were registered or under validation in 2008 and found that more than one-third included some technology transfer in the form of equipment or knowledge, and that these projects accounted for almost 60 percent of emission reductions. Technology transfer is more likely in agriculture, industrial gas emissions reduction, landfill gas, and wind projects, and less likely for biomass energy, cement, and hydro power projects. Another interesting finding is that, while the bulk of CDM transactions occur in the largest emitters—particularly Brazil, China, and India—projects in other countries more often provide technology transfer.

market niches, IFC's China Utility-Based Energy Efficiency Finance Program. The evaluation concluded that the program has been largely successful, but has been hampered by regulatory barriers, unready private sector partners, and failure to focus on market niches with high additionality (WBG 2009c). These findings illustrate a number of the largest challenges facing all programs aiming to accelerate deployment of new energy technologies.

Financing programs for market-ready energy technologies

Financing market-ready energy technologies is an area that is, for the foreseeable future, most readily suited for the WBG. Such financing activities may include programs to increase liquidity for clean energy investments, financing targeted to specific needs and end-users, risk mitigation instruments, demonstration projects, and the use of prizes and other innovative mechanisms. A key concern will be to define appropriate principles for use of public funds, particularly in support of new technologies with the potential for substantial private investment on international markets, and a corresponding potential for benefit in the private sector.

WBG funding at reasonable commercial rates, coupled with strong technical assistance and selective and carefully designed guarantees and other risk mitigation strategies, can accelerate the market penetration of clean energy technologies that appear to be ready for installation, but which may be limited by distortions or information gaps in private capital markets as well as information and institutional shortcomings in energy markets. Financing can be difficult and expensive to obtain in many developing countries, due in part to higher risks and transaction costs, but also due to underdeveloped financial sectors, lack of familiarity with specialized financial instruments, and other such barriers. These problems can be particularly acute in low-income countries.

Another barrier for institutional investors is lack of information about markets, and concomitant transaction costs in identifying, structuring, and managing clean energy technology investments in developing countries (UNEP/SEFI 2010). These barriers are particularly acute for institutional investors such as pension funds, sovereign wealth funds, and foundation and university endowments with broad portfolios and highly risk-averse investing strategies. Such institutions manage billions of dollars, but need guidance to invest in emerging and technology markets. Leveraging its reputation and expertise in developing world markets, the WBG could expand into asset management directly to facilitate the entry of such asset-holding giants. Targeted finance vehicles aimed at sectors and geographic areas also may provide platforms for reducing transaction costs.

Coupling private sector investment to public sector infrastructure commitments could unlock synergies among capital attraction, political will, and impact. Traditional World Bank credits and loans could also be used for projects involving technologies that are relatively new to the market but proven elsewhere.[16] There may be greater opportunities for such use of Bank instruments in the coming years in middle-income countries, particularly to support the implementation of *nationally* funded Nationally Appropriate Mitigation Actions. Countries eligible to borrow on the terms provided by the International Development Association (IDA) are less likely to request a credit from scarce IDA resources for this purpose. Another important channel is energy

[16] The Waigaoqiao Thermal Power and other projects in China show that traditional World Bank lending instruments have been used for technical demonstration effects.

efficiency improvement, which very often is economic on paper but difficult to implement in developing countries. In part this is because of inherent difficulties in aggregating a large number of individual activities into a concerted program. In addition, commercial financial institutions may be unfamiliar with the relevant technologies and assessment of financial returns based on expected savings. In turn the absence of experience may lead to higher interest rates, reducing the incentives for investment. Energy efficiency finance requires extensive capacity building with financial institutions in target markets as well as specialized investment vehicles that are closely tied to technical assistance. IFC's Sustainable Energy Finance, Cleaner Production Lending Facility, GEF Energy Efficiency programs, and IFC's leasing portfolio have successfully implemented programs of this type, but have not pooled their experience and expertise, and remain relatively small-scale.

General issues related to financing

There are several questions following from the discussion above for which answers should affect the way the WBG finances new technology development and commercialization:

1. *At what stage could the WBG provide funding?* In developing countries funding is often most difficult to obtain for research and early-stage commercial ventures. IFC is attempting to address the commercial gap with new commitments for support of clean tech ventures and clean tech funds, but does not target research. The WBG has also considered expanding its role in carbon finance beyond the purchase of credits. By considering up-front financing for carbon finance projects, the WBG could address a financing barrier for low-carbon technologies in markets considered high-risk. On the other hand, financing at this stage is subject to the risks typically found in venture capital investments, and the capacity to supervise projects of this type is limited. Moreover, increased WBG financing at this stage may crowd out some other international and domestic financing, especially in the venture capital arena.
2. *Channeling finance to low-income countries*. A preponderance of clean energy technology investment targets middle-income countries, as demonstrated by the distribution of CDM and CTF projects. Mechanisms and funds focusing on effective and locally-appropriate clean energy investment in low-income as well as small middle-income countries is a challenge that needs to be addressed in order to achieve broader diffusion of new energy technologies with local as well as global benefits. On the other hand, for supporting the maturation of emerging technologies, initial investments in middle-income countries can be more cost-effective and less risky. Mechanisms to support diffusion of new energy technologies to lower-income countries could therefore focus on a small subset of technologies with immediate and substantial development benefits, while waiting for hoped-for efficiency gains from pilot commercial investments in middle-income countries.
3. *Technology eligibility.* The CTF's investment criteria require that the technology to be financed be technically viable and commercially available. The CTF considers CCS for coal-fired power plants pre-commercial and hence ineligible (CIF 2009a). GEF relies primarily on a scientific and technical advisory panel to review and authorize technologies for support.
4. *Anticipating all effects of support.* Not all consequences of support are positive. For example, subsidizing technologies may be important for increasing the performance and

affordability of new markets, thus opening markets for greater penetration, but subsidies can be harmful to society at large if sustained for too long or at too high a rate. Consumers may come to expect that products will continue to be available for unrealistic prices, or if producers are subsidized, they may not have much incentive to lower costs and even inefficient producers may continue to operate. The WBG refers to the careful design of “smart subsidies” as among the lessons learned in renewable energy projects. Implementation of this lesson remains a work in progress, to which the experience with the CTF and other programs will further contribute.

5. *Coordination with the private sector.* One proposed role for the WBG is targeting its financial resources toward leveraging private sector investment. However, closely coordinating investment of public and private funds, as in the case of IFC’s Asset Management Corporation, may lead to conflicts of interest between investors and governments. Also, given the WBG’s limited technical expertise in growth-stage energy technologies and venture capital, it may be at risk of picking “losers” by misjudging the readiness or commercial viability of technologies in certain markets, as has been argued regarding the early years of the GEF CSP program.
6. *Ensuring adequate market and policy conditions.* A number of WBG and other clean energy programs, particularly in energy efficiency (although in renewable energy as well), have frequently encountered trouble introducing new technologies before the regulatory framework and market demand were sufficiently developed, leading to low adoption rates and/or unsustainable programs. Ensuring that the policy environment and private-sector demand are in place is essential to the success of financing efforts.

Capacity Building Efforts

The importance of building technical, policy, institutional, and business expertise to support new technology development and diffusion is widely acknowledged. The WBG is actively engaged in all of these activities, often as part of larger loan programs but sometimes through initiatives targeted to remove specific barriers or provide broad-based analytical and advisory work, as with the low-carbon growth studies supported by the Energy Sector Management Assistance Program (ESMAP) (see Box 6). More recently, in November 2009, IFC launched the Climate Change Investment Program for Africa, a sustainable energy financing and advisory program in Sub-Saharan Africa.

Another example of capacity building as well as support for innovation is the WBG’s Information for Development Program, *info*Dev (www.infodev.org). *info*Dev supports technology entrepreneurs and small business incubation—including providing enhanced business opportunities for thousands of SMEs both as energy producers and energy consumers—under its Innovation and Entrepreneurship program. *info*Dev is leveraging this experience to apply clean energy technologies in its design of Climate Innovation Centers to provide financing and services to enable the private sector to profitably develop innovative solutions that meet domestic needs in developing countries (www.infodev.org/climate). The Climate Innovation Centers are piloted in India and Kenya, with other countries planned.

Box 6: ESMAP Low-Carbon Growth Studies

Clean energy technologies often provide a wealth of benefits to societies and consumers. These benefits—which may include job creation, energy cost savings, supply security, improved health, and environmental benefits—are often not monetized and/or external to the market. Governments and development agencies have the opportunity and responsibility to recognize these market externalities and attempt to correct for them to fully capture benefits from energy investments. There is also a great need to track, record, and quantify these benefits so that projects producing them may be given appropriate priority. Leveraging existing social and environmental standards, the WBG may be in a position to introduce such practices.

Six low-carbon growth studies have been financed in part by ESMAP in Brazil, China, India, Indonesia, Mexico, and South Africa. These studies assist the governments in the study countries in assessing their development goals and priorities and examine the additional costs and benefits of growth patterns with lower overall GHG emissions than those that would occur under the current national policies.

Collectively, these studies identify some broad messages, such as making greater use of renewable energy and energy efficiency support, and country-specific opportunities such as low-cost transport options with lower carbon intensity and untapped cogeneration investments:

- The Indonesian study provides insight into fiscal and financial policy instruments and tax and spending policies to promote movement towards a lower-carbon economy. Strategic investment approaches and financing sources, as well as improved fiscal incentives in forestry, are also considered.
- Mexico's study provides a body of knowledge about prospective low-carbon "wedges," specific low-carbon projects, and the continuing policy reform agenda. Main energy savings arise from cogeneration and energy efficiency improvements in industry, while the forestry sector has untapped mitigation potential.
- South Africa's study is helping to create an enabling environment and to provide support for national and private sector organizations to undertake energy efficiency and demand-side management measures, identified as priorities in the government's Long Term Mitigation Scenario.

The goal is to use the knowledge generated to develop low-carbon pathways and to identify GHG reduction investments beyond these countries.

Source: ESMAP 2009.

There are several questions that affect the WBG's efforts at capacity building:

1. *Measuring effectiveness*. The success of training and knowledge-sharing efforts has tended to be measured by the number of workshops held and their participants. The actual impacts of such efforts in bringing about government engagement and on market development are much more difficult to evaluate, but need to be estimated to assess the cost-effectiveness of capacity building efforts.
2. *Engaging appropriate stakeholders.* Training and information sharing is meaningful only if addressed to parties who can use the information received. The private sector is often the key target group, but absent or only weakly represented in capacity building efforts.

3. *Linking capacity building to investment.* Capacity building without the necessary financing may only create frustration, as expectations are raised but cannot be met. There is evidence that the impact is greatest when technical assistance is combined with investment, but there is no obvious coupling with investment when, for example, projects influence tariffs or other key policy conditions (WB IEG 2009).
4. *Capacity retention.* Human capacities of developing country institutions can often be lost via brain drain from the public to the private sector, or from within the country to abroad. Efforts to build long-term capacity through ongoing training and education programs and through knowledge-sharing networks and libraries can protect against losses of individual staff.
5. *Legal frameworks and incentives.* Capacity of institutions and individuals can be hamstrung in efforts to manage and regulate by inadequate legal and regulatory frameworks.

Internal Changes

The breadth of geographic focus and depth of sector expertise within the WBG provides great scope for improving the use of energy technology expertise and implementing experience. On the other hand, Annex 4 provides examples of current procedures and practices that could act as barriers to the WBG's effort to scale up support for new clean energy technologies.

One of the most immediate and easily implemented strategies is to build upon this knowledge and expertise within the WBG (see Box 7) to address difficulties in obtaining objective information about technologies and their suitability to the needs of circumstances of client countries. The application of this role is illustrated by the case studies in annex 1, which highlight various ways the WBG explores technological opportunities through study tours, internal workshops, large internal conferences such as the Energy Week, invited presentations by experts, and site visits—all of which have been used in response to the increasing interest in CSP, for example.

Another way to utilize WBG expertise, consistent with its emerging role as a knowledge bank, is to identify and disseminate information on best practices generated in connection with projects through a centralized WBG technology clearinghouse. Building on existing efforts of the Sustainable Development Network and IFC's Knowledge Management program, such a clearinghouse could be a reference for use of best practices in the energy sector by non-energy sector project and investment officers. For example, the World Bank financed development of a toolkit for inclusion of PV solar panels into rural health center and school projects. The toolkit is designed to help staff avoid many of the routine pitfalls that plague poorly planned and executed PV solar projects to provide power to rural community infrastructure and is available on-line at http://go.worldbank.org/OWJW3JRYJ0. An internal technology clearinghouse could also spearhead capacity building efforts for WBG staff to identify novel technologies emerging from projects and redirect them to areas and programs where they might be most beneficially used.

Box 7: The World Bank Group and Science, Technology, and Innovation

The WBG has recently renewed its efforts to engage in technology development and diffusion. The World Bank included a science, technology, and innovation (STI) expert team among the ten new Global Expert Teams launched in February 2009. Their themes represent corporate priorities, identified and supported by senior management for their high strategic relevance to the WBG. Their mission is to ensure that the best internal and external expertise is available and deployed quickly and flexibly. The Global Expert Teams also ensure that the WBG's knowledge on each theme is captured and disseminated systematically to the broader community and clients.

The STI Global Expert Team has two key strategic objectives:

1. Help WBG teams and government policy-makers design, develop, and deliver STI capacity building programs tailored to each country's specific growth, competitiveness, and poverty reduction agenda, as well as to its specific stage of development and initial STI capacity.
2. Foster partnerships to intermediate knowledge and capacity flows between developing country clients that need to augment their STI capacity and development partners— in both the North and South—who possess a great deal of the required technical expertise and capacity building skills.

A lesson of past new energy technology projects is that they often require specialized expertise outside the experience of WBG task managers and IFC investment officers. IFC is beginning to address this gap through a joint-venture approach in which a new technology unit will have joint portfolio ownership with other industry departments for investments in new technology ventures. This structure recognizes that clean tech enterprises may arise in any industry sector but may require specialized expertise and attention for a smaller, higher-risk investment. This concept of a support unit to help address higher transaction costs and technical issues for innovative technologies could be applied more broadly across the WBG for all projects, or elements of projects. A related need is for a provider of training and related capacity building services for WBG staff and, in a supporting role assisting operational units, for client countries.

Finally, energy sector projects could benefit from multi-sectoral collaboration to design projects that maximize community and social co-benefits. By creatively amending its policies, procedures, and evaluation structures, the WBG could create incentives for proactive creation of energy technology integration and societal co-benefits, as in the case of the Community Development Carbon Fund. Cross-sectoral staff meetings during project development and strategic planning for countries and regions, best practice-sharing templates, and new evaluation metrics could help facilitate this effort.

Conclusions: Major Opportunities and Challenges for New Clean Energy Technologies

There is a substantial need for the deployment of new, clean energy technologies in developing countries in the coming decades. Apart from addressing local environmental problems, without such technologies, attempts to reduce and stabilize the growth of GHG emissions are unlikely to be successful. The WBG can play a part in several ways to encourage their deployment, but it can make only a small direct contribution to the total funding required. Accordingly, it is essential that its engagement with clean energy technology deployment be strategic and effective, have a powerful demonstration effect, respond to needs of client governments, and use the WBG's comparative advantages in areas of knowledge, skills, and financing instruments.

A summary of the options for approaching the encouragement of clean, new technologies are discussed, and arguments for and against them are given in Table E.1. Options 1–4 and 7 build incrementally on established or recent WBG initiatives, although in some cases operational changes may be required. These approaches will need to respond gradually to technologies not yet deployed in some or all client countries, and priorities between technologies will need to be established. Option 6 (targeting finance for poor and rural consumers and SMEs) addresses development niches that the private sector typically will not address without incentives, and in that sense represents an appropriate role for the WBG and is consistent with established policies. Here the issue is that of the technology that could become cost-effective with initial support once a market has been established. The timing of the introduction of such technologies will also be crucial.

The other approaches listed in the table are at present largely outside WBG practice and would need further evaluation before substantial internal resources are devoted to the teams needed for their establishment and to the investments that they would finance. Certain options may require significant internal new financial and human resources, making it quite difficult to give them treatment in a period of rapidly growing demands for WBG assistance and constrained institutional budgets. Options would need to be carefully reviewed prior to implementation, utilizing comparable experience in other sectors where serious problems sometimes have been encountered. An example is the effect of donor financing of research institutions by the Consultative Group on International Agricultural Research (CGIAR), which led to a shift in research emphasis toward donor priorities (World Bank 2004; see also Box 4 above).

Energy Access and Sustainable Development

In attempting to prioritize among the options, the two objectives of the energy sector strategy—increasing access to and reliability of modern energy services and facilitating the transition to sustainable energy sector development—offers some guidance. To address the energy access challenge, the WBG stands to gain much from the lessons from various agents of past successes in providing services and disseminating technology to the bottom of the pyramid at large scale. The Green Revolution (high-yield seeds and fertilizers), mobile phones, and microfinance stand out as major enabling technologies that have met these criteria (in the broader sense of the word, encompassing institutional and process innovation as well as tangible goods). These technologies share in common (1) the provision of direct, localized benefits at the village and household level; (2) the ability to channel individual incentives and initiative to spur bottom-up or organic development rather than top-down solutions; (3) a reliance on global research and best practices to take to scale; and (4) relatively low capital-intensity. It will be necessary to examine clean energy solutions to see whether they can replicate the conditions for these successes, especially since the particular technological and economic circumstances surrounding the breakthrough examples above do differ quite considerably from the circumstances surrounding new clean energy.

To bring energy access to scale through technology, the WBG can continue to deepen understanding of the barriers and opportunities by taking stock of the extensive amount of ESMAP and other work addressing these issues, in order to think even more creatively about which technologies and institutional structures can best meet the needs, and about how barriers and financing can be addressed. Ongoing questions in this arena include the following:

- Are these technologies scalable and available at reasonable cost?
- Do they meet the energy needs of the poor better than conventional solutions, such as liquid fossil fuels and fossil-fuel-based on-grid electricity, and under what conditions?
- Are cheap, locally-manufactured goods best, or are high-quality imports more appropriate?
- Are these technologies and institutional approaches suited to low-income countries, middle-income countries, both, or neither?
- How can financial and supply chain obstacles be lowered?
- What energy and perhaps financial sector policies in client countries need modification to lower barriers?

Because there may be limited appetite in IDA countries to use credits for such investments, the WBG's role may have to be limited to policy advice, support for market development (as in the Lighting Africa program), or the use of grant funding for demonstration projects (option 6 for targeted capital for the poor, rural areas, and SMEs).

Some of the other policy options could make a contribution to this target but are likely to have limited potential. Option 10 (aggregation and dissemination of energy technology knowledge on a global scale) could be valuable in answering the above questions and implementing solutions on a trial basis. At an earlier stage of technology, options 12 (global energy research fund) and 15 (regional or global science fund for pro-poor technology) could help to develop and disseminate the technologies of the future, and improve and adapt existing technologies, providing there can be improvement in targeting over past efforts in this area. Option 5 (public sector procurement mechanisms) more likely would have a limited role, but it could contribute in either (a) developing supply chains for local and regional energy technology goods and services, or (b) bringing down costs and raising quality for high-tech manufactured goods.

Low-Carbon Transition

The scale of energy-sector investment required in the coming decades to address even basic needs—independent of the imperative for low-carbon development—is well-documented and daunting. Particularly with skittish financial markets, risk-averse investors, and large fiscal deficits in developed countries, WBG and other donor funding will at best pave the way for private sector investment. The challenge is particularly significant in low-income countries with little foreign direct investment. Specially designed programs such as SREP and the Community Development Carbon Fund are helpful but are available in amounts that are far from being aligned with the scale of the challenge. Beyond such basic efforts, many renewable energy and energy efficient technologies not only have the disadvantage of being relatively new, unproven, and therefore risky compared to incumbent technologies, they also are often more costly than conventional alternatives, as well as being capital-intensive and thus requiring many years to recoup investment capital. To improve the risk-return profile of clean energy technologies, risks must drop, returns must rise, or both. The WBG has only limited scope to influence the main policy levers influencing return—tax and subsidy regimes, and international climate finance frameworks. Consequently, the WBG must focus on policy, finance, and technology support measures that may be able to reduce the perceived risk of clean energy technologies and that can provide demonstrations of what can be achieved at reasonable cost.

It is difficult to prioritize amongst the current measures the WBG already implements, because different goals, technologies, and country circumstances present varying opportunities and challenges. Nevertheless, it is important to highlight options that are and should remain the flagship WBG interventions, in contrast to those that are smaller-scale and experimental. Such interventions must accelerate the shift of incremental investments to technologies that are lower-carbon and economically efficient at the societal level, while focusing on areas of the WBG's comparative advantage. In particular, options 1 (WB loans and credits for new technology), 3 (grant financing), and 4 (IFC investment) can continue to generate momentum for clean energy investment in developing countries, providing implementing experience and economies of scale that bring down borrowing and manufacturing costs. The WBG should focus on those investments where its participation and/or demonstration can play a more catalytic role for increased private sector interest within markets. Where perceived risks are relatively high, donor funds should be deployed judiciously to facilitate investments that can succeed with such assistance, while being ready to pull the plug expeditiously on those that do not. Options 2 (World Bank loans and credits for technology capacity building) and 7 (policy and regulatory support) will continue to provide the physical, human, and policy infrastructure essential for a strong, long-term investment climate.

Bringing Greater Focus to WBG Efforts

While the preceding paragraphs suggest that the WBG should build on its established core competencies, the WBG could also consider ways of increasing its energy technology expertise. One option would be to concentrate within a single office efforts throughout the WBG to aggregate, analyze, and disseminate the resources—expertise, best practices, and global reach—in order to position the WBG to achieve greater results. Option 16 in Table E.1 (creation of a technology office) would create a central entity within the WBG capable of analyzing best practices, supporting research, aggregating and disseminating information on energy technology and on the needs of the developing world, and collaborating with other institutions to achieve these objectives. Such an office could also be a prelude to potentially larger technology research and dissemination initiatives that radiate beyond the WBG and require significant resources, such as options 10 (aggregation and dissemination of energy technology knowledge on a global scale), 13 (umbrella technology and research organization), and 14 (promotion of open-sourcing, databases, and portals).

However, such an office likely would be costly, especially in order to achieve scale consistent with its objectives. The costs would arise from a mix of adding to WBG staff additional experts and moving existing specialists away from their current work in support of WBG operations. To be effective, this approach also faces some practical questions that will likely take time to address: how to manage different perspectives on regional needs and technological priorities, how to provide timely technical advice for specific operations to the WBG's regional departments and their clients, and how to ensure that experts coming from outside the WBG achieve the necessary understanding of substantive and operational priorities as rapidly as possible. With significant resource constraints, accordingly, priority might have to be given to scale-up of existing activities that can be achieved at a low internal resource cost.

Annex 1: Case Studies

This annex presets case studies on CSP, CCS, biomass cookstoves, solar lanterns, and building energy efficiency codes in China. Each briefly describes the potential role and importance of the technology, its current status with particular reference to the role of the WBG, the key barriers, the type of intervention, and lessons learned. The lessons of these case studies are reflected in the proposals for possible expanded WBG efforts to promote new technology development and deployment.

Concentrating Solar Power

Technology descriptions

CSP—or solar thermal power—technologies utilize reflective materials to focus energy from the sun to make steam and generate power, in many ways like conventional thermal power plants but with the substitution of solar energy for fossil fuels (IEA 2008; Staley et al. 2009). There are four semi-distinct types of CSP power plants. Parabolic trough systems reflect the sun's energy on a receiver tube using mirrors that pivot in order to track the sun; the tube carries the heat to a central steam generator and turbine. Systems based on this design have been in operation since the 1980s. Compact linear Fresnel reflectors operate on a similar principle, but use flat mirrors arrayed in parallel, to replicate the function of trough mirrors. The lower optical efficiency of these systems is offset by lower capital costs and reduced risk of wind damage. Power towers use a field of mirrors (heliostats) to direct the sun onto a central receiver, potentially achieving higher temperatures and efficiencies. However, there is much less operational experience with this approach. Finally, dish-engine systems employ a modular approach to CSP generation. A parabolic dish mirror focuses solar insolation on an overhead absorber/engine. This approach is unique, in that power is generated separately within each dish-engine unit, and this modularity allows incremental installation, more readily adapted to uneven terrain. In total, commercial CSP systems with more than 400 MW capacity were operating as of end 2008: 418 MW of trough systems, an 11 MW of tower, and 1 MW based on compact linear Fresnel reflectors (Staley et al. 2009).

Status and current prospects

CSP development is the subject of increasing commercial interest as well as continuing publicly supported research and policy support. The two major markets for CSP currently are Spain and the United States, both driven heavily by supportive incentive programs. In California alone, as of March 2010 the state Energy Commission listed 12 projects formally under review with a total capacity in excess of 4,000 MW. Another 20 projects with a total capacity of about 6,000 MW have been announced but so far lack formal applications (CEC 2010). This commitment is being driven by the state's aggressive clean energy policy, which requires utilities to supply 20 percent of their power from renewable sources by 2010 and 33 percent by 2020. The mandate justifies utility commitment to purchase power from solar technologies, which are more expensive than more conventional sources. For California, the policy is based on the hope that increased volume in solar power, larger plant size, and technological advances will drive down costs and create associated industries.

Several studies have attempted to estimate the total subsidy required to achieve cost parity relative to baseload power generation. Key assumptions are the rate of cost declines due to learning and economies of scale, the discount rate, and the costs imposed on fossil fuel by climate policies (annex 2). The World Bank is currently preparing a CTF-funded Middle East/North Africa project, which aims to facilitate the installation of 900 MW CSP capacity. Analysis (see Table 3) indicates that while this technology remains uncompetitive with conventional baseload power sources, this can be partly offset through target financing programs.

Table 3: Estimated CSP Levelized Tariffs based on the regional project in the Middle East and North Africa ($/kilowatt-hour)

Scenatio	8% internal rate of return on equity	12% internal rate of return on equity	15% internal rate of return on equity
(A) No support	0.240	0.281	0.311
(B) 100% tax holiday, carbon finance at US$ 15 / ton of CO2, CTF at US$ 725,000 /MW	0.197	0.225	0.247
(C) B + concessional financing at US$ 1.5 mil/MW—public project	0.157		
(D) C (private project)		0.177	0.191

Source: CIF 2009b.

A number of large middle-income countries are pursuing CSP development at the national scale. The Government of India has announced a National Solar Mission that includes plans to develop 50–100 MW and 25–50 MW CSP plants and a policy support framework as part of the Mission's goal of 20 GW of installed capacity by 2022 (India MNRE 2009b). In China, a 50-MW CSP plant is planned in Gansu Province (Bradsher 2010) and a 92-MW plant in Inner Mongolia is part of a 2-GW deal between eSolar and two Chinese power companies for a series of CSP plants (Woody 2010). A number of other developing countries including Israel, Iran, South Africa, and Sudan have reportedly announced CSP initiatives or plans.

Niche and significance for development

There are several features of these technologies that make them appealing for development. First, many developing countries are in regions with high direct solar radiation, the primary requisite. The IEA projects that CSP may account for nearly 10 percent of global power generation in

2050, and that CSP will be able to generate reliable, base-load power for sunny countries (IEA 2010d). Consequently, when appropriately priced, CSP may be an attractive power generation source to meet many developing countries' rapidly growing power demand. Second, most CSP technologies are targeted toward large-scale projects (at least 100 MW by most estimates), to achieve economic optimum and thus can address the need for large amounts of power. However, to provide reliable power over a significant period of the day such plants need either to be part of a larger diversified system or coupled with storage technologies (Staley et al. 2009). In addition to electricity, CSP can also be used to provide direct heating/cooling for buildings and industrial processes including desalination. In some regions there is also the potential for building CSP plants to export clean power. The proposed Mediterranean Solar program calls for 20 GW of renewable energy from North Africa by 2020, much of it from CSP plants and exported as electricity to Europe to take advantage of the higher value given to renewable power by EU policy. The German consortium Desertec continues to discuss a massive, long-term €400bn investment in North African CSP for export to European markets (Connolly 2009).

Another potential benefit of the technology is that the necessary materials and construction skills are widely available and largely derive from well-established industrial technologies.

Major barriers to widespread use

The first and primary barrier is the current high cost relative to electricity from coal, gas, and oil. A recent World Resources Institute report estimates that the cost differential is equivalent to \$115 per tonne of CO_2, considerably higher than expected prices in the carbon market (Staley et al. 2009). Other barriers include the need for unobstructed land in areas with high solar insolation, preferably in close proximity to transmission lines, and, as with conventional plants, the need for cooling water or lower-efficiency, higher-cost air cooling systems. As with other new technologies with limited track records, investors are also wary. Areas high in dust or aerosols (such as ocean spray) also may be less attractive due to reduction in sunlight or cleaning requirements for efficient operation. Proven, cost-effective storage systems will also substantially enhance the appeal of the technology by increasing reliability and extending operating periods. Alternatives to large-scale storage include on-site backup generation capacity, typically provided by natural gas.

The aggressive policy support for grid-connected renewable energy, particularly the California target of 33 percent by 2020, has led to a rapid rise in commercial interest in all forms of this technology. Numerous commercial companies are now seeking permits and financing for projects worldwide. Deals have been made with auto companies and other manufacturers with relevant expertise to produce lower-cost and/or better performing versions of key components.

The implementation of supportive policy and regulatory frameworks is also a significant barrier in many developing countries, as the GEF CSP program in the 1990s revealed (Miller 2007). The high capital costs of CSP generation, estimated for North Africa at approximately \$4 per watt, are two to four times the unit capital costs of power generation for other renewable energy sources (CIF 2009b). Consequently, the combined sovereign, policy, technology, and performance risks in developing countries for such capital-intensive technologies as CSP will require concessionary funding and risk mitigation strategies to attract private capital at the required scale.

Ongoing role of the WBG

The WBG has a long history with CSP projects, with four GEF projects in Egypt, India, Mexico, and Morocco started in the latter half of the 1990s. All four projects were designed to the amount of funding available, about $50 million in each case, which resulted in less than optimum scale, and built as integrated systems with fossil fuels to allow reliable operation. The project in India has subsequently been dropped. The ain Beni Mathar CSP plant in Morocco became fully operational in October 2010, and the Kureimat CSP plant in Egypt is expected to become operational in early 2011. An evaluation carried out in 2006 for the World Bank recommended a phased strategy with inherent exit paths (World Bank and GEF 2006). More recently the WBG has formed a working group on the technology, organized a site visit to a working facility, provided internal training with external experts for interested staff, and sent representatives to investment meetings to assure it remains up to date on the status of the technology. The World Bank is also preparing a North Africa renewable energy program for the Clean Technology Fund that aims to bring approximately 900 MW of CSP online across Algeria, Egypt, Jordan, Morocco, and Tunisia. The program will mobilize $4.85 billion of financing, enabled by the $750 million of concessional finance provided through the CTF. This combination of financing, risk mitigation, and technical assistance to create an attractive national policy environment is an example of the role the World Bank can play in deploying commercial and near-commercial energy technologies.

Carbon Capture and Storage

Technology description

Carbon capture and storage refers to technologies for extracting and storing CO_2 from fossil and other fuels. While most often discussed as a means of reducing CO_2 emissions in the context of coal combustion, meeting aggressive climate targets could require the application of CCS to other fuels including biomass. Three distinct elements are usually required: (1) capture of CO_2, typically from power plant or industrial process emissions; (2) transportation to a storage site; and (3) injection into a suitable geological formation, such as depleted oil and gas reservoirs or saline aquifers. The bulk of the costs are associated with CO_2 capture, although finding adequate suitable storage capacity and addressing storage liability are among the litany of other challenges (IPCC 2005; Logan, Venezia, and Larsen 2007; IEA 2008).

There are three basic approaches to carbon capture:

- *Post-combustion* processes, which captures CO_2 after the fuel has been combusted. The higher the concentration of CO_2 in released gases, the more efficient and less costly is capture. To maximize the concentration, one approach is to use oxygen rather than air (which contains 21 percent oxygen) in the combustion process in a process referred to as oxyfuel. Although the cost of capture is significantly lowered, this is partially offset by an additional cost of separating oxygen from air. Another approach now at the demonstration stage involves mixing brine water with flue gas, resulting in calcium and magnesium carbonates with the potential to substitute for cement and aggregates (www.calera.com).

- *Pre-combustion* processes in which CO_2 is produced and separated before a fuel is burned for generating power and other forms of energy. Steam and air or oxygen are reacted with a carbon-containing fuel (hydrocarbons, coal, biomass) to produce carbon monoxide and hydrogen, called a synthesis gas. Carbon monoxide is further reacted with water vapor to form CO_2 and hydrogen, thereby producing a concentrated stream of CO_2 and facilitating its separation.

- *Miscellaneous industrial processes* also separate CO_2. Examples include natural gas processing near the point of production to achieve minimal gas purity specifications and sometimes with a view to reinjecting CO_2 into the reservoir.

Status and current prospects

Limited commercial use of CO_2 for enhanced oil and gas production is a well-established technology and includes transport by pipeline. However, the scale required to make a significant contribution to climate change is massive. According to an MIT study, sequestering one gigatonne of carbon per year (a “wedge” in the widely cited Pacala/Socolow analysis) would require daily injection of about 50 million barrels of supercritical CO_2 from about 600 one-gigawatt-equivalent coal plants (MIT 2007). Significant ongoing research and demonstration related to CCS is taking place in several countries, including an EU program for up to 12 demonstrations, funded in part by an allocation of revenue from carbon trading. In 2010, eight commercial-scale projects were in operation around the world, according to Australia’s Global CCS Institute. Significant government support for CCS development has been announced in several countries, including Australia, Canada, Norway, the United Kingdom, and the United States. In April 2009, the UK government released a budget for 2010 that created a new funding mechanism to support up to four CCS demonstration projects (UK government 2009), and £1 billion has already been allocated to one project. Norway has pledged $600 million in its 2010 budget for CCS, including two demonstration projects and R&D (Norway 2009). In May 2009, the U.S. Department of Energy announced $3.4 billion in grants for the Recovery and Reinvestment Act of 2009 for CCS development projects (U.S. DOE 2009). The province of Alberta, in Canada, has committed $2 billion in funding for four CCS projects, partly to further efforts to reduce CO_2 emissions from oil sands production. Interest in and support for CCS is also increasing in developing countries, especially China (Forbes, Seligsohn, and Verma 2009; DEFRA 2009).

There is as yet no fully integrated large-scale power plant capturing and storing more than half of CO_2 from the flue gas slipstream. A recent study comparing the costs of adding CCS to various configurations of greenfield power plants—post-combustion, with and without oxyfuel, in supercritical and ultra-supercritical coal-fired plants; pre-combustion in an IGCC coal plant; and post-combustion in natural gas-fired combined cycle—found that the levelized cost of electricity was the lowest for the natural gas combined cycle plant with carbon capture, and the cost of CO_2 avoided was the lowest for supercritical technology with carbon capture using oxyfuel combustion (Global CCS Institute 2009). The United Kingdom and the Canadian province of Alberta have decreed that coal plants being planned today will need to be designed for future retrofit of CCS with specific requirements, such as allowing for future land and siting needs. Further, the EU Directive 2009/31/EC on CCS mandates all new large combustion plants be constructed with "suitable space on the installation site for the equipment necessary to capture and compress CO_2 if suitable storage sites are available and if CO_2 transport and retrofitting for CO_2 capture are technically and economically feasible" (European Parliament 2009). In contrast, an MIT study concluded that the modifications that will be required for CCS retrofit are so significant that design-for-retrofit opportunities are in practice very limited (MIT 2007).

The prospect of a large market for CCS has generated substantial interest among firms and investors in less expensive, more efficient alternative processes; some are already in various stages of commercial development (Lovell 2011).

Niche and significance for development

The rationale for a major international commitment to CCS development and deployment is simple: there is no other likely alternative that allows continued use of coal and hydrocarbons without very large increases in atmospheric concentrations of CO_2 with large risks of climate change. How effective in the long run CCS is in storing CO_2, how rapidly associated costs can be brought down, and how widely it can be deployed are questions that affect large coal consumers in particular. The U.S. government has recently announced an initiative with China to support a Joint Clean Energy Research Center with CCS as one primary focus (Forbes, Seligsohn, and Verma 2009). Other major efforts to promote information sharing and collaboration, especially with China, are being organized by universities and other non-governmental organizations (Zhao, Xiao, and Gallagher 2009). These include the Carbon Sequestration Leadership Forum, the Global CCS Institute, the EU Zero Emission Platform, and the Clean Energy Ministerial, among others. Some environmental advocates have identified CCS in combination with biomass power generation as a potential means of achieving negative GHG emissions (Hare 2009).

Major barriers to widespread use

The primary barriers to CCS are cost, the absence of regulatory incentives, long-term liability issues for the stored CO_2, and the need for large commitments of funds for research and demonstration. There is a range in the cost estimates, since a fully integrated power plant and CCS system at scale currently do not exist. One study estimates that the expected increase in capital cost is on the order of 40 percent for an IGCC plant and 70 percent for a supercritical pulverized coal plant (Rubin 2009). In climate policy terms, a price of $150 per tone of CO_2 or higher is likely to be needed for first-in-kind plants, falling to between $35 and $70 per tone of CO_2 for more mature technologies, equivalent to about $0.10/kilowatt-hour (kWh) declining to approximately $0.02–0.05/kWh (Al-Juaied and Whitmore 2009). A McKinsey study of CCS scale-up makes projections of €60–€90/tonne for early demonstration projects, falling to approximately €30–45/tonne by 2030 (McKinsey & Company 2009a). This cost is substantially less where the captured CO_2 can be used for enhanced oil and gas recovery, enhanced methane coal bed recovery, or otherwise sold on the market. One of the cost uncertainties is the energy penalty associated with the series of measures required for capture, transmission, and storage (Page, Williamson, and Mason 2009). Another study estimates the incremental energy use of a CCS-equipped facility over a conventional one at approximately 29 percent, with a range of 11–40 percent (House et al. 2009). Some industry estimates, based on the results of on-going demonstration projects (such as Alstom's Mountaineer project), put the energy penalty in range of low-20 percent.

A further barrier is the high capital cost of full-scale demonstrations, estimated to be of the order of $1–2 billion. The IEA has recommended in its 2009 CCS technology roadmap that, over the next 10 years, OECD governments increase average annual investments in CCS to $3.5–4 billion, while non-OECD countries invest $1.5–2.5 billion (IEA 2009a). This government funding should be combined with a range of policy incentives to encourage private participation, including bonus allowances and revenue set-asides in carbon trading programs, with the aim of both proving workability and reducing costs (Kerr 2009). Legal uncertainties and public acceptance also need to be addressed (Jacobs et al. 2009). Additional issues have to do with the rationale of accelerating introduction of a pre-commercial technology in developing countries, given concerns about additional financial risk/cost, protection of intellectual property and the need for reliable and low-cost power. There are also concerns about storage permanence and long-term liability, since CO_2 storage has existed for less than 50 years and is subject to uncertainties over leakage and venting.

Ongoing/proposed roles for the WBG

The WBG has had a limited engagement with CCS for more than a decade. A concept for a project to study CCS in conjunction with a power plant in China proposed by the WBG was approved by GEF more than a decade ago. As the first such proposal submitted to GEF, the appropriateness of funding was reviewed and approved by the GEF Scientific and Technical

Advisory Panel. However, the project did not proceed because of a decision not to pursue an associated IGCC project.

The WBG monitors the status of CCS through participation in and presentation at international forums and regular expert consultations (such as the 2009 Energy Week, an international WBG-IEA joint CCS workshop in September 2009, International Energy Forum CCS Conference in Algeria in June 2010, and the Annual Meeting of Members of the Global CCS Institute in Kyoto in October 2010), participation in other international meetings, and discussions with enterprises seeking financing. The lack of incremental financing resources to offset the high up-front cost and reduced efficiency of power generation installations equipped with CCS, along with limited international experience to date with integrated power plants (electricity generation and carbon capture) and the need to assess long-term environmental impacts from subsurface storage of CO_2, have so far not presented any serious opportunities for WBG participation in a CCS project in a client country.

Whether the WBG might consider using donor funds for CCS projects has been discussed in the context of the multi-donor Clean Technology Fund (see www.climateinvestmentfunds). The CTF eligibility guidelines severely restrict use of funds for CCS technology on the basis that it is still in a demonstration phase and outside the scope of the program.

In 2009, the World Bank created a specific Carbon Capture and Sequestration Capacity Building Trust Fund, with contributions of $11 million received from Norway and the Global CCS Institute. This trust fund has two primary objectives:

- To support strengthening capacity and knowledge sharing, to create opportunities for developing countries to explore CCS potential, to increase access to carbon markets and realize benefits of domestic CCS technology development.
- To facilitate inclusion of CCS options into low-carbon growth strategies and policies developed by national institutions and supported by WBG interventions.

Activities supported by the World Bank's CCS trust fund are implemented as technical assistance programs, stand-alone and/or connected to investment operations (e.g., investment loans, credits, and grants) and development policy operations, and analytical advisory activities. As of January 2011, the World Bank's CCS trust fund is financing projects for CCS capacity building in nine client countries and one analytical study to examine options for creating and financing regional CCS networks and impact from potential CCS deployment in regional electricity markets that rely on interconnected power systems.

Cookstoves for Solid Fuels

Discussions of new energy technologies tend to focus on opportunities for large-scale power generation such as wind turbines and CSP. However, tackling the challenge of reaching a large number of poor small energy consumers, with low-cost, distributed energy technologies presents a different challenge. The speed with which cell phones have been adopted by the poor, in both urban areas and rural areas demonstrates that, given the right business model, poor households have the capacity to adopt beneficial technologies. This case study, and the one to follow, reviews two efforts to bring higher-performance cookstoves and efficient lighting to the poor.

Technology description

For those relying primarily on biomass fuels for cooking and heating, cookstoves engineered to reduce the amount of biomass consumed and/or emissions of harmful pollutants have many potential benefits: reducing the time required to collect fuel, improving indoor air quality, and/or reducing emissions of gases and particles with global warming potential. Where there is concentrated consumption of woodfuels, such as charcoal used by urban households and small industries, woodfuel use have even contributed to deforestation and forest degradation. In appropriate climates, solar cookers can largely eliminate the need for biomass fuel. Consumer acceptance of cookstoves is closely connected to local cultures, diets, and cooking methods, which often requires designs tailored to localized markets. The stoves must also be durable in challenging conditions, yet sufficiently low-priced to be affordable.

Although the term “improved cookstoves” is often used to refer to stoves burning solid fuels with higher efficiency, it is critically important to distinguish between fuel efficiency (needed for fuel savings but could worsen indoor air pollution) and combustion efficiency (essential for improving public health). When one does so, what emerges is that it would be far more challenging to reduce indoor air pollution sustainably over the long run than to achieve fuel savings.

Fuel efficiency, or overall efficiency, is greatly increased by increasing heat transfer efficiency. When accurate measurements of fuel use and emissions have been taken, a very large increase in overall efficiency enabled by heat transfer efficiency has been found at times to mask a decline in combustion efficiency, that is, increasing fuel efficiency can actually increase, rather than decrease, pollutant emissions (Smith 2002) and associated health damage. Aggregating all stoves with improvement in some aspect of performance under the rubric of “improved stoves” is therefore not helpful. Some “improved stoves,” such as those with chimneys, increase neither fuel efficiency nor combustion efficiency. In some parts of the world, such as India, the health benefits associated with chimney installation are likely to be much less than previously believed, because outdoor air pollution in rural areas, which would worsen by installing chimneys on stoves, is now recognized to be a serious problem. Improved fuel-use stoves have higher fuel efficiency, and advanced-combustion stoves have higher combustion efficiency, than traditional stoves. Substantial health benefits call for advanced-combustion stoves.

A recent paper by Kirk Smith’s group points out that advanced-combustion stoves generally require fuel processing before use (even if that means just chopping wood), and materials of construction make them unsuitable for local manufacture at the point of use. These have significant implications for adoption and sustainability. More specifically, the paper cites the following observations (Venkataraman et al. 2010):

- The best approach to tackle fuel savings, public health protection, and GHG emissions is to move toward high-combustion-efficiency and low-emissions advanced-combustion devices that do not produce any significant pollution in the first place. There are now stoves for solid biomass that produce emissions per meal that are less than one-fifteenth that of traditional stoves in lab tests, with greater reductions seemingly possible.
- To achieve reliable long-term high performance, advanced-combustion stoves must use either advanced ceramics or metal alloys as well as other components (such as blowers), which must be made in centralized manufacturing facilities with good quality control and other modern mass production techniques. The incorporation of these materials and components in artisanal manufacturing is not easy, and generally requires the development of sophisticated supply chains.
- Truly improved stoves tend to have a narrower tolerance to biomass size and moisture content and thus generally require more fuel processing at the household or, for high performance, preprocessing as pellets or briquettes.
- Hybrid gasifier stoves (with small electric blowers) effectively maintain good performance over a wider variety of fuel characteristics. Some half a million such stoves have been sold in India to date, but to the more well-to-do segments of rural populations because of their higher cost and need for electric connection. There are technologies now becoming available that, at relatively small additional cost, generate the electricity for a stove's blower from the heat produced by the stove, which can be used by households without electricity.

There are not yet advanced combustion stoves for dung or charcoal, and for crop residues outside of China. For charcoal, the focus has been on fuel efficiency, not combustion efficiency.

Status and current prospects

In the 1980s, China and India launched country-wide clean stove programs. There have been many programs to test and promote higher-performance cookstove designs in a large number of developing countries, but to date achieving a combination of low cost, durability, performance, consumer acceptance, and continued use has proven challenging. *World Development Report 2010* suggests that "[g]iven recent technological progress in biomass cookstoves, their impact on health, and their recently revealed impact on climate change, it is appropriate to massively scale up and commercialize high-quality biomass-based cookstoves" (WBG 2010). One cookstove expert at the U.S. Environmental Protection Agency observes that "none of the existing stove technology was commercially available 3 years ago, and even better devices will be introduced in the next 3 years" (Adler 2010). In December 2009, the Indian Ministry of New and Renewable Energy announced a National Biomass Cookstove Initiative, one of the largest such initiatives in the world and incorporating lessons from the earlier National Programme on Improved Chulhas (India MNRE 2009a).

Niche and significance for development

An estimate 3 billion people rely primarily on solid fuels—coal, wood, dung, and crop residues—for cooking and heating (WHO and UNDP 2009). The World Health Organization estimates that indoor air pollution from solid fuels might have caused 1.6 million premature deaths in 2000, more than half of which were infants below the age of five (WHO 2002). A recent paper looking at sector-based emissions of GHGs and particulates suggested that traditional use of biomass fuels by households might be responsible for the second-greatest short-term increase in net warming, and that emissions of household cookstoves at current levels might do more to warm the climate in the next twenty years than any other individual sector except on-road transport—including the power sector, industry, agriculture, and aviation (Unger et al. 2010). The climate and health impacts of cookstoves have recently spurred donors and governments to action. The United Nations Foundation has recently announced an ambitious new initiative, the Global Alliance for Clean Cookstoves, the mission of which is "supporting large-scale adoption of clean and safe household cooking solutions as a way to save lives, improve livelihoods, and reduce climate change emissions." The Alliance's founding partners—including the UN Foundation, the Shell Foundation, Morgan Stanley, the U.S. Department of State, the U.S. Environmental Protection Agency, the German Ministry for Economic Cooperation and Development, the World Food Program, the World Health Organization, and UN-Energy—have set a goal of enabling an additional 100 million homes to acquire clean and efficient stoves and fuels by 2020 (UN Foundation 2010), to which the U.S. government has pledged $50 million (U.S. State Department 2010). The government of India has also recently launched a $30 million prize competition with the X Prize Foundation for the "development and deployment of clean and efficient cookstoves (X Prize Foundation 2010).

Major barriers to widespread use

The most significant barrier is the cost of a high-performance stove that is durable, adapted to local cooking needs, and attractive to users. Many stove programs have failed because the stove performed poorly in the field—they broke down after a few months and could not be repaired easily, did not conserve as much fuel as designed, or did not emit significantly less smoke after some weeks of use. Higher-quality stoves would cost more than many earlier prototypes. Even in cold-climate countries, where households consume significant biomass for space heating, the upfront cost of stove purchase deters many poor households from switching to improved fuel-use stoves. Where biomass use is limited only for cooking and heating water, and especially where biomass is free or cheap, financial savings from lower biomass consumption may be small or nonexistent, and households may not be able to recover the higher upfront cost of stove purchase. Advanced-combustion stoves for reducing emissions cost even more.

User acceptance is another challenge. Changing preferences for cookstoves is a highly complex process that includes economics and culture as well as technical performance. In an evaluation of five improved biomass cookstoves in Kenya, users showed strong preference for using two out of five models (USAID 2010).

In summary, the cookstove market has significant commercial potential, but faces an array of challenges and user constraints—emissions reduction, fuel efficiency, performance, cost, and durability—in a broad range of environments.

Ongoing/proposed roles for the WBG

The WBG has had projects to promote dissemination and commercialization of higher-performance stoves in six African countries, often linked to community forestry programs that support more efficient charcoal production. The range of activities in these projects includes research and pilot testing; training of stove producers; consumer awareness and marketing support; and financing for small entrepreneurs (Pew Center for Global Climate Change 2009). The WBG can play a role in highlighting issues, such as the need for international standards and testing procedures, and can help convene related discussions. This includes, for example, sessions including international donors and major international companies, such as Shell and Bosch-Siemens, at Energy Week 2009.

The WBG can also do more to work in partnership programs, such as the Global Alliance for Clean Cookstoves which ESMAP joined in 2009, and other networks focusing on R&D and technology dissemination. By deepening its links to technology experts, current field research, and industry players, the WBG can position itself to scale up successful pilot projects; adopt cutting-edge, low-cost cookstove models; and disseminate best practices and technological breakthroughs to new regions.

Solar Lanterns

Technology description

For poor rural households the lack of modern lighting is a significant issue for development, a deterrent to evening activities including education. The use of kerosene lanterns provides low-quality light at a high cost and also is a source of pollution and fires. The lower power requirements of new lighting technologies such as light-emitting diodes (LEDs) and compact fluorescent light bulbs (CFLs), coupled with advances and cost reductions in PV solar panels, have created myriad market opportunities for low-cost, portable solar lighting devices. Products range from small, portable solar lanterns to home energy systems with numerous modular components. In contrast with earlier efforts to promote systems based on independently mounted solar panels, these products can be less costly, give users much greater flexibility, and present fewer problems with respect to maintenance and theft. However, they must still prove durability and performance over time and achieve consumer acceptance, and for very poor consumers some financing may still be required.

Status and current prospects

Efforts to promote alternatives to kerosene lanterns and other liquid-fuel lighting devices have increased substantially in recent years. Two particularly noteworthy initiatives are the WBG initiative, Lighting Africa, launched formally in 2007, and Light a Billion Lives, a nationwide initiative in India led by The Energy Research Institute and launched in 2008. Light a Billion Lives focuses on building solar lantern rental networks in villages, based on a fee-for-service payment system and an infrastructure of trained entrepreneurs and charging stations in each village. The focus of the Lighting Africa program has been largely on market facilitation through independent testing and quality assurance, identification of tariff and other policy barriers, and bringing together technology suppliers with potential distributors and vendors to speed the creation of supply chains. While products are evolving rapidly and prices are expected to decline, recent tests by the German development agency GTZ concluded challenges remain: "The quality of solar lanterns on the market is mixed, and prices are still too high for them to sell in great numbers in view of the low saving rates of poor households. However, we expect prices to drop below 50 percent of 2008 values over the next few years, which will make solar lanterns clearly more economic than kerosene lamps" (GTZ 2009).

Over the last decade, learning rates in the PV solar and fluorescent and LED lighting industries have been impressive, giving credence to future cost reduction claims such as GTZ's. For example, IFC's Efficient Lighting Initiative interventions helped Argentine imports of CFLs to increase from 1 million in 2000 to 5.1 million by 2003. Simultaneously, the retail price of CFLs fell from an average of $23 each to $3. In terms of solar PV, recently supply has far outstripped demand as a result of significant growth in global production capacity and the financial crisis, declining subsidies, and falling costs of conventional energy. As a result, solar PV panel prices fell by 30–40 percent in 2008–09 (*Economist* 2009b), and in April 2009 a number of PV solar panel manufacturers in China announced a targeted generation price of $0.14/kWh by 2012 (*Goliath Business News* 2009). Consequently, quality controls, enabling policy environments, and delivery mechanisms will likely be able to unlock large markets for increasingly affordable lanterns.

Additionally, carbon finance-facilitated programs for the free public exchange of CFLs for traditional incandescent bulbs have recently been attempted at large scale, sometimes with spectacular results. On June 19, 2010 in Bangladesh, a nationwide CFL exchange with carbon financing reportedly succeeded in distributing 5 million bulbs in one day. These CFLs alone, exchanged at no cost to the consumer, may reduce peak demand in the country by approximately 140 MW (Sarkar 2010).

Niche and significance for development

Currently, at least 1.4 billion people worldwide are without electricity. The IEA forecasts that, absent major policy changes, projected investments in grid electricity expansion will leave 1.3 billion people without electricity in 2030. The problem is most acute in Sub-Saharan Africa where 585 million people were estimated to be living without electricity in 2009, with rural electricity access rates averaging only 14 percent. More than a quarter of the world's unelectrified population is in India, numbering 400 million (IEA 2010b). Excluding the connection cost, which can be very high for grid electricity, fuel-based lighting can be more expensive per unit of lighting provided. Modern lighting has many developmental benefits: extending the day for enterprises, enhancing safety and security, expanding time for reading and education, allowing for improved delivery of health services, and increasing opportunities for women. The economic and lifestyle benefits of solar lighting, coupled with the high cost of current alternatives, suggest a large share of those currently without electricity may be willing to pay enough to offset distribution expenses: rural Indian villagers under the Light a Billion Lives program pay up to $0.13 per day to lease lanterns (NEWS24 2009). However, financing may be required to reach some market segments.

Major barriers to widespread use

Fuel-based lighting is a multi-billion dollar market.[17] This fact alone implies a well-established market that may not be quickly and easily displaced by new products with high initial costs: distribution channels must be created, consumers must become aware of and accept the new promises of the new products, financing will be required for some, and the products will have to prove durable over time.

Lighting Africa's focus on product quality assurance, policy and regulation, and market intelligence ahead of financing reflects the hierarchy of barriers to be addressed.

Ongoing/proposed roles for the WBG

The WBG has worked on efficient lighting since the 1990s when it began to support CFLs through GEF and IFC. During 1995–1997, an IFC/GEF market development project in Poland conducted two separate promotions with jointly-funded manufacturer-donor subsidies. The project's results include 1.2 million CFLs sold among 40 models represented, and the participation of five manufacturers (Miller and Martinot 2001). As a sequel to the Poland lighting project, IFC developed the six-country Efficient Lighting Initiative (www.efficientlighting.net), also with GEF support, framed primarily around market facilitation measures including consumer awareness and quality assurance (a testing and quality logo developed in the program continues post-project). The World Bank also promoted CFLs in several projects as a low-cost, quick-return means of improving energy efficiency and helping meet demand for electricity. The WBG's long engagement with lighting products has enabled staff to build relationships with manufacturers, understand distribution channels, and become aware of innovative products and new opportunities. As initially introduced, LEDs were

[17] Assuming the average household size of the 1.4 billion without access to electricity is 5, there are 300 million households needing lighting. If all of them used kerosene—and they do not (Bacon, Bhattacharya, and Kojima forthcoming)—for lighting and consumed 3 liters a month, the total annual consumption of kerosene would be 11 billion liters, or $11 billion at $1 a liter.

developed for high value-added mobile phones and laptops; their potential application for solar lanterns was originally proposed outside the industry by academics and development advocates who brought the idea to the WBG.

The WBG Lighting Africa program illustrates a shift from subsidies and incentives to a broader focus on developing markets through consumer awareness, quality assurance, product testing, and modest financing for SMEs and entrepreneurs. One of the initial activities was a three-day meeting in Accra, Ghana, attended by more than 500 persons from more than 50 countries and from across the range of perspectives—manufacturers, potential vendors, donors, and non-governmental organizations. Other activities include a financing resource guide and awards and recognition for outstanding products. By May 2010, Lighting Africa was working with 50 manufacturers that offer over 70 such products. In contrast to the paucity of solar lighting products in the market just a few years ago, now there is a wide variety of quality products priced between $25–$50, and a growing number of good products under $25 (Patrick 2010). (For more information, see www.lightingafrica.org.)

The WBG may also help foster new technology development and attract companies and private capital to the market. For example, the WBG approached major lighting industry players, including Philips and Osram for the Lighting Africa Program, and has also been involved in exploring opportunities for financing of efficient lighting through carbon credits. On the technology side, the WBG sponsored a solar lighting technology grant competition modeled after the Development Marketplace. The WBG may also pursue links and synergies between lighting (and other consumer goods) with electricity provision. Distributed PV solar programs have promoted solar electricity for lighting, including the Portfolio Approach to Distributed Generation Opportunities in Sri Lanka, a jointly financed IDA-IFC investment project, and solar home systems in Bangladesh through Rural Electrification and Renewable Energy Development, which could mesh well with CFL and LED lantern distribution.

Building Energy Efficiency Codes

This case study provides a brief overview of the importance of enhancing energy efficiency in buildings and takes China as an illustrative example.

Technology description

Building energy efficiency technologies span a broad range of design, including HVAC (heating, ventilating, and air conditioning), water use/plumbing, and building envelope (windows, doors, walls, floors, roofs, and insulation) technologies. Making buildings efficient is often as much about design and maintenance as about hardware, especially in commercial buildings, and may combine elements of well-established products like insulation with innovative technologies like PV panels and low temperature geothermal systems. Building energy efficiency codes can create standards and regulatory mandates for specifications of individual elements as well as aggregated building energy efficiency performance. Building energy efficiency codes can also extend to "smart" applications such as programmable thermostats and appliances, real-time electricity metering, electricity storage, distributed generation, and motion-sensor lighting. While innovative technologies would rarely, if ever, be mandated, they can be encouraged by point systems and flexible regulations, which allow trade-offs between superior performance on some elements (e.g., installation of solar water heating or PV panels) with greater flexibility on others. Other residential and commercial energy efficiency components, such as appliances and lighting, can be included in building energy efficiency codes but are often considered separately.

Status and current prospects

Energy efficiency in buildings is one of the largest expected sources of greenhouse gas emissions and energy use reductions in the years to 2030. The IEA estimates that the buildings sector will contribute 30 percent of the savings in total final energy consumption in 2035 to meet the target of ambient concentrations of 450 ppm of CO_2-equivalent in the long run (IEA 2010b). Because much of the future building stock in 2035 has not yet been constructed, the policy instrument of building codes is the principal lever for achieving these results in China and other rapidly developing countries. Although they require trained staff and institutional capacity to effectively implement and enforce, building codes are a potentially efficient and effective contributor to containing energy demand, energy costs, and GHG emissions.

In the run-up to the Copenhagen climate negotiations, China announced a 45 percent energy intensity reduction target by 2020. Energy consumption in the buildings sector has increasingly dominated total consumption as the building stock has mushroomed. Sixty percent of the residential and commercial building stock in Chinese cities as of 2006 had been built since 1996, and 60 percent of the residential and commercial building stock in Chinese cities by 2030 will have been built since 2006.

China has a relatively long history of implementing building energy efficiency codes, dating back to the mid-1980s:

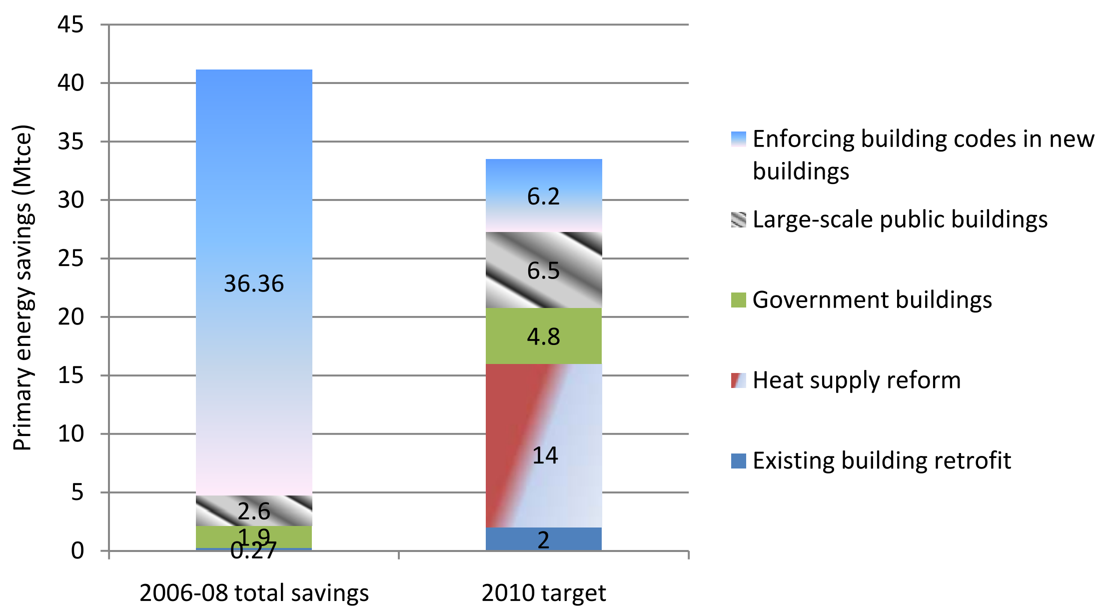
- **1986**: Trial building energy efficiency codes for centrally heated new residential buildings in cold climate regions
- **1995**: National building energy efficiency codes for new residential buildings in cold climate regions
- **2001**: National building energy efficiency codes for new residential buildings in hot summer and cold winter regions
- **2003**: National building energy efficiency codes for new residential buildings in hot summer and warm winter regions
- **2005**: National building energy efficiency codes for new commercial buildings in all climate regions

- **2007**: National Code for Acceptance of Energy Efficient Building Construction
- **2010**: Revised national building energy efficiency codes for new residential buildings in cold climate regions

These codes were part of the central government's conservation strategy from the outset. They focused on high-impact buildings first, set clear and realistic efficiency targets, and kept requirements simple (Feng, Meyer, and Hogan 2010). Twenty-four years of experimentation with federal, regional, and local building codes, coupled with an excellent and still-improving track record of implementation and compliance, makes China an instructive case study.

China has also made buildings energy efficiency a central tenet of its 11th Five-Year Plan Energy Intensity Reduction program. Buildings are targeted for 112 million tonnes of coal-equivalent (Mtce) in energy use reduction, or more than 6 percent in total primary energy use reduction targeted, all in just a five-year time span, 2006–2010 (Levine and Price 2009). Of this total, building energy efficiency codes account for 62 Mtce. For the period from 2006 to 2008, 41 Mtce in energy use reductions were achieved, of which 36.6 Mtce, or more than 90 percent, came from enforcement of new building codes (Figure 4). All residential and commercial buildings in Chinese cities have been subject to mandatory building energy efficiency codes since 2005. The stringency of building energy efficiency codes has been gradually ratcheted upward, and new cold-climate building energy efficiency codes take effect in 2010 (Liu 2009).

Figure 4: China's 11th Five-Year Plan Energy Use Reduction Targets for Buildings

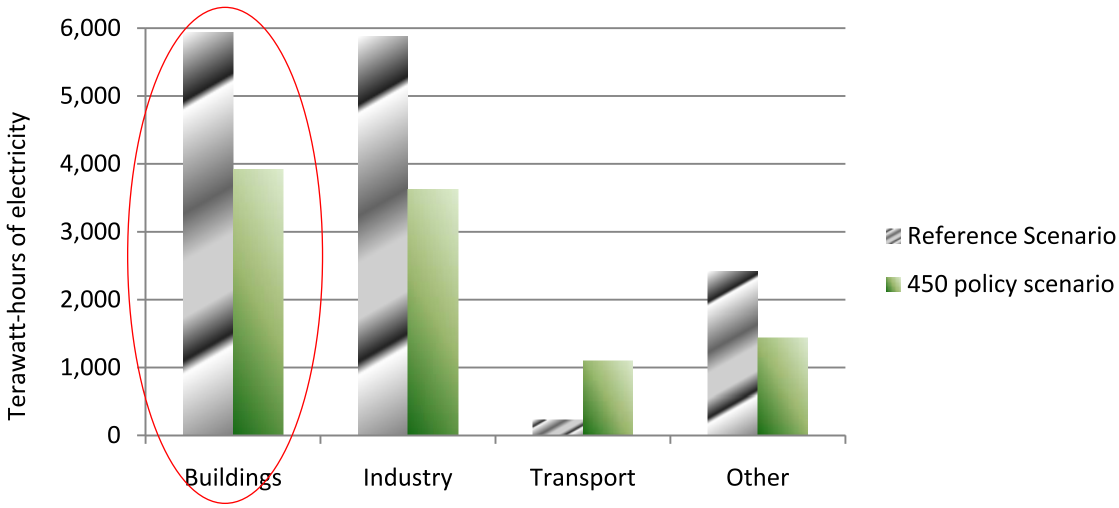


Source: Levine and Price 2009.

Niche and significance for development

The IEA estimates that the building sector will be a major driver of GHG emissions reduction in the decades to come. China accounts for 17 percent of the total energy consumed in residential buildings globally, and its new buildings will contribute to 40 percent of the total annual global additions to 2030. End-use efficiency in buildings alone is expected to reduce global annual electricity consumption by 2,000 terawatt-hours between 2007 and 2030 in the 450 ppm scenario (Figure 5). Combining direct emissions from fuel use and indirect emissions from electricity consumption, incremental CO_2 emissions between 2007 and 2030 in China in the 450 Scenario can be reduced to one fifth of that in the Reference Scenario (IEA 2009b).

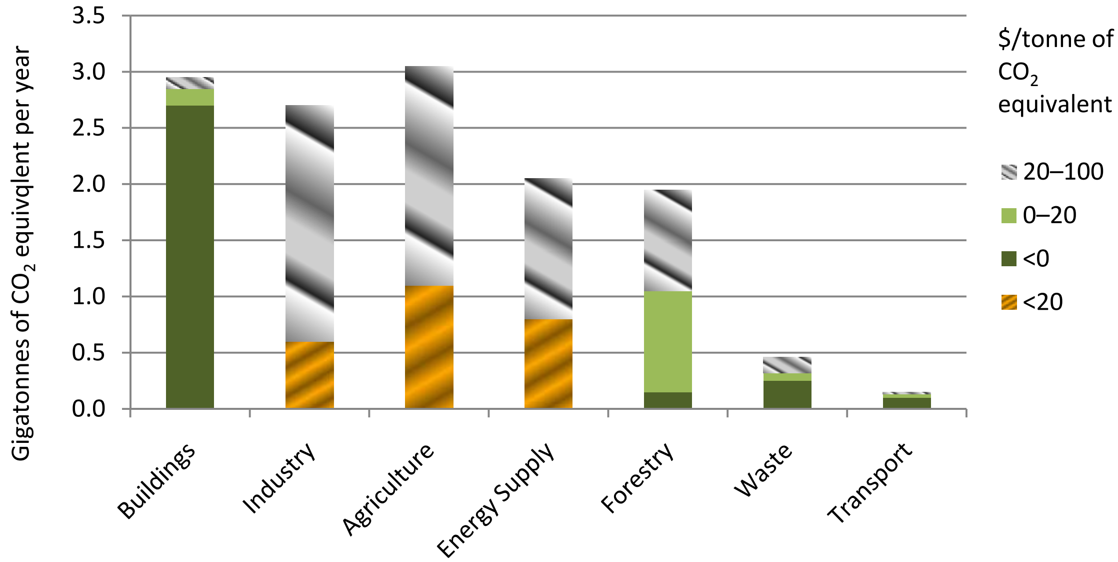
Figure 5: Incremental Global Electricity Demand by Sector and Scenario, 2007–2030



Source IEA 2009b.

The savings from energy efficiency investments can be massive. Not only are energy efficiency investments in buildings—particularly in developing countries—often the least-cost mitigation actions with large negative costs, savings from avoided investment in generation capacity are enormous, particularly as incremental costs rise. According to one estimate, more than 2.5 gigatonnes of CO_2 equivalent of annual mitigation actions are available by 2030 to developing countries at negative cost (IPCC 2007).

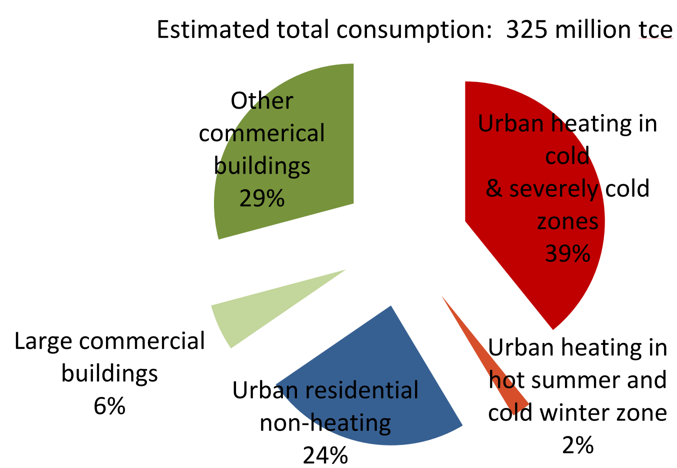
Figure 6: Estimated Potential for GHG Mitigation in 2030 in Developing Countries



Souce: IPCC 2007.
Notes: For industry, agriculture, and energy supply, the results for less than $0 and between $0 and $20 per tonne of CO_2 equivalent are reported as aggregated into one category, under $20 a tonne. Developing countries here are economies in transition and countries that are not members of the Organisation for Economic Cooperation and Development (OECD).

China stands to gain enormously from energy-efficient buildings that reduce heating demands. Space heating in China's cold-climate regions is the largest single use of energy, at 39 percent of total end-use energy in urban residential and commercial buildings (Figure 7). Cold and severely cold climate zones are home to 550 million people and 43 percent of urban residential and commercial buildings (Liu 2009). Consequently, building energy efficiency codes can significantly affect long-term energy use in China's building sector.

Figure 7: Energy Use in Urban Residential and Commercial Buildings in 2004 in China



Source: Liu 2009.

Because of the rapid growth in China's building sector, energy efficiency measures, led by energy efficiency building codes, can also have a disproportionately high impact on future GHG emissions. McKinsey projects that the direct and indirect GHG emissions from the energy consumption of China's buildings and appliances sector will nearly triple between 2007 and 2030, rising from 1.1 to 3.2 gigatonnes of CO_2 per annum. In fact, the buildings sector in China could mitigate fully half of future baseline emissions, or 1.6 gigatonnes of CO_2 a year, by 2030 through aggressive energy efficiency policies (McKinsey&Company 2009b).

Major barriers to widespread use

The most significant barriers to the implementation of building energy efficiency codes are institutional strength, government commitment and enforcement capacity, and the availability of high-quality, relatively low-cost suppliers. Building energy efficiency codes are frequently strong on paper but ineffective in practice, due to overly ambitious targets that the construction sector has neither the know-how nor the buy-in to implement. When building energy efficiency codes are complex, cumbersome, and expensive to comply with, compliance is more likely to be low. Corporate and public-sector buildings built, owned, and operated by large, professional organizations are the buildings most likely to successfully implement building energy efficiency codes: the builders and operators have reputations and potential tax liabilities at stake. Large corporations are also the most likely entities to have well-trained, capable staff comfortable with and most able to meet or exceed code requirements.

Incentives and financing also must be in place. Penalties for non-compliance must be non-negligible and enforced. Multiple layers of building review—at the commissioning and construction stages, and with requirements for architects, contractors, and builders—are helpful. Governments must have the capacity and manpower to provide such multi-layer oversight. As such, adequate training and political pressure (or incentives) must be in place for regional and local government, including regulatory overseers, to support the program. Corruption can also undermine well-designed building energy efficiency codes.

On the finance side, by addressing public buildings first, the Chinese government created demand for higher-quality building materials and practices that meet codes, which spurred the market for suppliers. If the materials to comply with codes are not readily available at reasonable cost, compliance is accordingly less likely. Public awareness campaigns and building energy efficiency education centers may also be necessary to address the public's lack of information and understanding. The principal-agent problem—where builders look to reduce construction costs because the owners and occupants of the buildings pay for ongoing operating costs (such as heating and cooling)—is also a serious barrier to compliance. The structure and composition of the real estate market may affect prospects for introducing building energy efficiency codes if the principal-agent divide is pronounced.

In China, compliance in about one third of the urban construction market in the largest 30 or so cities is at about 80 percent. In these areas the political pressure from the Five-Year Plan and government and construction-sector capacities are highest. The compliance level in the rest of the urban construction market is believed to be significantly lower (Liu 2009).

Subsidized household energy prices and retail consumer energy costs are policy barriers that weaken the price signal to consumers to value energy efficiency in buildings. Correcting market distortions can powerfully reinforce and complement the market impact of building energy efficiency codes to stimulate energy efficiency technology adoption.

Ongoing/proposed roles for the WBG

The WBG currently provides policy support to national and municipal governments and capacity building to ensure satisfactory implementation of energy efficiency programs. By extending and deepening these efforts into the areas of building energy efficiency code development, implementation, and compliance, the WBG can build on its existing energy efficiency policy expertise. Municipal and local-level projects are particularly important because building energy efficiency codes are necessarily site-specific (for local climate, building materials, and human capacity reasons) and dependent on local enforcement capability.

The WBG has had many programs addressing various aspects of energy efficiency—more than 40 with an energy efficiency policy component from 1996 to 2007 (WB IEG 2009, appendix B)—but relatively few in the building sector and in building codes. The World Bank and GEF run an ongoing flagship $99 million program on Heat Reform and Building Energy Efficiency in China, focusing on technical building energy efficiency demonstration and national and local level policy guidance. ESMAP has conducted a number of studies of the building sector and energy prices, including a report on national heat pricing and billing in China to complement the WB/GEF program (Meyer and Kalkum 2008). These studies provide in-depth analyses to inform policymakers.

Training for national, regional and local building regulatory authorities, construction companies, architecture firms, and real estate investors can be an effective policy intervention, and help governments gather information about the sector to devise realistic and applicable building energy efficiency codes. The WB/GEF China program can expand these activities, and also replicate best practices in other developing countries.

ESMAP launched the Energy Efficiency Cities Initiative in 2008. The initiative promotes energy-efficient programs and planning, focusing particularly on collaboration and best-practice sharing among cities in developing countries. Based on feedback from stakeholders and discussions with potential global partners, a five-year plan for the initiative was developed and presented in December 2008 at the ICLEI-Local Governments for Sustainability side event at COP-14 in Poznan, Poland.

Energy efficiency finance is also sometimes important in promoting building energy efficiency codes, particularly where the principal-agent problem of builders versus owners/occupants of buildings can be addressed. Where the finance sector is sufficiently developed, IFC can help local financial institutions develop "green mortgages" and other financial products that provide up-front financing for incremental building costs associated with energy efficiency compliance and reduce capital costs (interest rates) by leveraging future energy savings (See Taylor et al. 2008).

Annex 2: Comparing Costs – A Matter of Assumptions

A frequently used analytical approach for comparing electricity and other energy technologies is to identify the potential alternatives and reduce all of them to equivalent costs based on some common unit, such as cost per kWh. Two widely cited examples of such analysis are by the IEA/Nuclear Energy Agency (IEA/NEA 2005) and the State of California Energy Commission (CEC 2007). Both provide levelized cost estimates. The IEA/NEA study was based on 130 power plants including coal, gas, nuclear, wind, solar, combined heat and power. Estimates were included for units under construction or planned for operation between 2010 and 2015. Costs were estimated using two discount rates, 5 and 10 percent. A key conclusion is that while conventional, widely deployed energy technologies tend to be lowest cost, site-specific considerations and differences in national circumstances are critical elements of the analysis; "none of the traditional electricity generating technologies can be expected to be the cheapest in all situations" and the choice of technology "will depend on the specific circumstances of each project."

The CEC study covers 8 standard and 20 alternative technologies. Component as well as levelized costs are provided for three classes of developers reflecting different costs of capital: merchant, independently owned utilities, and publicly-owned (municipal) utilities (the latter have lower costs in California due to lower financing costs and their tax-exemption status). The analysis distinguishes six categories of fixed and variable costs, each of which is in turn based on numerous additional underlying assumptions spelled out in the analysis:

Fixed costs	**Variable costs**
Capital and financing	Fuel costs
Fixed operating and maintenance costs	Variable operating and maintenance costs
Insurance	
Property taxes	

The need to project costs and performance for the life of the technology—frequently 30 years—almost guarantees significant changes over time. In this 2007 California study, for example, the projected cost of one widely used technology, gas combined cycle, was 72 percent higher than an earlier version of the same study completed in 2003. Three factors were primarily responsible: empirical evidence that the 2003 study had assumed erroneously high capacity factors; 40 percent higher fuel costs; and a 25 percent increase in installed costs. Between 2003 and 2007, the estimated levelized cost for solar stirling dish technology rose three-fold due to a lower capacity factor, higher installed cost, and increased estimate of operating and maintenance costs.

Another fundamental source of uncertainty is the need to compare technologies with very different characteristics. Solar and wind energy systems generate power only when the sun shines and the wind blows. They are thus intermittent and less reliable than generation technologies based on fossil fuels or nuclear energy, although their intermittency can be addressed in part by the addition of storage systems (at an additional cost),by integrating wind and solar energy from regions with weakly correlated solar and wind availability characteristics, or using fossil fuel-based backup systems. The value of solar and wind power is thus a function of both the local resource and the characteristics of the system into which they provide power. The European Wind Energy Association reports that, based on 2003 calculations, the difference between wind speeds of 5.4 and 6.9 meters per second is equivalent to 6 to 8 Euro cents with lower wind speeds and 4 to 5 cents with higher wind speeds (EWEA undated).

A key source of uncertainty in projecting costs for new technologies is the expectation of cost declines with scale and learning (IEA 2000). With new manufactured technologies it is frequently, but not always, the case that costs decline in a consistent, logarithmic relationship with learning and scale economies. Thus those technologies that lend themselves to high-volume, mass production such as thin-film PV are most likely to benefit; large-scale technologies with unique, site-specific characteristics (such as nuclear power plants in the United States) much less so. For example, as defined by the IEA, the learning rate for PV modules in the period 1976–1992 was 18 percent, meaning that each cumulative doubling of production reduced the price by 18 percent.

The learning effect is primarily associated with the component(s) unique to the technology, e.g., wind turbines rather than the towers and support structures and other components that are already produced in large volume and therefore are mature products. Consequently the learning rate for wind machines has been much lower than for PV modules; wind turbine costs declined several percent per year from 1989 to 2001 as the industry grew. Learning is applicable to all elements of a product and not restricted to manufactured components. In the case of wind power, this includes several non-hardware considerations such as site selection, sizing and system design, and maintenance; collectively, cost reductions for these factors have been faster than for wind turbines (IEA 2000). For distributed solar PV, creating and maintaining a service network for household PV systems requires sophisticated customer outreach, trained personnel, and discipline. Yet high initial time and capital investments from business fall rapidly with scale and experience (Miller 2009, pp. 89–97).

Other factors may at times outweigh the effects of scale and learning. Both wind and solar costs increased in the mid-2000s as demand growth outstripped supply because aggressive policies provided large financial incentives to these forms of renewable energy in several industrialized countries and bottlenecks arose in key materials and manufacturing capacity. On the other hand, technology breakthroughs and large increases in production capacity can lead to more rapid cost reductions, a phenomenon some experts now expect will lead to dramatic near-term declines in solar cell prices (Deutsche Bank 2009) and significantly enhance the economics of solar thermal power plants.[18] Due to sharp declines in silicon prices, the cost of solar PV installation has plummeted in 2008 and 2009, leading to construction costs below $2/watt, ahead of projected cost declines (Miller 2009, pp. 224–226; Wang 2009).

Differences in financing cost are another important variable for the most capital-intensive technologies like wind, solar, and nuclear. The California study shows the impact of differences in financing based on three different types of owners—private (merchant), regulated privately owned utilities, and public (municipal) utilities. The cost of wind generation varies from $60.78 per megawatt-hour (MWh) to $99.03 based solely on this factor, compared with a much smaller range from $81.90/MWh to $95.59 for advanced combined cycle. The assumed discount rate (the

[18] Major cost reductions and weight reductions are expected in the mirrors used for solar thermal power plants due to recent agreements between solar developers and automobile component makers with specialized expertise in glass making for car windshields (Staley et al. 2009).

adjustment made to calculate the current value of a future expense) can also make a significant difference for fossil fuel or other technologies with large variable costs.

Depending on the technology, environmental costs can differ significantly depending in part on regulation including local pollution standards. In the future, climate change regulation could make a marked difference in the prices of renewable and nuclear technology relative to more carbon-intensive power sources. One way of thinking about the cost implications of possible future climate change regulation is to assign a *shadow price* to carbon emissions to test the effect on economic rates of return. Carbon taxes or other policies penalizing carbon emissions could also affect financial return. There are a range of values in the literature, but no objective "correct" answer. At IFC, shadow pricing is being tested on a pilot basis as a way to evaluate the cost of carbon necessary to justify less-carbon-intensive alternatives, if any, and also to test how high the price of carbon would have to become to make the financial return of carbon-generating investments no longer attractive (IFC 2008, paragraph 4.10.3).

Finally, in addition to the inherent uncertainties, there are continuing methodological issues about the proper approach to making cost comparisons (Bazilian and Roques 2008). For example, Awerbach and Berger (2003) discuss the usefulness of portfolio-based approaches that look at both maximizing the expected return for a given level of risk and minimizing risk for a given level of expected return. They used a detailed portfolio model that reflected fuel, operation and maintenance, and construction period price risks. Such an analysis points to the danger of excessive dependence on one or two resources, such as oil and coal in many developing countries.[19] California tested a portfolio-based approach and found that it made a considerable difference:

- An optimal generating portfolio for California includes greater shares of renewable technologies than that based on a least-cost approach that does not take price variation into account.
- Adding a non-fossil technology that does not suffer from fuel price volatility, such as wind, to a risky generating portfolio lowers expected costs at any level of risk. Adding too much renewable generation increases portfolio risk, but those levels are substantially greater than 33 percent in 2020, which is the official State goal for renewable generation (CEC 2007, p. 138).

The foregoing discussion suggests that the costs of energy technology should be compared with considerable caution recognizing the need to allow for site differences, the impact of uncertainties when projecting costs over decades (particularly with respect to fuel costs), and the potential for cost reduction when dealing with new technologies.

[19] Insofar as fossil fuel projects are able to negotiate fixed price fuel contracts this risk can be mitigated to varying degrees. However, such contracts are themselves not immune from price risk, as illustrated by the recent floods in Australia, which forced several major global suppliers of coking coal to declare force majeure and miss contracted deliveries, resulting in a three-fold increase in prices. The price of thermal coal used by power stations also rose, although not as much.

Annex 3: Recent Publications on New Energy Technology and Technology Promotion

This annex briefly summarizes key messages from 10 recent publications.

"Who Owns Our Low Carbon Future? Intellectual Property and Energy Technologies" (Lee, Iliev, and Preston 2009)
"Technological innovation and diffusion take too long under business-as-usual practices. Our findings confirm the mismatch between the urgency of climate challenges as set out by the IPCC, and the time taken historically for technology systems to evolve and provide a return on investment. Sticking to what we know—and business-as-usual practices—will not bring these much-needed technologies to markets fast enough. Analysis shows that inventions in the energy sector have generally taken two to three decades to reach the mass market. This time lag is mirrored by the time it takes for any patented technology to become widely used in subsequent inventions. . . .Much has been made of the fast growth in innovation capacities in emerging economies such as Brazil, China and India. But these countries have no companies or organizations in the top 10 positions in any of the sectors and sub-sectors analysed. (A few can be found among the top 20, pointing to these economies' growing innovation capacities.) . . . [L]arge incumbent companies—whether multinationals or national corporations—are the main players today. SMEs account for a relatively small part of overall patenting in these sectors, in contrast to biotechnology and information technology. The median age of wind-energy patent owners—the 'youngest' sector—is 54 years. This suggests that the most successful strategy for developing countries wishing to enter these areas may initially be driven by larger firms and be pursued through acquisition of foreign technologies rather than internal growth. It is important that such strategies for technological acquisitions are complemented by investment in indigenous innovation capacities in developing economies."

"Technology Action Plan: Executive Summary" (MEF 2009)
"International coordination through the Global Partnership can accelerate RD&D-driven clean energy innovation. First, a coordinated increase in public and private R&D investment by major economies could help to ensure that the most critical global investment gaps are covered within a robust global portfolio that maximizes risk-adjusted returns on innovation investment. Second, international coordination can help to ensure key emerging clean energy technologies cross the valley of death between pilot projects and commercial success. Finally, joint public-private international research efforts can further accelerate global clean energy innovation. Although future cost reductions for any given technology category are uncertain, globally-coordinated investment in a broad portfolio of emerging clean energy technologies could accelerate major reductions in the long-term cost of clean energy, with the benefits shared globally as low-cost clean energy solutions spread worldwide."

"America's Energy Future: Technology and Transformation" (National Academies 2009)
"To enable accelerated deployments of new energy technologies starting around 2020, and to ensure that innovative ideas continue to be explored, the public and private sectors will need to perform extensive research, development, and demonstration over the next decade. Given the spectrum of uncertainties involved in the creation and deployment of new technologies, together with the differing technological needs and circumstances across the nation, a portfolio that supports a broad range of initiatives from basic research through demonstration will likely be

more effective than targeted efforts to identify and select technology winners and losers. High-priority technology demonstration opportunities during the next decade include CCS, evolutionary nuclear power technologies, cellulosic ethanol, and advanced light-duty vehicles. Research and development opportunities during the next decade include advanced batteries and fuel cells, advanced large-scale storage for electrical load management, enhanced geothermal power, and advanced solar photovoltaic technologies."

"Breaking the Climate Deadlock: Technology for a Low Carbon Future" (Tomlinson 2009)
"We need to invest now in the development of those future technologies that will take time to mature, in particular CCS, large scale solar and new generation nuclear, along with public infrastructure such as smart grids; international cooperation spurred by an ambitious agreement in Copenhagen can rapidly bring costs down and accelerate scale up of both current and future technologies."

"Task Force on Low-Carbon Prosperity: Summary of Recommendations" (WEF 2009)
"The international community's ability to transform energy systems to meet future demands for growth and lower GHG emissions will ultimately depend on a burst of technological innovation over the next few decades. The potential of key low-carbon technologies is now well known—the latest microeconomic analysis suggests they can offer up to 11% of GHG abatement potential to 2030; and up to 27% by 2050. Technology's biggest contribution to a low-carbon future will be its ability to expand low carbon choices and make the options ever cheaper. This requires driving technologies down the cost curve through advancements in science, engineering and mass deployment. The long-term, risky and often very costly nature of research, development and deployment of potentially revolutionary technologies requires intensified and better coordinated public and private sector efforts."

"Catalysing Low-Carbon Growth in Developing Economies: Public finance mechanisms to scale up private sector investment in climate solutions" (UNEP and Partners 2009)
"It is estimated that pension funds alone control assets worth more than $12 trillion and that sovereign wealth funds have a further $3.75 trillion under management. However, to stimulate their engagement the expected returns on climate-change mitigation investment need to be commensurate with the perceived level of risk. This is not currently the case… Some publicly-funded bodies undertake early-stage project execution for infrastructure projects, such as securing consents and offtake arrangements. Infraco and Infraventures are examples. Building on this experience, vehicles specialising in early-stage low carbon projects could be developed. They could be complemented by technical assistance grants for project development. The spending priorities for such technical assistance grants would be determined in conjunction with the host country."

"Patent-Based Technology Analysis Report: Alternative Energy Technology" (WIPO 2009)
"By the 1990s, environmental concerns had taken the forefront, leading to a new phase in the development of alternative energies. This new phase coincided with an increase in the number of patent applications as well as the number of applicants involved in developing alternative energy technologies, particularly from 2000 onwards, when a rapid acceleration in patent activity took place. Among the major patent offices at which patent applications for alternative energy technologies were filed, namely those of the United States, Japan, and Germany, the distribution of applications among different areas of technology appears to be related strongly to the

countries' geographic and resource situation as well as the distribution of research and development budgets and supporting policies. . . .In Korea and China, most patent applications were filed by domestic applicants. Though the initial number of applications filed at the patent offices of these countries was quite small, the growth rate has been very high. While patenting activity at the Korean Intellectual Property Office (KIPO) has focused on wind power and hydrogen and fuel cell technologies, the largest number of applications at the State Intellectual Property Office (SIPO) in China have been for solar energy and hydropower technologies."

"Chapter 7: Accelerating Innovation and Technology Diffusion" in *World Development Report 2010* (WBG 2010).
"Meeting climate change and development goals requires significantly stepping up international efforts to diffuse existing technologies and develop and deploy new ones. Public and private investment—now in the tens of billions of dollars per year—need to be steeply ramped up to several hundreds of billions of dollars annually. "Technology-push" policies based on increasing public investments in R&D will not be sufficient. They need to be matched with "market-pull" policies that create public and private sector incentives for entrepreneurship, for collaboration, and to find innovative solutions in unlikely places. Diffusing climate-smart technology requires much more than shipping ready-to-use equipment to developing countries; it requires building absorptive capacity and enhancing the ability of the public and private sectors to identify, adopt, adapt, improve, and employ the most appropriate technologies."

Energy Technology Perspectives 2010: *Scenarios & Strategies to 2050* (IEA 2010a)
"ETP 2010 estimates that to achieve the 50% CO_2 emissions reduction, government funding for RD&D in low-carbon technologies will need to be two to five times higher than current levels. This message is being taken seriously by many countries. Governments of both the Major Economies Forum and the IEA have agreed to dramatically increase and co-ordinate public-sector investments in low-carbon RD&D, with a view to doubling such investments by 2015. Simply increasing funding will not, however, be sufficient to deliver the necessary low-carbon technologies. Current government RD&D programmes and policies need to be improved by adopting best practices in design and implementation. This includes the design of strategic programmes to fit national policy priorities and resource availability; the rigorous evaluation of results and adjusting support if needed; and the increase of linkages between government and industry, and between the basic science and applied energy research communities to accelerate innovation."

Innovation in Energy Technology: Comparing National Innovation Systems at the Sector Level (OECD 2006)
"This report reviews efforts under way in a number of OECD countries to advance innovation in energy technology, with a particular focus on hydrogen fuel cells… Successful innovation in fuel cells requires much more than R&D. Market development is extremely important as fuel cells represent a novel approach to satisfying energy needs in application areas served by a number of entrenched technologies. The costs and risks of switching to fuel cells are high, and customers may be understandably reluctant to invest in fuel cells until they are more fully convinced of their capabilities and reliability. Fuel cell innovation programmes, as many energy innovation programmes, tend therefore to aim not just at promoting R&D, but at encouraging a fuller spectrum of activities commonly referred to as RDD&D—research, development, demonstration

and deployment. The demonstration and deployment components of this approach aim to test fuel cell technology in operational settings to illustrate their capabilities, identify infrastructural needs and gain operational experience that can lead to successful market entry. . . . Policy can affect other elements of the innovation system as well. The creation of regional, national and international programmes for hydrogen fuel cells plays a catalytic role in engaging the diverse set of actors in the innovation system. They can help create a common vision that minimises uncertainties as technologies are advanced toward commercialization and complementary investments are required (such as for hydrogen storage and distribution). Development of skilled human resources required for the emerging fuel cell industry is also important. International codes and standards for fuel cells are considered instrumental to the successful commercialisation of hydrogen fuel cell technologies. Addressing these issues requires productive collaboration between the public and private sectors."

Annex 4: Issues Related to World Bank Group Operations

In addition to strategic issues, proposals for greater WBG engagement in promoting new energy technologies, especially at a very early, pre-commercial stage, raise some potential operational issues. There is sufficient precedent and experience to expect none of these issues are likely to be very serious—the WBG has managed projects supporting pre-commercial energy technologies and, with the creation of the CTF, may be doing more than ever before. IFC has recently begun investing in start-up companies with innovative technologies as well as dedicated clean tech funds. These projects encompass a wide range of roles including investments, capacity building, and knowledge sharing. The innovations supported are sometimes, but not always, based on protected intellectual property. The CGIAR has addressed these issues for much longer and on a much larger scale, although with a key difference being that, in this case, the WBG shares in the overall strategic direction and financial obligation but relies on a network of centers to implement the research program. One question is whether engaging in the development stages of new technology, potentially on a much larger scale, will result in different challenges.

1. Procurement of innovative technologies with limited competition

Procurement in the absence of competition, as might occur with funding for an innovative technology with only one supplier of a key component, is not part of standard WBG procurement procedures. This is particularly problematic for the World Bank; IFC typically is extending financing rather than managing procurements. Existing procurement rules may also require competitive bidding for large contracts in cases where single-party negotiated advanced market commitments (AMCs) may be more appropriate. Procurement rules may also place legal restrictions on use of funds inconsistent with prize competitions, insofar as much or all of the work of the winner is completed prior to the award of the prize (this has not been a problem for the Development Marketplace, although, as with the CGIAR, funding is provided through an external legal entity). Additionally, AMCs and prize competitions are likely to require contracts and grant agreements with highly technical, customized provisions concerning technology performance criteria and governance of intellectual property. The WBG would likely need to engage outside legal and technological expertise not only to design these legal agreements, but perhaps also to amend existing procurement protocols.[20]

2. Intellectual property rights

The WBG currently does not have a framework or policy for handling, promoting, protecting, valuing, and marketing intellectual property. The absence of such a framework gives rise to a number of problems. First, the WBG does not have structures in place to foster IPR development and sharing. WBG staff, including program officers, investment officers, and in-house legal counsel, do not have the expertise to recognize, promote, and manage IPR.

Second, there are no broad protocols for managing, protecting, and disseminating the intellectual property that results from WBG procurement and investment. Consequently, new initiatives expressly designed to generate intellectual property, or that generate intellectual property as a byproduct, would need to develop explicit policies and knowledge sharing measures.

[20] The same argument can be applied to other sectors, such as transport, water, and health.

To address these issues, a strategic and focused effort to address IPR may be appropriate. A new working group, task force, or office expressly focused on intellectual property procurement and transfer would likely best be able to identify the challenges and opportunities, and identify opportunities for program work and internal capacity building. Creating an office to facilitate and disseminate IPR—like a trade development agency, trade publication, or industry promotional group—could be particularly valuable. Such an office could be internal to the WBG, or created in an independent entity, as with GEF, CTF, and CGIAR. Targeted funding facilities could also support this function. Such an agency could address the country-specific patchwork of patent, trademark, and copyright rules and laws governing IPR concerning specific technologies and products in individual countries

Drawing on its implementation experience and partners, the WBG could explore targeted initiatives to create portals, platforms, networks, and databases for South-South sharing of best practices and deployment of technologies. Conferences for small businesses, industry partners of the WBG, North-South partnerships, and technology laboratories could add value to existing knowledge and information dissemination activities under the WBG umbrella.

Capacity building efforts within the WBG could include training staff to recognize IPR issues and opportunities, understand the policy and welfare tradeoffs of IPR protection versus dissemination, and the legal frameworks for managing IPR. Procurement staff could be provided with training and templates for processing IPR transactions. It may be useful for staff to know how to draw IPR from open innovation databases, and how to contribute to them.

The WBG could also consider targeted efforts to better manage intellectual property using information technology. One of the added-value propositions of WBG engagement could be leveraging intellectual property databases for the client user of technology, and monetizing technologies protected by IPR for the client-innovator. The WBG could use its internal knowledge management services as an asset and model for providing added-value to client countries and companies. The WBG could explore the creation of special clean energy technology information services whose job it is to collect, refine, and disseminate clean energy technology in accessible forms, and to provide a conduit for the inter-linkages of funders, implementers, companies, consultants, public servants, and innovators.

3. Investing in companies based in high-income countries

While IFC's bylaws and policies do allow it to invest in companies based in "type 1" (high-income countries) when development impacts benefit "type 2" (countries eligible to borrow from IDA and the International Bank for Reconstruction and Development), such investments have in practice been limited to a small group of unusual cases, where such companies will generate products or services of particular benefit to client countries. The World Bank tends not to engage in program activities outside of its target countries (its headquarters excepted).

It may be appropriate for the WBG to create narrowly targeted programs and funds to partner with institutions in high-income countries, particularly bilateral aid agencies, to develop, demonstrate, and adapt technologies conceived in high-income countries for application and deployment in developing countries. GEF operates a small portfolio of technology transfer projects whose purpose is to bring companies based in high-income countries to emerging markets. This model could be studied and applied judiciously where the WBG has a comparative advantage in providing accessible capital at a reasonable rate, targeting social needs in developing countries, and in pairing technology developers (companies and research institutes) with application opportunities in target countries.

4. Sitting on corporate boards; public-private partnerships

Although IFC sometimes takes positions on corporate boards in the context of its equity investments, there are limitations on the World Bank's and IFC's ability to enter into joint ventures and partnerships with private companies. IFC is now pursuing an off-balance sheet asset management company, an innovative new method of partnering with the finance sector to raise capital. These policies allow some flexibility to the WBG and IFC in particular to leverage its priorities, capital, and expertise to bring the private sector into energy markets in developing countries. In turn, the WBG can best access the know-how, reach, expertise, and capital of the finance and business communities.

The WBG may wish to review a menu of strategic options for partnering and otherwise engaging with the private sector to deepen and accelerate the development and deployment of clean energy technologies in developing countries. Participation on boards and more intensive engagement in public-private partnerships (including joint ventures, public procurement contracts, social entrepreneurship, etc.) could be strategic pathways of entering the clean energy technology space.

5. Internal WBG resource constraints

For the foreseeable future, the need to operate in a flat budget environment will argue against options that are resource-intensive. A new entity (office, unit) is likely to require a certain scale to be minimally effective, making it particularly resource-intensive. Creating an action plan for furthering clean technology in an integrated rather than piecemeal approach would need careful analysis, starting with resource requirements. Priority may have to be given where scale-up of existing activities can be achieved at a low internal resource cost.

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