Building capacity through Research, Development, Demonstration and Deployment (RDD&D) collaboration: Evidence from the transfer of low carbon energy technologies in India*

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Abstract: There is a growing consensus that effectively addressing climate change requires a global concerted effort towards low carbon pathways. Many suggest that the diffusion of affordable low carbon technologies in developing countries represents one important channel to assist their transitions to low carbon development pathways, and yet the goal of achieving effective technology transfer remains elusive. Some indicate that effective technology transfer can be achieved by building up technological capabilities – or the abilities of actors to contend with technological change. Collaboration between parties at various stages of the innovation process, through research, development, demonstration and deployment (RDD&D) mechanisms is viewed as being pivotal to building technological capabilities along with more effective international technology transfer.

Nevertheless, debates exist regarding the role of RDD&D in stimulating capacity building and in encouraging successful low carbon technology transfer. For instance, there is disagreement regarding the key drivers for RDD&D collaboration; which policy levers can encourage effective RDD&D collaboration; and which types of RDD&D mechanisms are most successful.

Drawing on empirical insights based on research in India, this paper argues the following points. To begin with, the role of intergovernmental processes in driving low carbon RDD&D collaboration has – in certain instances – been minimal. Rather, market access has been the key driver instigating and fostering action in the area of low carbon technology transfer. In addition, while debates continue regarding whether the key driver of technology transfer and capacity building should be the public or private sector, evidence suggests that *both* the private and public sectors along with intermediaries play an important role in encouraging collaboration. Thirdly, more effective RDD&D strategies involving international knowledge and expertise have resulted in more successful and rapid technology transfer, but – perhaps unsurprisingly as they generally have more resources at their disposal – this type of collaboration is more frequent amongst larger firms. Furthermore, more successful collaboration can be traced to needs driven initiatives which engage local actors. Finally, partnerships which targeted building local technological capacities elicit more success.

Introduction

Global energy demand is expected to grow by 55% from 2005 to 2030, with the lion's share of this increase (74%) coming from developing countries (IEA 2007). Within this context, a number of forecasts indicate that energy demand in the Asia-Pacific region will be particularly pronounced. For instance, Christophe Bongars (2006), of SustainAsia estimates that the Asia-Pacific region is projected to surpass the rest of the world in terms of global energy demand (accounting for more than half) by 2030. The region – like much of the rest of the world – is heavily dependent on fossil fuels to meet their energy needs.

At the same time, there is a growing consensus that meeting this energy demand through conventional means (characterized by high-carbon, non-renewable means) warrants a rethink. The challenge of addressing climate change becomes particularly acute in this region due to rapid urbanization, where the construction and use of buildings often

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involves energy-intensive processes (e.g. steel, cement) and because a number of economies are heavily based on manufacturing and industry – often highly carbon intensive activities.

These trends – exponential growth in energy demand in Asia, and the nature of that demand (often based on highly carbon intensive activities), and the need for action to reduce greenhouse gas (GHG) emissions – have led to growing support for a call for these countries to transition to low carbon development pathways. An important component in these transitions is the development and use of low carbon technologies – the majority of which are owned by firms in developed countries (Lee 2008).

Many agree that for developing countries, an important channel in which to foster low carbon technology development and use is through technology transfer, and yet the goal of achieving effective technology transfer remains elusive. In this vein, people suggest that effective technology transfer can happen through building up technological capabilities – or the abilities of actors to contend with technological change (Ockwell et al. 2008; Benioff et al. 2010). A distinction of this approach is that it recognizes that how a technology is developed, produced and used – in other words innovation and adoption -- are integrally linked. By contrast, studies have tended to isolate their focus on research and development (R&D) (innovation) or demonstration and deployment (D&D) (adoption). This is important because some studies suggest that segregation between the efforts / priorities of research programs (e.g. in the case of wind, increased technical and economic performance) and deployment efforts (e.g. in wind, grid connection / infrastructure) can lead to challenges / bottlenecks (Justus and Philibert 2005) – particularly relevant for low carbon technologies, where urgency requires their rapid deployment. Our view is that collaboration between parties through various stages of the innovation process, through research, development, demonstration and deployment (RDD&D) mechanisms is viewed as being pivotal to building technological capabilities along with more effective international technology transfer.

Nevertheless, debates exist regarding the role of RDD&D in stimulating capacity building and in encouraging successful low carbon technology transfer. For instance, there is disagreement regarding the key drivers for RDD&D collaboration, globally speaking and in developing countries – with some purporting that although bilateral arrangement between governments continue (e.g. see Xingang et al. (2011) study examining China), multilateral policy mechanisms between governments are key, (see Hascic et al. 2012's study on the International Energy Agency's Implementing Agreements); others which suggest that the private sector and markets are most important, and so policies which spur actions by the private sector by creating an enabling environment (actions include more general initiatives, such as through support to technical education to more specific endeavours such as a carbon price, the Clean Development Mechanism (CDM))[1] can encourage technology transfer, which may help RDD&D (Schneider et al. 2008 Haites et al. 2006); some suggesting that domestic policies are paramount (Tan 2010); or a combination of national and international policies (Watson et al. 2011; Popp 2011). Linked to the above, debates also arise regarding which instruments to draw from in a policy makers' 'toolbox' to help foster RDD&D collaboration (e.g. through encouraging indirect action such as through tax credits, or more direct means – such as through sectoral development policy (a modern version of 'industrial policy', capturing the key role that services and knowledge also play in many countries' contemporary economy (Stanford 2011).

This paper stems from work initiated at the G8 Gleneagles dialogue on climate change in 2006 which commissioned research through a collaborative study between the United Kingdom and India on low carbon technology transfer assessing the barriers and the role of Intellectual Property Rights (IPRs) and Research Development Demonstration and Deployment (RDD&D) on its effectiveness (See Ockwell et al. 2008; Ockwell et al. 2007 for Phase I and Mallett et al. 2009 for Phase II details). The study team consisted of researchers from Science, Technology and Policy Research (SPRU) (Phases I and II), and the Institute for Development Studies (IDS), University of Sussex, United Kingdom and The Energy and Resources Institute (TERI) (Phases I and II). For Phase II (the focus of this paper) one member of the SPRU study team was housed at TERI in Fall 2008.

One key component of the Phase II research was to scrutinize RDD&D collaboration in emerging economies to help determine if there were certain aspects which were present in which to help determine success – success defined as contributing to sustained low carbon technology use and building technological capacities. To gain insights into the above our initial question asked: 1) How are Indian firms acquiring low carbon technologies (in other words, are they engaging in RDD&D collaboration)? From there, we asked (if relevant): 2) what were some of the key drivers for initiating and maintaining low carbon RDD&D collaboration; in other words, what brought people to the table, and got them to stay; 3) To what extent did policy (international and domestic) play a role?; 4)which 'types' were most prevalent (e.g. domestic only, or ones with foreign presence; informal (e.g. personal contacts) or formal / institutionalized (e.g. Technology Transfer Agreements, Joint Ventures); 5) within these 'types', were there certain collaborative RDD&D forms that were more successful?

A case study approach was adopted to answer these questions, whereby it was sought to ground the analysis in real world examples of Indian firms currently working, or seeking to work, with specific low carbon technologies. This allowed the study team to determine to what extent the various ideas and policy discussions on low carbon technology transfer and capacity building in developing countries through RDD&D reflect the reality faced by Indian firms

[1] The Clean Development Mechanism (CDM) is a tool under the Kyoto Protocol (Article 12) where industrialized nations which have absolute greenhouse gas (GHG) emissions targets (Annex 1 countries) can meet their goals (during the first commitment period, 2008-2012), through purchasing carbon 'credits' through various projects in developing countries. These carbon credits are given to an entity after it has been demonstrated (and verified) that investments in ways to reduce GHG emissions have brought about actual reductions in GHG emissions than would have been otherwise the case under a business as usual scenario. Discussions continue at the time of writing to determine applicable actions post-2012. See http://unfccc.int/kyoto_protocol/mechanisms/clean_development_mechanism/items/2718.php

working with low carbon technologies. The choice of potential case studies was initially informed by a number of meetings and workshops. At the very outset of the study, a Steering Group consisting of Indian and UK policy representatives was convened. This provided a starting point for case study identification and, following the detailed process described below, the five case studies selected were all ones that were identified by the Steering Group in that initial meeting. Two other meetings/workshops were important in informing the case study selection. These were a workshop held at a side event of the UNFCCC COP in Bali in December 2007 and an internal project kick-off meeting held in March 2008 via video conference between TERI and SPRU. This process resulted in a very broad list of potential case studies and relevant initiatives that might warrant consideration during the study.

To help narrow down the case studies, selection criteria was established, as described below. The case studies needed to inform all three of the study aims, namely:

1. Development of a decision making guide of barriers to low carbon technology transfer;
2. Conduct further work on intellectual property rights (IPRs), including the development of policies that could help to overcome IPR barriers; and
3. Develop recommendations of mechanisms and technologies to foster joint research, development, demonstration and deployment (RDD&D) between developed and developing countries

Key issues that the study team used to guide their selection were:

- How much information is likely to be readily available regarding the technology?
- How likely is it that industry representatives in India and in the host country will speak openly with the project team?
- Are there any technologies or sectors (e.g. Indian SMEs or the Phase I casestudies) that the research team has existing expertise in / knowledge of and that would therefore be likely to yield greater insights or easier access to industry via existing contacts?

Using the above criteria to guide their analysis, a process was agreed that would maximise the level of scrutiny that the original list of possible case studies was subjected to and provide an in built process of expert peer review. This consisted of TERI and SPRU working separately to produce a list of case studies that the teams at each institution independently believed to have the most potential to yield useful insights. These were then written up, together with the rationale for each institution's selection, and shared with the partner institution. A face-to-face meeting between TERI and SPRU was then held at the University of Sussex at which each team presented their case study selection and, following in depth discussion, a final list of five case studies was agreed upon.

In the event, all three case studies suggested by TERI were also independently suggested by SPRU for similar reasons. SPRU also suggested three additional potential case studies that were, via discussion at the meeting with TERI, filtered down to two additional case studies. This brought the final number of technology case studies to five. Following Phase I, the idea of these case studies was – in addition to meeting the above criteria – to provide a range of different types of technologies at varying stages. See Figure 1.

Figure 1 – UK-India Collaborative Study on Low Carbon Technology Transfer – Phase II

	Status of Technology		
Sectors	**Pre-commercial**	**Supported commercial**	**Commercial but slow diffusion**
Low carbon power generation technologies	Integrated gasification combined cycle (IGCC)	Photovoltaics	Wind power
Network / infrastructure technologies			
Low carbon end use technologies		Hybrid vehicles	Energy efficient Technologies in Small and Medium Enterprises (SMEs)

Source: Adapted from Ockwell et al. 2008, p. 4105

This paper focuses on two of the five case studies as these insights reflect highlights found in the other case studies as well. More details about the three case studies can be found in **Annex 1**.

The emphasis throughout the study was on a consultative approach that engaged directly with industry, government and researchers, both to yield grounded empirical insights and to raise awareness of the study amongst potential end users. About 200 people provided insights for this study. The majority of informants were based in India. However, where possible, discussions were also held with actors from the industrialized world.

Data collection focused on both primary and secondary sources, including:

i) Face-to-face and phone interviews with key players in the low carbon energy sector. The bulk of these interviews occurred during October-November 2008, however a few occurred in January-February 2009. Interviewees were asked questions regarding the present status of technology development in their organization and future plans, issues and apprehensions related to Intellectual Property Rights (IPRs), perceived risks and constraints, collaborative RDD&D initiatives, and government engagement with their sector. Furthermore, the questions were designed to serve as posts, to guide discussions, and to create a more informal atmosphere.

ii) Presentations and / or sideline informal discussions with participants at six meetings and workshops such as:

a. A Side event at the UNFCCC 13th Convention Of the Parties in Bali December 2007;
b. A National Conference-cum-Exhibition, “Solar PV: Emerging Viable Options with Technology and Policy Thrusts”, India Habitat Centre, New Delhi, October 30, 2008[2];
c. A Workshop on “National Hybrid Propulsion Platform (NHPP)”, Mahindra and Mahindra, Mumbai November 24-25, 2008[2];
d. A workshop with around 20 representatives from industry, government and academic institutions working in the case study sectors, held at The Energy and Resources Institute (TERI), New Delhi, India November 28, 2008;
e. Two side events at the 14th Conference of the Parties in Poland, December 2008; and
f. A side event of the Delhi Sustainable Development Summit, February 2009.

iii) Desk-based analysis of academic and grey literature.

Technology transfer and technological capabilities

Technology transfer has been defined a number of ways. We consider technology to be products (e.g. physical equipment), processes (e.g. organizational and management practices, production processes), and knowledge (tacit and codified); also termed “hardware” and “software” (IPCC 1996, Lall 1995, Teece 2005). Importantly, as elaborated on by Bell (1990), there are qualitatively different types of knowledge which contribute to building different types of capacity within recipient countries.

Bell articulated technology transfer as a series of flows from one location – Flow A consists of goods and equipment, Flow B consists of skills and know-how regarding how to operate, maintain and fix these technologies, and Flow C is the knowledge and expertise needed to develop the technology in the first place, or what Lall (1995) refers to as “know-why” skills, when agents understand the principles behind the technology. A key insight to emerge from this approach and supported by empirical evidence is that sustainable technology transfer is not just a process of capital equipment supply from one firm or organization to another. Comprehensive technology transfer also includes the transfer of skills and know-how for installing, operating and maintaining technology hardware – leading to the accumulation of new production capacities in the recipient firm / country. It can also include knowledge for understanding technology so that further independent innovation is possible by firms / organizations – enabling the recipient to move beyond mere production capacities towards the accumulation of new innovation capacities (Bell 1990; Worrell et al. 2001; Ockwell et al. 2008).

The ability of firms / organizations to undertake innovation can be expressed in terms of the concept of **technological capabilities**. Drawing from experiences beyond low carbon and environmental technologies, the field of evolutionary economics has yielded a number of insights in this area. It is important to underline that in evolutionary economics no sharp differentiations between innovation and diffusion / adoption exist. For certain technologies to diffuse their constant modification is necessary e.g. lowering cost to open the technology for wider user groups or adapting it to local circumstances. These "modifications" are considered specific incremental innovations requiring relevant technological capabilities.

The concept of technological capabilities tries to capture the ability of these agents to make use of technology as well as to engage in technological change (Romijn 1999; Ernst et al. 1998; Madanmohan et al. 2004). Bell and Pavitt (1993) define technological capabilities as “the resources needed to generate and manage technical change, including skills, knowledge and experience, and institutional structures and linkages” (p. 163). Bell and Pavitt (1993) differentiate technological capabilities from production capacity, which describes the ability of a firm to produce a product without ever changing production input and organization.

The role of RDD&D in the formation of technological capabilities and international technology transfer

The framework outlined above denotes two roles for (international) RDD&D cooperation in enhancing the technological capabilities of technology recipients with regard to international technology transfer. The first role of this type of cooperation is to complement, facilitate and accelerate international technology transfer. RDD&D may help a firm or a group of firms increase their absorptive capacity and therewith make a certain transfer possible, through lowering its cost (sometimes referred to as ‘frugal’ innovation, or ‘*jugaad*’ – ‘resourcefulness amid serious constraints’[3] where the cost point is fixed), or, through tweaking and incremental changes, bring about improvements (e.g. in case the supplier withholds some knowledge).

The second role that RDD&D mechanisms can play is through substituting international technology transfer. Firms might be put in the position to develop or deploy a certain technology in case it is completely or partially unavailable on international technology markets through these RDD&D mechanisms. In fact, the literature has long been differentiating between firm R&D collaboration and technology transfer although both lead to (however different) technological capabilities.

Hagedorn (2002) defines research and development(R&D) in relation to (international), inter-firm collaboration as "the standard research and development activity devoted to increasing scientific or technical knowledge and the application of that knowledge to the creation of new and improved products and processes" (p. 447). For a definition of RDD&D one simply needs to add "and/ or for their demonstration and / or deployment". (International) RDD&D may take place

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[2] There were approx. 75-100 people at the first meeting, but about 20 people provided information. There were about 20 participants at the second meeting, and almost all participants provided information.

[3] Pronounced *“joo-gaardh”*, the idea is to improvise based on what is available. See http://www.innovationmanagement.se/2012/02/27/jugaad-lessons-in-frugal-innovation/

within or between sectors (the public, private, academic, and more recently community groups / non-governmental organizations (NGOs). This collaboration can happen either directly or with the engagement of intermediaries (e.g. consultants).

Support for low carbon research and development (R&D) mechanisms in “developing and least-developed countries alike” is increasingly gaining currency among decision makers as a way in which to maintain momentum through “bottom-up, national, and technology-specific policies” (Benioff et al. 2010, p. iv); particularly so absent a global agreement on climate change to supersede the Kyoto Protocol.

(International) RDD&D collaboration in the field of low-carbon technology has two main advantages from a public good perspective. Firstly, these initiatives could lower the cost for such technologies, thereby potentially increasing their diffusion and in turn their contribution to mitigation (Newell 2010). Secondly, they could stipulate that additional international transfer of low-carbon technology engage developing countries more and increase their share in the value, with associated economic benefits. But more than this, building capacity among developing country players can create more of a sense of ‘ownership’ of the technologies which they have helped to create / generate and adapt / make more appropriate to their circumstances. This has led to a call for increased engagement from relevant public authorities as research indicates that while the majority of low-carbon technologies have been developed within industrialized countries, their international transfer through private actors, especially to developing countries, has been disproportionally slow (Dechezleprêtre et al., 2011). In other words, international low carbon RDD&D and technology transfer is happening but ‘left to its own devices’ (i.e. the market), is not seeing anywhere near the penetration rates in developing countries that effectively addressing climate change warrants.

Governments have various incentives to enter or support RDD&D collaborations. These include knowledge creation, cost sharing, to enhance domestic technological capabilities, the creation of political goodwill, etc. From the perspective of firms, their motivations for collaborating on RDD&D may be different. They face a number of opportunities and challenges. RDD&D collaboration might lead to new knowledge or access to markets but also to the loss of competitive advantage or loss of resources invested in the project. Collaborations, where participants act more like partners, are therefore more often found at early stages of technology development then later, when products move towards commercialization. Building on this, it may not be surprising that firms with low technological capabilities find it harder to enter such collaborations then companies with a high level of technological capabilities – this is true in the area of low carbon energy and beyond (Justus and Phillibert 2005, Freeman and Hagedorn 1994).

These trends are important to understand as policy makers deliberate over how best to instigate collaborative RDD&D mechanisms:

- Through a more, indirect, ‘hands off’ approach, by creating an enabling environment for the private sector to lead, or through more direct means (interventionist);
- Through international or domestic policy tools;
- Through a more generic or targeted approach

Case Study A – Solar Photovoltaics

Indian market - Solar PV manufacturing is increasingly being conducted in developing countries. These countries, and especially China and India, are expected to provide a larger part of the manufacturing base for PV technology by 2011-12 (ISA 2008).

The beginnings of the Indian PV industry date back to the early seventies when the Indian government mandated the state electronic companies to develop and produce solar cells and modules. The Indian government started at the same time to fund public R&D projects within Indian universities. The industry grew slowly until the mid-nineties mainly through procurement by the Indian Department of Telecom as well as the Indian Railway and other government corporations (Satry 1997; Bhargava 2001). In the mid-nineties, procurement through the mentioned institutions stopped as PV technologies were replaced with alternatives. Manufacturers started to export PV modules to make use of their excess production capacities (Srinivasan 2005). At the same time, the Indian government expanded its demonstration and rural electrification program and tried to integrate private actors into SPV based rural electrification. Export and rural electrification provided commercial alternatives for the Indian PV industry, the former being more significant than the later. Existing production capacity could however not be completely put to use.[4]

According to the majority of industry experts, in the past, the Indian solar PV industry was driven by the activities of governments, Non-Governmental Organizations (NGOs) and International Organizations (IOs), including rural electrification programs and Corporate Social Responsibility (CSR) programs. By and large, the private sector involved in PV focused on exports, as the domestic market was not deemed profitable. However, the situation has changed since early 2007, as more and more companies are becoming interested in producing PV systems for the domestic as well as international markets. The main reason for this increased interest is due to two recent government policies, which will be discussed in detail in the section entitled “Policy Implications”. At present, about 75% of capacity is for exports while the rest is for the domestic market.[5] The majority of these exports are for European markets, especially Germany, as well as Japan and the United States.

Comprehensive, publicly available studies on the Indian SPV industry (contrary to China) do not exist. Private companies undertake market research on a regular basis. Companies are state-run, joint sector, or private sector

[4] Interview, one PV company, October 2007
[5] Interviews, industry experts, October and November 2008

companies. Private firms include firms of complete Indian ownership, joint ventures with multinationals and foreign owned subsidiaries (Srinivasan 2005).

Due to the recent interest in the industry since early 2007, it is difficult to pinpoint the current number of PV companies operating in India.[6] However, previous research indicates that there were around 19 companies producing wafers, cells, modules and systems in India in 2008 (ISA 2008; Haum 2010). The majority of companies in India are producing First Generation (crystalline silicon) cells and / or modules. Two of the key players in India include:

- Tata BP Solar, a joint venture between British firm BP (51%) and Tata Power Company (49%), in operation since 1989, with annual turn around of about US$200 – 250 million. Tata BP Solar is expanding its capacity to 180 MW, with a plan to increase capacity to 300 MW by 2010;[7] and
- Moser Baer Photo Voltaic Ltd., created in 2005, a subsidiary of Moser Baer, has 40 MW capacity to produce solar cells, with the aim of increasing capacity to 240 MW, and 40 MW capacity to produce solar modules, with plans to increase capacity to 200 MW. In 2009 the company was also constructing a 200 MW thin film manufacturing plant.[8]

Other companies include Central Electronics Limited (CEL), KSK Energy, Maharishi Solar, HighHindVac (HHV), Environ, SemIndia Systems, Titan, Bharat Heavy Electricals Limited (BHEL), Signet Solar, among others. Many existing firms have plans to increase capacity.[9]

Larger energy firms are also expressing an interest in the sector. For instance, Lanco Infratech created Lanco Solar in October 2008, with plans to manufacture the entire value chain in the PV process and invested US$ 1 billion to do so. However, after the financial crisis of 2008 / 09 Lanco indicated that they were holding off plans to enter the solar energy industry (Sreekala 2008; Solar India Online 2009). Suzlon Energy, a world-renowned Indian wind energy firm, also indicated in November 2008 that they would be investing in solar power, identifying sites in Rajastan and Gujarat, but revealing little details about the investment (Business Standard 2008). Reliance Industries Limited (RIL) had also indicated plans to invest in PV with a 1GW plant, but with the global economic downturn in autumn 2008, decided to hold off on their plans. In addition, international groups like the Clinton Foundation have been in India seeking out potential Indian investors for PV applications in India.[10]

The Indian PV companies vary in their level of integration. Some companies just cover one step of the PV value chain while others cover up to three. A few companies including Moser Baer and Environ have indicated plans to produce the entire PV value chain, starting with producing PV grade silicon from sand. An increasing number of companies are involved with or exploring thin film solar technology including Titan, Signet Solar, Moser Baer PV Ltd., KSK Surya Energy, and HindHighVac (HHV).[11] Despite this, companies involved in First Generation solar PV technology dominate India’s market. Respondents indicated that they were particularly focusing on silicon technology, as it is a technology that is well known and because the main mineral required to produce silicon was plentiful. One firm also noted that they were ‘wedded’ to that technology in the near to medium term, due to the amount of infrastructure, equipment and personnel investments already made in this area.[12] There was also a minority opinion by some government officials, academic researchers and some firms, that there was a need to access and master state of the art technologies as a way to develop technological capacity within the country.[13]

Technology Access - Before we turn to the specifics regarding RDD&D collaboration, we first asked: *How have Indian firms and / or Indians accessed low carbon technologies?*

The most common way in which firms acquired technology was through licensing. This point in and of itself is particularly telling as it decreases the chances of building up technological capabilities. But, two ways to access technology with more direct links to RDD&D was through collaboration / acquisition and through in-house R&D as noted below.

The second manner in which Indian firms acquire technology is through collaboration and acquisition. For instance, Tata Power, through Tata BP Solar, one of the most successful Indo-British joint ventures to date, was able to access the knowledge and expertise of BP. Moser Baer PV Ltd. is also working in partnership with Applied Materials, a firm that produces solar cell manufacturing equipment. In 2006, Moser Baer PV Ltd. gained “significant equity”[14] in a number of American firms including Solaria and Stion Corporation, involved in frontier PV technology (MBPVL 2008).

Collaboration between personnel was also occurring. According to one industry expert, if one looked at the names of the researchers doing work on PV in the United States (from firms and government institutions), over 60-70% of

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[6] For instance, at the time of research, two interviewees indicated that their businesses had only officially been in operation for less than one year. Moreover, these companies were in the process of building manufacturing plants (acquiring the necessary permits, personnel, equipment, etc.).

[7] (ISA), P. a. I. S. A. (2008). Solar PV Industry: Global and Indian Scenario. New Delhi, ISA: 174.
, Solar, T. B. (2008). "webpage information." Retrieved January 12, 2009, from www.tatabpsolar.com., Interview, one PV company, November 2008

[8] (MBPVL), M. B. a. M. B. P. V. L. (2008). "Strategic Partnerships." Retrieved January 20th, 2009, from http://www.moserbaerpv.in/strategic_partnerships.asp.; Interviews, industry experts, October and November 2008

[9] Interviews, industry experts, October and November 2008

[10] (ISA), P. a. I. S. A. (2008). Solar PV Industry: Global and Indian Scenario. New Delhi, ISA: 174, Online, S. I. (2008). "Solar India Online December 2008 Newsletter." Retrieved December 31, 2008; Personal Communication, one infrastructure firm, November 2008.

[11] (ISA), P. a. I. S. A. (2008). Solar PV Industry: Global and Indian Scenario. New Delhi, ISA: 174.; Interviews, industry experts, October and November 2008

[12] Interview, one PV firm, November 2008

[13] Interviews, industry experts, October and November 2008

[14] It is not clear if this amount constituted majority ownership (i.e. acquisition versus partnerships).

leading personnel are of Indian origin.[15] In addition, another interviewee noted that he had recently returned to India after having spent time abroad in Germany, learning more about the technology. Similar to what we found in some of our other case studies (e.g. hybrid vehicles), some Indian firms have acquired personnel who have spent periods of time studying and / or working abroad and when these people have moved to India, they have been able to draw upon these networks.[16]

Other Indian firms are a subsidiary of an international PV firm, allowing some access to the knowledge held by the mother company. In these instances, the head company has collaborative arrangements with universities in that country (e.g. the United States). However, one consideration with this approach is that these types of arrangements may not be as conducive to supporting technological capacity. This is based on findings from Phase I which state that, "less integrated approaches to technology transfer that include the use of recipient country manufacturers to supply parts and labour are more likely to improve technological capacity within recipient countries"(Ockwell et al. 2007, p. 8).

Collaboration is also occurring on a smaller scale – including individual projects where advances are being made. For example, a university architecture professor spoke about his experience on a PV project at the India conference on Solar PV. He was interested in BIPV and approached Siemens about a potential project. Siemens deemed it too expensive, and so a group of professors and students came up with BIPV options on their own in consultation with other researchers in India and elsewhere (e.g. a professor working at an Israeli university).[17]

The least common manner in which Indian firms access technologies is through in-house research and development. One PV firm noted that they were starting to develop more capacity in the area, through creating a team, working on innovation.[18] Another PV manufacturer involved in thin film solar cells, HHV, developed the majority of their technology indigenously. Dr. Barua, one of the founders of the company, began his research at a university in Kolkata and did his PhD research on thin film. He received support from one of the Indian Institutes of Science to work on a program within the Indian government-owned firm Bharat Heavy Electricals Limited (BHEL). However, when results were not happening, the program was cut. In 2002, he and five team members (all with doctorates in this area) turned their attention to making advances in thin film technology within HHV. After 6 – 7 years of R&D they were expecting to have operations in place with efficiencies of 6.5% by April 2009.[19] The concerns with using mainly indigenous sources for R&D are that there are often time delays with respect to making a technology available, thus slowing the speed of diffusion.

To provide a contrast, Moser Baer Photo Voltaic Limited (MBPVL), another Indian firm planning on manufacturing thin film PV, was incorporated in 2005 and announced thin film plans in 2008, after partnering with some American firms working in this area. However, MBPVL, is a subsidiary of Moser Baer, an Indian firm that is the second largest producer of optical storage devices worldwide (MBPVL 2008). As a larger company, they have more resources (personnel, financial and technical) available to offer other organizations they are interested in partnering with.

Research Development Demonstration and Deployment (RDD&D) Collaboration

After assessing how Indian firms have been able to access these technologies, we now turn attention to RDD&D cooperation. There are two ways in which RDD&D collaboration is occurring between Indian firms and foreign organizations in this area. The first way is through independent actions taken by PV manufacturers, through a series of bilateral discussions and arrangements. Indian firms are leading this process by conducting their own research and targeting appropriate manufacturers of equipment and entering long-term collaborative arrangements. These arrangements ranged from joint ventures, such as Tata BP Solar, where talks began in the mid-1980s, to memorandum of understanding, to more informal agreements. Only one firm, Tata BP Solar, indicated that they are actively engaged in creating awareness about this technology in the community. Moreover, Indian firms were tapping into the Indian diaspora community, allowing them access to networks overseas.

The advantages of this approach are that Indian firms are actively driving the process, and so are playing more of a leadership role in the technology transfer process. On the other hand, identifying the appropriate companies and / or personnel independently often takes more time, and so likely affects the rate of technology diffusion. This is especially an issue for those companies that were conducting in-house R&D through mainly indigenous channels as noted in the previous section. Despite this, the majority of Indian firms did not see this as an issue.

When asked about the potential to partner with universities, Indian PV firms recognized that some of the Indian technical institutes are actively engaged in research, and that some of this research was excellent. According to Dr. Kumar, Lanco Solar, the Indian Institute of Technology (IIT) Delhi had achieved some of the best efficiencies in the world with respect to non-silicon solar cell technology, stemming from research in the 1980s.[20] A few *ad hoc* examples exist. However, the general consensus amongst respondents was that there is a disconnect between how the private sector and academia operates. One interviewee noted that:

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[15] Interview, one PV manufacturer, October 2008
[16] Interviews, industry representatives, October and November 2008;
[17] Krishnan, Presentation, SEARCH Foundation and Government of India, M. o. N. a. R. E. (2008). Various presentations and discussions. Solar PV: Emerging Viable Option with Technology and Policy Thrusts, India Habitat Centre, New Delhi. .
[18] Interview, one PV firm, November 2008
[19] Interview, HHV, November 2008
[20] Kumar, presentation, SEARCH Foundation and Government of India, M. o. N. a. R. E. (2008). Various presentations and discussions. Solar PV: Emerging Viable Option with Technology and Policy Thrusts, India Habitat Centre, New Delhi. .

> "The mentality of academic institutes is different. Their approach to timelines and achieving results is not in sync with the private sector….researchers present papers, attend workshops, but they are unable to answer the question 'how can you deploy this tomorrow'?"[21]

The second way RDD&D collaboration happens is through a number of indigenous intermediary groups, which seek to create awareness and facilitate interaction amongst key players in this industry. Through seminars, exhibitions, online material and studies, cooperation is increasing. Three of the key groups operating at the national level promoting this work stood out at the time of research. These include the most active trade association, the Indian Semiconductors Association (ISA) under their PV section; SolarIndiaOnline, a small group of people actively engaged in creating an online "one stop shop" for PV players to turn to for events, key information including government policies, etc.; and the Renewable Energy Action Forum (REAF), a group out of Bangalore of key players stemming from diverse background including industry, academic institutes and the United Nations.[22] The existence of these groups is encouraging; however, they are all relatively new. For example, the oldest group, the ISA – PV section has only been in operation since 2004.[23]

The role of policy – The last section of our case study honed in on the potential role that policy played in fostering RDD&D cooperation. Speaking about the Indian PV industry in general, although nascent, most PV industry experts agree that it began as a result of government policies including rural electrification and government procurement policies. These policies are at various levels of government. For instance, a number of respondents indicated West Bengal's state government, which has done a lot of work promoting PV.[24]

Many informants also argue that recent PV industry development is largely driven by two additional relatively new domestic policies. The two recent key policies at the national level that have encouraged interest and investment in this industry are:

1. The Government of India (GoI)'s Semiconductor Policy Guidelines in September 2007, which was essentially a tax holiday until March 2010. The Policy Guidelines include a Special Incentive Package Scheme (SIPS) (a 20% or 25% subsidy for capital costs) for setting up semiconductor fabrication and other ecosystem units, including PV; and Special Economic Zones (SEZs), where numerous tax breaks are in place and where PV manufacturing is an eligible activity.[25]
2. Electricity Generation Based Incentives (GBI) – here the MNRE will provide a subsidy for grid connected PV power plants. The limit for the subsidy is up to 1MW per project, 5MW per developer in the country, and 10 MW per state, up to a total of 50 MW countrywide. The MNRE will guarantee PV project developers a tariff of 15 rupees per kWh. In some cases the MNRE will need to pay the difference between their guarantee and what the state electricity agency is offering. For example, at present the sate electricity organization offers four rupees per kWh in West Bengal while in Gujarat, the state electricity organization offers a little over 15 rupees per kWh.[26]

A number of government policies at the state level were also introduced around the time of research to encourage PV use including Punjab, West Bengal, Rajastan and Haryana.[27]

Also, Solar Energy is one of the eight missions in the Government of India's National Action Plan on Climate Change, a key area in which the GoI is prioritising climate change efforts. One of the Mission's aims is to have local PV integrated production in place at a level of 1 000 MW / annum from 2007-2017 (Government of India 2008).

The majority of informants **saw the two recent policies as important steps in encouraging development of the PV sector** – both manufacturing and use – in India. However, many argued that these **policies were not enough** and that the GoI had a long way to go to really ensure India would be a key global player in this industry. For example, some criticized the fact that the GBI had numerous ceilings, including the 50MW limit in the country and the 5 MW limit per developer, and that the GBI was only for 10 years, versus other countries' feed in tariff policies, like Germany's where PV project developers are guaranteed a rate for 20 years. In addition, one interviewee also raised the question of providing electricity for poverty alleviation. He noted that this subsidized power (with the large investors focusing on huge plants in isolated areas in Rajastan and Gujarat to provide power to urban centres) would target the wealthy of India rather than the rural poor.[28]

In addition, although there was consensus amongst all interviewees that these various government policies would help to support the industry, some noted that these various policies and programs were not well known, were sometimes complex and operated in isolation, being run by various departments, etc.[29] This experience is similar to other developing countries, such as Mexico, where industry leaders claimed that programs and policies to help renewables were often complicated, convoluted, and / or unknown (Mallett 2007).

With respect to government support for RDD&D in the area of PV, there are a few *ad hoc* examples (e.g. state Ministries of New and Renewable Energy), but no broad policy on a large scale. In addition, the NAPCC indicates that "another aspect of the solar mission would be to launch a major R&D programme, which could draw upon international

[21] Interview, one PV manufacturer, November 2008
[22] Interview, industry representatives, October and November 2008
[23] Interview, one trade association representative, November 2008
[24] Interviews, industry experts, October and November 2008
[25] For specific details see (ISA), P. a. I. S. A. (2008). Solar PV Industry: Global and Indian Scenario. New Delhi, ISA: 141-142.
[26] Ibid.: 142-144.; Interviews, industry experts, October and November 2008;
[27] For details see (ISA), P. a. I. S. A. (2008). Solar PV Industry: Global and Indian Scenario. New Delhi, ISA: 144-145.
[28] Interview, one PV manufacturer, November 2008
[29] Interviews, Industry experts, October and November 2008

cooperation as well, to enable to creation of more affordable, more convenient solar power systems, and to promote innovations that enable the storage of solar power for sustained, long term use" (Government of India 2008, p. 3). Within the area of PVs, the GoI has indicated proposed R&D activities to increase solar cell efficiency to 15% at a commercial level, to improve modules to have higher packing density and suitability for solar roofs, and improve lightweight modules to be used in applications such as solar lanterns (Government of India, p. 21).

Discussions continue to refine these points further. However, because details on how these R&D activities, as well as other aims within the Solar Mission, will occur were scarce (e.g. which institutions, which incentives), it is difficult to ascertain the potential for this policy to encourage technology transfer and development in this sector. Furthermore, the majority of PV industry players were not involved in this process.[30]

Regarding policies to support technological capacity, there are almost no policies in place to encourage collaboration at the national or international level. However, a number of interviewees indicated that India's investment in their National Systems of Innovation (NSI), especially their IITs and IIC, with world class reputations for research and teaching, have provided Indians involved in these organizations with the necessary reputation to work and / or study abroad, fostering links between those people at home with the Indian diaspora abroad. Only one informant noted a government program under the Confederation of Indian Industries (CII) to encourage collaboration amongst Indians conducting research with other countries (e.g. Canada, Israel).[31]

Moreover, the NAPCC specifically mentions the potential for collaboration to occur between Indians and institutions in other countries, with the resulting IPRs being shared. The GoI also recognizes the need for technology transfer and the need to provide support to entrepreneurs to demonstrate solar PV technology to help develop the sector in India (Government of India 2008).

Indian firms were the most dominant player in fostering links with other partners, whether international or domestic. This has important implications for the potential for technological capacity development, which often occurs as a result of acquisition of new knowledge and expertise, usually via interactions with others.

Case Study B – Energy Efficient Technologies in Small and Medium Enterprises

Indian market

The SME (small and medium enterprises) sector plays a vital role in the Indian economy, contributing around 45% of manufacturing output and 40% of exports, and employing an estimated 59.7 million people spread over 26.1 million enterprises according to recent estimates. Small-scale industries manufacturing energy-intensive products form the backbone of many developing country economies. SMEs in energy-intensive manufacturing sectors like castings, forgings, glass and ceramics, food processing, textile processing and so on, use obsolete, inefficient technologies to burn commercial fuels like coal, oil, and gas, leading to wastage of fuel as well as release of high volumes of greenhouse gases (GHGs) and particulate emissions that are harmful to health and damage the atmosphere. While individual SME units are relatively small in size, their sheer numbers, coupled with the fact that they depend on low-efficiency fuel burning technologies, make the SME sector a sizeable source of carbon emissions. Hence, there is a clear and urgent need for SMEs to adopt EE (energy-efficient) technologies that will help them reduce both fuel consumption and carbon emissions.

In 1992, the Swiss Agency for Development and Cooperation (SDC) initiated a macro-level study by TERI of energy consumption patterns in the Indian SME sector. Based on this study, SDC partnered with Indian Non-Governmental Organizations (NGOs) / research institutions and international consultants to initiate a programme aimed at introducing clean, EE technologies in four energy-intensive SME sub-sectors. Two of these sub-sectors—namely, the foundry and glass industries—are discussed in this case study. The other two sub-sectors identified were the small-scale brick industry, and small/micro enterprises that burn biomass fuels. The overall goals of the SDC programme were:

- To help SMEs achieve energy savings and thereby improve profitability of operations
- To bring about reduction in CO_2 and other emissions and thereby address environmental concerns at both local and global levels.

Foundry industry in India

Foundries make iron castings from molten iron. Castings find diverse applications such as in the manufacture of sanitary pipes and fittings, automotive parts, and engineering equipment like pumps, compressors, and electric motors. There are about 5000 small-scale foundry units in India, with a collective annual output of about six million tonnes of castings. While their output predominantly caters to domestic markets, a small percentage is exported. The foundry sub-sector is growing at 8%–9% annually and provides direct employment to an estimated half-a-million people. Foundries are mainly located in clusters across the country. The clusters vary in size: some have less than 50 units, while others have over 500 units. Typically, each cluster specializes in producing castings for specific end-use markets. A foundry makes iron castings by melting a variety of iron-containing materials such as pig iron and cast iron scrap in a furnace called a cupola. The molten iron so obtained is then poured into moulds to make castings of desired shapes. Usually, cupolas burn coke as fuel. Melting is by far the most energy-intensive stage of a foundry's operations. Till the early 1990s most Indian foundries were using the conventional 'cold blast' cupola. As described later, TERI partnered with a United Kingdom (UK)-based consultancy firm to identify, transfer and adapt a more energy-efficient melting technology for small-scale Indian foundries—the divided blast cupola (DBC).

Glass industry in India

[30] Interviews, industry experts, October and November 2008

[31] Interview, SolarIndiaOnline, October 2008

Almost the entire small-scale glass industry in India is located in a single cluster in Firozabad, about 40 km from Agra. According to a TERI estimate, each day glass units in Firozabad produce around 2000 tonnes of glass products including 50 million bangles, and provide direct employment to an estimated 150,000 people. Glass for making bangles is melted almost exclusively in open-pot furnaces. Till the early 1990s, almost all these furnaces operated on coal. By 1996, most tank furnaces in the cluster (about 55 numbers) had switched from coal firing to oil firing, but pot furnaces (about 100 numbers) were still being fired by coal. As described later, TERI worked with British Glass and other U.K. partners to transfer know-how for the development and promotion of a more energy-efficient melting technology for small-scale glass melting units in Firozabad—the gas-fired recuperative pot furnace. The fuel switch from coal to natural gas was mandated by the Supreme Court of India in December 1996 with the Taj Trapezium Zone (TTZ) - an area of 10,400 km² around the Taj Mahal, within which Firozabad is located.

Technology access

The technology development and demonstrations were undertaken during the period 1995–2000. A detailed account of the process adopted under the two projects is provided in the books published by TERI (Pal 2006; Sethi and Ghosh (eds) 2008). A summarized version of the account also appears in the UK-India collaborative study on the transfer of low carbon technology: Phase II report (Mallett et al. 2009).

It is important to note that TERI played two key roles during this project:

1. As primary collaborator of the improved technological know-how, through ongoing capacity building of the TERI team by its overseas partners.
2. As facilitator and technology service provider for the development, adaptation, demonstration and promotion of the improved technologies in the concerned SME sectors, through direct field-level interactions with entrepreneurs and other industry stakeholders.

Having identified the areas in which to introduce EE technologies—namely, the cupola furnace in foundry units and coal-fired open pot furnace in glass units— TERI teamed up with international partners to select appropriate technologies which could be transferred and adapted to the local industry needs. In the case of both small-scale foundries and small-scale glass industries, EE technologies were identified, transferred and adapted to local conditions and requirements. In setting up the demonstration plant for small-scale foundries, Cast Metals Development Limited, U.K., provided crucial support and expertise in transferring technical know-how related to the divided blast cupola (DBC), and at every stage during the design and commissioning the demonstration plant. The British partner assisted the TERI team in conducting an energy audit of the existing cupola in the demonstration unit; analysing the results of the audit so as to evolve design parameters for the new DBC; ensuring that quality and design norms were adhered to during the fabrication of various components of the DBC; and fine-tuning various sub-systems during the trial runs.

In designing, developing and demonstrating the new gas-fired pot furnace, TERI worked closely with a number of British partners whose key roles are summarized below.

- British Glass, U.K., provided expertise in glass technology. Along with other partners, British Glass also finalized the conceptual and detailed designs of the new pot furnace.
- AIC (Abbeville Instrument Control Ltd), U.K., helped in developing the concept and design of the new furnace, including its heat recovery unit (recuperator).
- Chapman and Brack, U.K., provided guidance in constructing the crown of the furnace.
- TECO (Toledo Engineering Co. Inc.), U.K., provided expertise in commissioning the recuperator for the furnace.
- NU-WAY, U.K., supplied the burners for the furnace.

During the TT processes, TERI obtained strategic support and inputs from Sorane SA, Switzerland. Sorane SA provided advice in energy management and systems integration, helped identify and coordinate activities with international energy and environmental consultants, and assisted by way of technical support.

Research Development Demonstration and Deployment (RDD&D) Collaboration

Divided blast cupola (DBC) for small-scale foundries

The demonstration DBC was successfully commissioned in mid-July 1998. The DBC showed a marked improvement in energy efficiency compared with the existing cupola. In effect, the new plant yielded an energy saving of about 40% compared to the earlier cupola. The DBC also yielded additional benefits in terms of an increase in metal temperature and a substantial reduction in silicon and manganese losses. The payback period worked out to less than two years on the investment in the DBC alone. Although the new DBC had proved itself to be far more energy-efficient than the existing cupola, proper operating practices had to be followed to reap the full benefits of its improved design. Hence, following the demonstration, TERI and its British partners worked for several weeks in training the furnace operators and maintenance personnel to follow BOP (best operating practices) in the day-to-day running of the plant.

Recuperative pot furnace for small-scale glass melting units

The gas-fired recuperative pot furnace was successfully commissioned in February 2000. Following the demonstration, TERI and its British partners trained furnace operators and other workers in monitoring and operating the new system. The British partners continued to provide support for a few years after demonstration in trouble-shooting the furnace system and in fine-tuning its performance parameters. The energy consumption of the gas-fired recuperative furnace was 58% lower than the traditional coal-fired pot furnace. Because of its increased fuel efficiency, the recuperative furnace promised a payback within two years.

Technology dissemination and results

Following the successful demonstration of the two EE technologies—the DBC and the recuperative pot furnace—TERI focused its efforts on disseminating these technologies through:

- providing customized design solutions and installation/commissioning support to other entrepreneurs on the new EE technologies
- awareness generation among industry stakeholders at both policy and cluster levels
- capacity building programmes involving entrepreneurs, fabricators, local consultants, masons and other stakeholders

The Swiss and British partners continued to provide technical support to the project so as to facilitate replication of the EE technologies. As of September 2010, around 95 TERI-design DBCs of different capacities (based on local requirements) have been adopted by foundry clusters across the country (Ahmedabad, Rajkot, Coimbatore, Nagpur, etc.)[32]. The adoption of this energy efficient technology has yielded an estimated cumulative energy savings of 33,000 toe (tonnes of oil equivalent) and a cumulative CO_2 savings of about 120,000 tonnes to date. The DBC technology has also been replicated in two foundry units in Bangladesh with technical support from TERI—an example of successful South-South technology transfer. Widespread adoption of the DBC will make it possible to save about 25% of the coke consumed by the Indian foundry industry, that is, 150,000 tonnes of coke annually. The overall CO_2 emissions from conventional cupolas used by the foundry industry are estimated at 2.5 million tonnes per annum. The CO_2 emissions could be reduced by around 0.6 million tonnes annually through the widespread adoption of DBC technology.

Similarly, with ongoing technical support from TERI, 76 of the 100 odd operating pot furnace units in the Firozabad cluster have since switched over to the TERI-designed recuperative furnace, yielding an estimated cumulative energy savings equivalent to 79,000 toe. Most of the remaining pot furnace units are expected to follow suit in the next few years. These replications have brought about a cumulative reduction in carbon emissions of 245,000 tonnes CO_2. In addition to these 'direct' replications of the TERI-designed furnace, reportedly almost all pot furnace units in Firozabad have adopted the *concept* of heat recuperation from the TERI-designed furnace. This in itself indicates that the TT process has succeeded; that the entrepreneurs have shed their traditional reluctance to consider changes in their technology, and is becoming increasingly confident in learning from the improved EE technologies and adapting them to suit their individual needs**.**

Role of policy

Enabling policy framework has an important role to promote innovations and reduce CO_2 emissions in this sector. This is important, considering the fact that SMEs in general do not have either the inherent financial capacity or the technical capacity to undertake research or adaptation activities that would help them improve their energy and environmental performance. It is therefore important to identify energy intensive SME sub-sectors and then develop tailor-made RDD&D programmes for them (which may be industry/cluster-specific) with support from government and multilateral/bilateral agencies.

The present discourse on technology transfer focuses a lot on new technologies. However, there is a significant potential to reduce carbon emissions through process improvements (software inputs) as well. The main barrier to technology dissemination in developing countries is not technology itself but the lack of appropriate policies and local capacities to absorb, implement and innovate on new technology. Hence, more attention needs to be paid on developing people (capacity building, handholding) and policies and implementation. Multilateral/bilateral agencies the development sector can play an important role in facilitating transfer of technologies to developing countries. The successful model of technology transfer established by SDC for these two sectors needs be replicated in other sectors and countries as well.

It is equally important for funding agencies to have a long-term commitment and a flexible approach in RDD&D programmes; for, change is invariably a slow process at the small-scale industry level. A prime factor that has contributed to the success of the TT project highlighted in this case study is the flexibility and long-term engagement with the project shown by SDC, and the unique partnership arrangement that exists among the project partners at different levels—between funding organization (SDC), the implementing agency (TERI), local consultants, international consultants, industry associations at cluster level and grassroots-level agencies.

For a collaborative RDD&D venture in the small-scale sector to be effective in bringing about sustainable change, technology transfer should not take place directly between technology supplier(s) and end users. Rather, it should be routed through an intermediary institution (such as an R&D establishment, consultancy organization), which can act as a facilitator to disseminate the improved technology on a large scale. An example is the TT project described above, in which TERI as an intermediary institution was able to absorb two improved EE technologies, and then transfer and adapt them for dissemination among a large number of SMEs across India.

Discussion / Policy Recommendations

The case studies above yielded the following insights, which have important policy implications. Here, we focused on the key drivers for collaborative RDD&D mechanisms and secondly, whether or not certain facets tended to elicit success. These are described below.

1) *Market access generally drives international private sector and foreign government involvement in collaborative RDD&D. In addition, the pivotal player is the private sector.*

[32] The number of replications needs to be viewed in light of the fact that they focused in a limited number of foundry clusters in India. An external review of the project conducted in July 2011 mentioned that a much larger number of cupolas have adopted certain innovative design features introduced under the project, if not the entire cupola. Hence there are spin-offs of the innovation. Some factors which have inhibited quicker replication are the slow pace of change typical among small-scale industries, higher capital cost, lack of life cycle costing by SMEs and limited capacity for and availability of the DBC technology at the cluster level.

In the case studies, it was shown that collaborative RDD&D initiatives in India are generally driven by domestic industry. Indian firms conduct research and identify potential partners to work with based on numerous attributes including: access to and knowledge of cutting edge technologies, willingness to work with Indian partners, etc. From there, the key driver for international company involvement is access to the Indian market. There are no stipulations in place by the Indian government regarding collaboration between foreign and domestic firms for many low carbon energy technologies. Rather, there are only a few industries, such as defence and aspects of nuclear, where the government has requirements on these initiatives in place (e.g. a certain percentage of the technology be controlled by Indians, using local manufacturing capabilities as in the case of Boeing)[33]. That said, discussions with a number of informants in India indicated that there could be more of an opportunity for Indian firms, government and institutions, to harness opportunities to develop innovative capabilities through technology transfer, as will be discussed further below.

2) *However, important exceptions exist where intermediaries have spurred RDD&D collaboration*
   The role of intermediaries in helping to foster links through the development, production and use of technologies was particularly prevalent in the energy efficiency technologies for SMEs, where TERI played an important intermediary role. In the PV case study, Indian intermediary groups, such as the ISA, REAF and SolarIndiaOnline, also played a role who are creating links through organizing conferences, workshops and seminars at the national level, as well as an electronic "one stop shop" for industry players to examine relevant policies, companies and other pertinent information.
3) *The general consensus from various stakeholders indicates that the public sector also plays a key role in encouraging collaborative RDD&D*

Findings from our case studies suggest that technology transfer activities must include cooperation between both the public and private sectors. Using evidence from EE technologies for SMEs, and PV and hybrid vehicles, our case studies show that the private sector is an integral actor in the transfer of low carbon energy technologies as this is where the majority of these actions take place. At the same time, interviewees for this study indicated that India has developed a reputation for having a highly educated pool of talent due to public sector investments in its National Systems of Innovation (NSI), or National Innovation Systems (NIS), which focuses on the interactions of actors, such as those involved in academic institutes, industry and the public sector, in innovation[34]. This enables India to produce high quality products at lower cost.[35] Highlighting this point in his study on the Indian automotive sector more generally, Mittal (2003) notes, "the cost differential enjoyed by India ranges from 10 to 35 percent depending on value addition, engineering complexities, and level of assembly" (2003, p. 2). Thus, the public sector also has an important role to play in encouraging collaborative RDD&D programs.

This can be done through formal partnerships, or through initiatives driven by the private sector, but where the public sector provides some incentives. Actions can include a focus on a country's NSI, as India has done. This focuses on infrastructure and political stability, along with more direct efforts such in helping to spur investments through a feed in tariffs or tax breaks, or through providing financial and human resources for RDD&D. This finding is also similar to other studies which examine the potential of RDD&D in the area of low carbon technologies (Chiavari and Tam 2011).

Industry players have little awareness of and pay little attention to international intergovernmental mechanisms

Industry players only briefly mentioned (if at all) existing international intergovernmental initiatives to assist technology transfer. This is not to say that Indian firms are unaware of current frontier research trends and global efforts relating to these technologies. In fact, in all of the case studies Indian firms had identified the countries and / or companies and to a lesser extent the research institutes engaging in cutting edge RDD&D. However, Indian firms have largely adopted an independent, bilateral approach with foreign firms and / or institutes, rather than joining multilateral government initiatives[36].

To summarize, low carbon technology cooperation is happening. However, we found that the main drivers for this action warrant closer scrutiny. Indeed, although the role of international climate processes has been pivotal in spurring low carbon technology development and uptake in certain cases (e.g. ICTSD-UNEP-EPO 2010; Betz and Sato 2006; Dechezlepretre et al. 2011), in India, market access, as opposed to intergovernmental mechanisms, has been the key trigger. While actions to encourage low carbon technology collaboration through United Nations (UN) channels are to be lauded, they are by no means the only way in which to invigorate technology transfer. This suggests two key dynamics. First of all, the amount of attention, resources, debates and discussion surrounding the shortcomings and strengths of these intergovernmental efforts appear to be disproportionate to their *actual* ability to affect (whether positively or negatively) low carbon technology transfer in some cases. Secondly, this evidence shows that there is a disconnect between supranational governmental efforts aiming at increasing technology cooperation in this area and key drivers instigating action among low carbon technology players. These facets imply that re-thinking the technology transfer process comprehensively, through a systemic lens, building innovative capacity, will be more effective.

[33] Interview, one intellectual property expert, November 2008

[34] Interviews, key informants from various case studies, October-November 2008. For further details on NSI or NIS see (OECD), (1997). National Innovation Systems. OECD. Paris, OECD. http://www.oecd.org/dataoecd/35/56/2101733.pdf

[35] Discussions, industry informants from various case studies, October-November 2008

[36] Interviews, key informants from various case studies, October-November 2008

As noted above, the second part of our research focused on the characteristics of the RDD&D mechanisms to determine whether or not certain elements were common in more successful endeavours. Here, we found that:

1) *Strategies that involve knowledge and expertise from international sources appear to have resulted in more successful and rapid technology transfer and diffusion*

As demonstrated in the PV case studies, one of the strategies that Indian firms use to develop technologies is through in-house Research and Development (R&D). However, the strategies and experiences of individual firms differ. For example, in the PV case study, it has taken the Indian company HHV, which is using mainly indigenous resources, 10 years to move from research to commercial production of thin film solar PV. By contrast, Moser Baer PV Ltd., incorporated in 2005, by partnering with several American firms working on thin film, announced plans to build a thin film production plant in three years, thus emphasizing the value of international collaboration[37].

Collaborative RDD&D mechanisms have clear potential for developing capacity in and access to new technologies, as well as increasing the rates of technology diffusion, all pivotal goals in addressing climate change. Our research indicates that international collaborations on research, development, demonstration and deployment show the highest potential for facilitating the transfer of knowledge and hardware, over less time. Better engagement at the international level with such initiatives can therefore play a role in improving the effectiveness of these collaborations by sharing knowledge.

2) *Technology selected for RDD&D must be needs-based & involve local actors*

To ensure their sustainability in the long term, RDD&D programmes should have a strong partnership element and involve local actors from the outset. In the SME case study, SMEs were looking for technology alternatives for a number of reasons. For example, in the glass industry case study specifically, an environmental law on December 30, 1996 required industries within the “Taj Trapezium Zone (TTZ)”, or areas around the Taj Mahal (over 10 000 km^2) to switch from coal-based fuel to an alternative fuel (natural gas) aimed at reducing air pollution within this. Also, in this case study local actors took over once the foreign consultants and expert R&D organizations had helped the SMEs identify and demonstrate the benefits of cleaner technologies. The inclusion of intermediaries in such processes (trade associations, NGOs) also helped ensure success by providing on the ground knowledge, access to local contacts, and a local “go to” place should technology purchasers have challenges, etc.

3) *Partnerships for RDD&D must target building of local technology capacities to deploy and develop technologies*

Finding from our case studies indicate that technology transfer must take place as part of a wider process of technological capacity building in developing countries. In the hybrid vehicles case study for instance, the complex nature of the hybrid vehicle technologies calls for firms to have the ability to understand and ‘master’ the numerous intricate details for technology transfer and development.[38] Firms’ / organizations’ ability to understand these aspects often depends on their innovative capacity, which can be developed via international collaborations involving knowledge sharing and skills development. This finding is echoed in other studies regarding innovation for environmental technologies. Popp (2011)’s overview of a number of studies in this area reflects this importance where “foreign knowledge serves as a blueprint for further improvements, rather than as a direct source of technology. This suggests that when policymakers consider the potential for technological change to reduce environmental impacts in developing countries, they must make allowances for adaptive R&D to fit technologies to local conditions or else be prepared for less successful results.” (p. 136).

4) *International collaboration on RDD&D is more frequent amongst larger Indian firms*

Linkages through efforts initiated by Indian companies were observed to occur more frequently amongst larger Indian firms. These larger firms have easier access to resources including capital, personnel and global networks. International policy could therefore benefit economy-wide technological development by helping to facilitate collaboration between smaller firms and international organizations involved with frontier technologies.

Conclusion

To summarize, our research indicates that in India efforts to engage in international technology transfer regarding low carbon energy technologies are happening. At the same time, similar to views held at a more global level, a number of informants in India indicated that in order to effectively address global climate change, further efforts are needed. Here we found that many Indians familiar with the climate negotiations are aware of industrialized countries’ obligations to developing countries on technology transfer, but their view is that the current arrangements under the United Nations Framework Convention on Climate Change (UNFCCC), including market mechanisms (finance), are not enough to help developing countries on this issue. They argue that different mechanisms are needed to make technology transfer more effective.[39] The Government of India (GoI) also echoed that view in their proposal for a multilateral technology transfer mechanism to the UNFCCC in November 2008 (GoI 2008).

In conclusion, our evidence examining these case studies from India suggests that in certain instances, market access rather than intergovernmental processes has been cardinal at fostering low carbon technology collaboration. This implies that the current ways in which to conduct low carbon technology transfer require a fundamental shift – in strategy, tactics and actions. We purport that in order for technology transfer to be effective, it must be a component of a broader strategy in which to build innovative capacity among participants. Building on this, our research points to the fact that more successful instances of RDD&D collaboration is occurring when some sources of knowledge and

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[37] Interviews, PV industry informants, October-November 2008

[38] Interviews, hybrid vehicle informants, October-November 2008; Discussions, NHPP workshop, November 2008

[39] Discussions, Stakeholder Workshop, November 2008

expertise are foreign, and when it is based on needs in developing countries and involves local actors. Another important facet to consider is the fact that although the private sector is a pivotal driver for international technology transfer, the government also plays an important role, and particularly so in the cases of SMEs, which often lack sufficient capital, resources and expertise to become involved in international collaborative initiatives on their own.

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