UK–India collaboration to identify the barriers to the transfer of low carbon energy technology

FINAL REPORT

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March 2007

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Executive summary

At Gleneagles in July 2005, the G8 highlighted the importance of strengthening technology cooperation between developed and developing nations to develop low carbon energy options. Many developing countries pressed for a new approach to international cooperation in the area of clean energy technologies. As a follow-up to this, the UK Government and the Government of India decided to collaborate on a study to assess the barriers to the transfer of low carbon energy technology between developed and developing countries. This is an executive summary of the findings from this collaborative study.

Key messages

1. The transfer of low carbon technologies to developing countries is central to tackling climate change. Governments in both developed and developing countries have a key role to play in facilitating technology transfer through both national and international initiatives.
2. There is no "one policy fits all" solution to facilitating low carbon technology transfer. Relevant policy interventions vary according to the nature of the technology, its stage of commercial development and the political and economic characteristics of both supplier and recipient countries.
3. Due to the early stage of development of many low carbon technologies, vertical technology transfer (transfer of technologies from the research and development stage through to commercialisation) is as much an issue as horizontal technology transfer (transfer from one geographical location to another, including transfer from developed to developing countries).
4. In order to be sustainable, technology transfer must take place as part of a wider process of technological capacity building in developing countries. Building technological capacity relies on the transfer of knowledge and expertise as well as hardware during the technology transfer process.
5. Recipient firms must take a strategic approach to acquiring knowledge and expertise as part of the technology transfer process.
6. 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.
7. Improving firms' capacity to absorb new technologies (their 'absorptive capacity') is essential to enabling firms to take full advantage of new low carbon technologies. Different kinds of absorptive capacity may be required for technologies at different stages of development. For those at an early stage, this is likely to include competencies in related technologies as well as commercialisation skills. Improving absorptive capacity in developing countries requires bilateral and multilateral collaborative initiatives to undertake research, development, demonstration and deployment of low carbon technologies.
8. Intellectual property rights (IPRs) may be a necessary, but not sufficient requirement for successful technology transfer. New, internationally collaborative approaches to low carbon technology research and development may have an important role to play in overcoming IPR issues in future at the same time as contributing to building technological capacity in developing countries. Specific instances of IPR related barriers to acquisition of existing proprietary technologies should be addressed through dialogue on the basis of further work analyzing how other international funds and public/private initiatives have fostered technology transfer covered by IPRs.
9. The interests and power of different actors involved in technology transfer may have an important bearing on the outcome of the transfer process.

Technology transfer and tackling climate change

Low carbon technologies have a central role to play in reducing emissions of carbon dioxide. Most new low carbon technologies are being developed in industrialised countries. However, much of the potential for these technologies to make significant reductions in carbon emissions is in developing countries where fossil fuel consumption is increasing rapidly – particularly in India and China. The migration of global energy systems to lower carbon pathways therefore depends upon the successful transfer and absorption of these low carbon technologies within developing country economies.

This summary provides an overview of the central findings from a UK-India collaborative study that aims to inform intergovernmental discussions about the development and transfer of low carbon energy technologies. In particular, it aims to inform discussions under the UN Framework Convention on Climate Change (UNFCCC) and the Gleneagles Dialogue, on clean energy, sustainable development and climate change. The study focused primarily on technology transfer to India. It is, however, hoped that the insights provided by the study can inform more general discussions on low carbon technology transfer to developing countries.

The study was approached in three stages:

1. Analysis of existing literature on technology transfer and technological change.
2. Analysis of five case studies of low carbon technologies that covered technology sectors at different stages of commercialization – outlined in Table 1.
3. Analysis of the findings of the literature review alongside the findings of the case studies to draw out the key recommendations presented here.

Table 1: Low carbon technologies for case studies

	Stage of technology development		
Sectors	**Pre-commercial**	**Supported commercial**	**Commercial but slow diffusion**
Low-carbon power generation technologies	Coal gasification – particularly IGCC	Biomass – including fuel supply chain issues	Improving combustion efficiency
Network/ infrastructure technologies			
Low carbon end use technologies	LED lighting	Hybrid vehicles	

Based on combined analysis of the findings of the literature review and the case studies, this section presents a summary of key areas for future action in order to facilitate the transfer of low carbon technology to developing countries. It begins by outlining six key issues that this study has highlighted as important when addressing technology transfer. After highlighting several areas that require further research, it then moves on to make recommendations for national and international policy initiatives.

Key considerations when addressing technology transfer

The analysis of the literature on technology transfer and the case studies examined during this study has highlighted a number of key issues that require consideration when addressing technology transfer. These can be summarised around six themes, namely:

1. Technological change and capacity building
2. Levels of integration in the transfer process
3. Supplier/recipient firm strategies
4. Absorptive capacity
5. Stage of technology development
6. Intellectual property rights (IPRs)

These themes are explored below.

Technological change and capacity building

An essential insight highlighted by the literature review is that technology transfer takes place within a broader context of technological change. A useful image is a drop of water (the transferred technology) hitting the surface of a pond. The pond represents the technological capacity of the country receiving the transferred technology. In the long term, it is the ripples that spread across the pond as a result of the transferred technology that are the most important consideration. These ripples represent the impact of the transfer of low carbon technologies on the overall technological capacity of recipient countries. It is this capacity that enables future innovation to take place and that is most likely to ensure long term adoption and development of low carbon technology in recipient countries. Building technological capacity is especially important in developing countries where long term economic development and poverty reduction are central concerns.

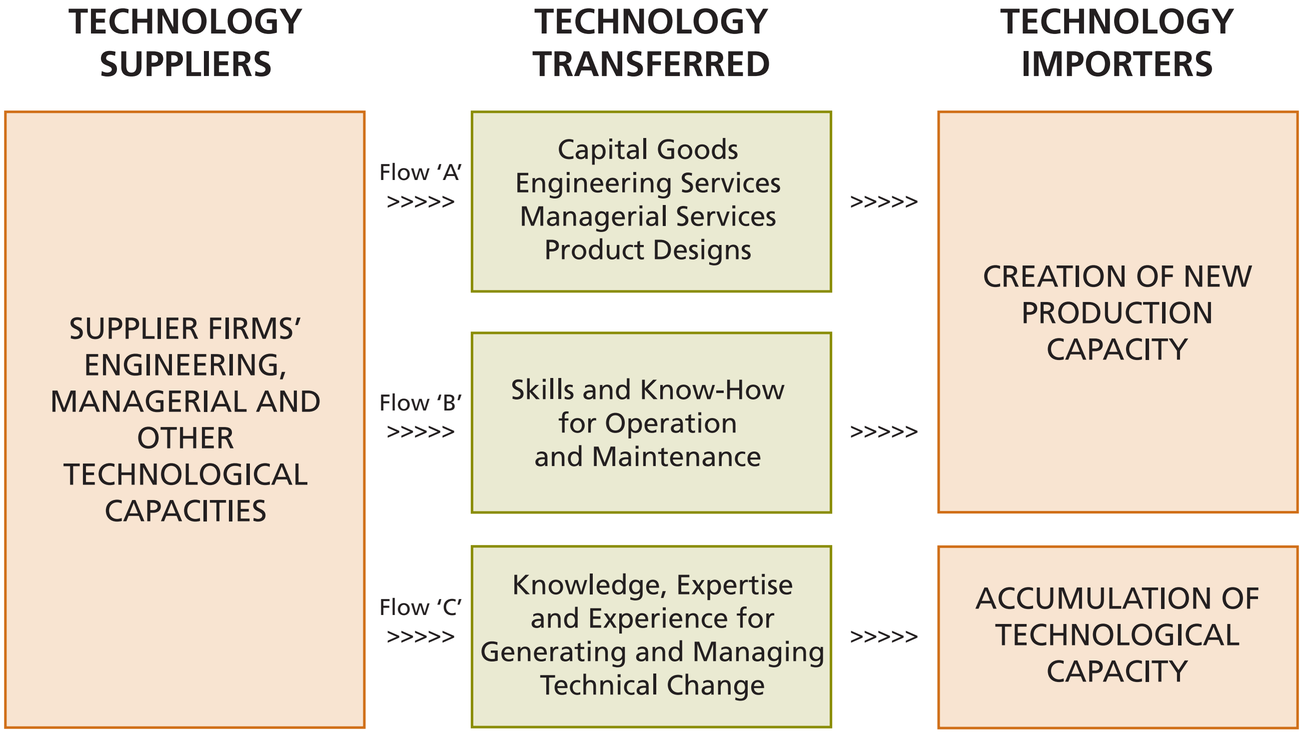
Importantly, the literature review also highlighted the fact that technological change mostly occurs as a series of incremental changes. For example, through a line of continuous incremental innovations over forty years, the Korean steel industry eventually overtook the technological capabilities of more developed economies in this industry.

Another central insight that the literature review highlighted is that there are essentially three different flows that make up the technology transfer process. These are:

A. Capital goods and equipment
B. Skills and know-how for operating and maintaining equipment
C. Knowledge and expertise for generating and managing technological change

As Figure 1 illustrates, Flow C, the flow of knowledge and expertise, determines whether or not technology transfer results in the development of technological capacity within recipient countries. The transfer of knowledge and expertise is therefore an essential part of technology transfer.

Figure 1: The three flows of international technology transfer



Levels of integration in the transfer process

The literature review also highlighted that an important determinant of the impact of technology transfer on the technological capacity of recipient countries is the degree of integration involved. This is the extent to which technology suppliers integrate the different flows involved in the transfer process (flows A-C in Figure 1). For example, the transfer of technology might be highly integrated (e.g. involving some form of turnkey project), or highly disaggregated (e.g. via the acquisition of different items of plant from a wide range of host country equipment manufacturers). These links with host country companies are integral to knowledge generation among local suppliers. They are therefore central to developing technological capacity within recipient countries.

In the case study of hybrid vehicles, for example, it was found that Toyota is manufacturing its Prius hybrid in China. However, even though Toyota has established a joint venture with Sichuan FAW to manufacture the Prius in China, they are taking a fairly integrated approach. It seems that they are importing most of the parts directly from Japan and then assembling the vehicles in China as opposed to manufacturing the individual parts (including, presumably, the hybrid drivetrains) in China. This implies that there might be limited technological capacity building amongst Chinese firms as a result of this arrangement in the short term. In the long term, however, FAW's involvement with hybrid technology could result in the gradual development of technological understanding of hybrid drivetrains so Toyota's decision to enter into a joint venture should still be viewed as a positive step.

The LED case study also highlighted the importance of technological capacity. Indian firms dealing with LEDs currently act only as packaging vendors for international firms that actually manufacture LEDs. This means that Indian firms have not been able to develop any technological capacity in this area. In China, on the other hand, a number of international firms have set up LED manufacturing plants leading to the development of considerable capacity building in this technology amongst Chinese firms.

Supplier/recipient firm strategies

The level of integration in the transfer process discussed above is often a direct result of strategies adopted by supplier firms. The strategies adopted by recipient firms may be equally important to the outcome of the transfer process. Recipient firms that, as part of the transfer process, strategically aim to obtain technological know-how and knowledge necessary for innovation are more likely to be able to develop their capacity as a result. Examination of hybrid vehicles within this study highlighted the example of Hyundai's approach to gaining knowledge and expertise in conventional vehicle manufacture. Managers within Hyundai have proactively taken a strategic approach to acquiring knowledge during the acquisition of foreign technology in order to expand the firm's knowledge base and shift its learning orientation from imitation to innovation.

Absorptive capacity

Absorptive capacity is a firm's ability to absorb new technology. If absorptive capacity is weak amongst recipient firms, they are less able to take advantage of collaborations with international technology suppliers. For example, in the case of LEDs, this study has identified that, whilst individual skills exist in India that are of relevance to manufacturing LEDs (e.g. engineering, material sciences, control electronics), the capacity does not exist to harness these skills to actually manufacture LEDs. This lack of absorptive capacity is a key barrier to LED manufacture in India. The biomass case study also highlighted a lack of capacity in rural areas of India for carrying out maintenance on briquetting machines as a key barrier to the expansion of briquette production in India.

A two-way relationship exists with regard to the absorptive capacity of recipient firms. Absorptive capacity *impacts on* the outcome of technology transfer (higher absorptive capacity implies a higher propensity to develop capacity as a result of transfer). It is also *influenced by* technology transfer, in that transfer activities have the potential to increase recipient firms' absorptive capacity depending on what flows are included in the transfer process (flows of hardware, know-how and knowledge – Figure 1 above).

Developing national systems of innovation in developing countries has an important role to play in developing firms' absorptive capacity. National systems of innovation refer to a country's infrastructure and capacity for undertaking innovation related activities such as R&D. This includes universities as well as networks of R&D facilities and expertise in the public and private sectors. The findings of all five case studies highlighted the fact that, in order to contribute to developing absorptive capacity, R&D activities must include collaboration across public and private sectors – it is within the private sector that most technology transfer activities take place. R&D activities must also include bilateral or multilateral collaboration in order to share lessons learned from experience with new low carbon technologies.

Stage of technology development

The five case studies of low carbon technologies within the study covered technologies at different stages of commercialization (Table 1 above). This is because the barriers to successful technology transfer are likely to vary according to the stage of technology development. For example, the case studies suggest that absorptive capacity is a more significant barrier to technology transfer for technologies at early stages of development than for technologies at later stages of commercialization. There may also be a need to encourage market development for these early stage technologies, as was the case for the LED, biomass and hybrid vehicles cases studies examined in this study.

The stage of technology development highlights an important issue in low carbon technology transfer, namely that transfer may be both vertical (from the R&D stage through to commercialisation) and horizontal (from one geographical location to another). The early stage of development (pre-commercial and supported commercial) of many low carbon technologies implies a need to focus on barriers to both vertical and horizontal transfer. In some cases, such as hybrid vehicles and IGCC examined within this study, this may mean that similar barriers exist to the adoption of low carbon technologies at early stages of development in developed countries as in developing countries. However, where these technologies are owned by companies based in developed countries, generic barriers to technology transfer between developed and developing countries will also need to be addressed.

Intellectual property rights (IPRs) and commercial interests

Technology transfer can impact on the relative commercial standing of technology owners as well as owners of alternative technologies. It may also impact on the relative economic wealth of supplier and recipient countries. The interests and political and economic power of the different actors involved in the technology transfer process are therefore likely to have significant bearing on the barriers to, and outcomes of, technology transfer processes. This may be of particular relevance in the case of low carbon technologies where a wide range of powerful interests stand to be affected. One example is the supply of advanced industrial gas turbines for IGCC. Previous experience shows that suppliers from industrialised countries tend to form alliances with developing country equipment companies such as BHEL. However, in order to maintain competitive advantage, they often retain control over the design and manufacture of the most advanced, high tech parts and/or products (e.g. the first row of turbine blades, incorporating advanced materials, cooling technologies and manufacturing techniques.)

The clearest specific way in which these commercially driven interests appear in technology transfer is in relation to IPR. Protection of IPRs by supplier firms can prevent recipient firms from gaining access to the knowledge necessary to imitate and then innovate on the basis of new technologies. This can act to prevent or inhibit the development of technological capacity within recipient countries. For low carbon technologies, gaining ownership or access to IPRs may therefore be a necessary, but not sufficient requirement for successful low carbon technology transfer. IPR issues are not framed narrowly in terms of access but also address other factors and barriers, such as tacit knowledge and absorptive capacity. As these factors differ by country, technology and sectors, a case by case approach may yield more useful insight in how to address IPR related barriers. For example, in case of LEDs , industry commentators felt that without improved technological capacity in India in this industry, ownership of relevant IPRs would make little difference to India’s ability to manufacture white LEDs. Another example comes from the IGCC case study, where the key barrier to transfer is not ownership of IPRs but rather a lack of knowledge of whether IGCC will work with low quality Indian coal and the overall lack of worldwide successful commercial demonstration of this technology.

In some cases, in the long term, protection of IPRs for some technologies may not be a barrier to developing technological capacity in recipient countries. One possible example arose from the hybrid vehicles case study . Hybrid drivetrains are subject to strict IPRs. But, where they have been supplied to other countries, the firms owning the IPRs have had to train engineers and mechanics in the recipient country in fitting and maintaining the drivetrains. This implies the potential for companies in recipient countries to develop their own technological capabilities in hybrid drivetrains which may also filter through to the wider economy in the longer term.

An important issue that needs to be understood in relation to low carbon technologies is whether IPRs as a barrier to technology transfer might vary in importance according to the stage of technology development or the nature of the technology itself. For example, the stage of development of a particular technology may have implications in terms of the level of private investment already made in a technology and the level of returns that IPR owners need to derive before they are happy to release the IPR.

Furthermore, there is a complex relationship between the strength of the IPR regime in a developing country and the extent to which this fosters technology transfer. There may also be implications of country specific IPR regimes for different types of technologies at different stages of development.

One possible route forward in addressing IPR issues in the context of technology transfer is international collaboration on low carbon technology development. This could be on the basis of international collaborative R&D initiatives on technologies that are at a very early stage of development. As these technologies would be collaboratively developed, the IPRs could be structured to benefit the various partners involved, including with the aim of making the IPR available as a free or low cost public good. This kind of international collaborative R&D based approach has the added benefit of enabling knowledge sharing between collaborators which could aid long term capacity building in developing countries. The idea of a Global Research Alliance was put forward by the UK Commission on Intellectual Property Rights as a way of linking developmental objectives (capacity strengthening and sustainable development) with the more commercially driven IPR framework (UK CIPR, 2005).

In cases of technologies covered by existing IPRs, international initiatives and international funds, such as those established under the Convention, could potentially play a role in facilitating role in negotiating licences or buying down the costs of specific technologies to make them more widely accessible – as has happened in the case of the Montreal Protocol dealing with ozone depletion. Insights from how global private/public partnerships have addressed issues of access to proprietary technologies in other sectors, such as public health, might also provide a fresh approach to the issue of technology transfer.

Knowledge gaps and future research

As well as yielding a number of important findings, this study has highlighted several areas that require additional research. These include[1]:

1. There is a clear need for internationally comparative analysis of technology transfer to developing countries to understand what barriers to technology transfer are country-specific as opposed to generic. For example, this might explain why only 7.3% of CDM projects in India mention technology transfer in their initial project documentation compared to 55.1% in China or 83.3% in Malaysia. Understanding the different issues faced by countries at different stages of development would also be of value. One output would be to propose changes to national approval processes and the CDM project cycle that could advance the transfer of low carbon technologies.
2. Analysis of the technology needs assessment (TNA) studies submitted by countries to the UNFCCC secretariat to compare the perceived needs for technology transfer by project type, and the perceived barriers to technology transfer by country. This would distinguish between projects that include significant technology transfer, those that favour local technology and those that are “indifferent”. Similarly host countries could be grouped into those whose policies favour or discourage technology transfer to see if there is a difference in the barriers they identify, and their proposals to address those barriers.

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[1] The authors would like to thank Erik Haites, Margaree Consultants Inc, Toronto, for his helpful comments and suggestions.

3. Much technology transfer literature focuses on the challenges faced by developing countries in accessing technologies. Additional work may be required to build on the smaller body of work (e.g. Watson, 1999) that analyses perceptions of barriers to technology transfer within firms, governments and other actors in developed countries. The US, for example, believes that barriers to the transfer of low carbon technologies could result from the actions of developing countries and not just the actions by American firms. Further work is planned in the US to analyse this issue. When the results become available in 2006/7, it could be useful to compare any technology-specific barriers with the lessons from this study and the TNAs from developing countries.
4. Valuable work could be done towards the development of specific assessment criteria for international financing, information sharing and R&D mechanisms based on the ability of these mechanisms to contribute to long term low carbon technological development. This should include criteria to assist in the identification of suitable institutional structures within which these mechanisms would be most effective. As part of this, there is a need for ongoing evaluation of various mechanisms designed to deliver R&D collaboration and other technology transfer objectives. This could include, for example, analysis of the Asia Pacific Partnership, FutureGen, and the Carbon Sequestration Leadership Forum.
5. A review of the mandate of the UNFCCC Expert Group on Technology Transfer (EGTT) is envisaged at the Conference of Parties meeting in Nairobi in November 2006. Since the EGTT was established, several international bodies and initiatives, such as the World Bank, IEA and Asia-Pacific Partnership, have increased their work on low carbon technology and innovative financing of these. This presents an opportunity to study how the EGTT can work with these other initiatives in its future work.
6. Further analysis needs to be done of IPR issues within the context of specific technologies and problems with the aim of developing an approach that brings together relevant stakeholders to address specific problems on a case by case basis. An area with considerable potential highlighted by this study is the scope for bilateral and multilateral collaboration on R&D for new low carbon technologies to help overcome IPR barriers.
7. Examining lessons learnt from successful examples of technology transfer (such as wind turbines in India) would be complementary to the analysis carried out in this report of technologies that have not yet been successfully transferred.
8. More detailed analysis of the specific technologies examined in this study over a longer time period than was possible during this study would be valuable. This would enable consultation with a wider number of actors and stakeholders and the development of more concrete actions that could be taken to facilitate transfer. The potential for developing underground coal gasification in India also warrants future detailed investigation.
9. The potential for integrating PV with LED lighting in rural areas that was highlighted in this study points towards an important area that requires focussed research. This would involve the analysis of specific development oriented technology transfer such as that facilitated by NGOs. This could be linked with a focus on matching the needs of developing countries with technology transfer activities.

Government influence on technology transfer

Governments in both recipient and supplier countries have a key role to play in facilitating low carbon technology transfer. There are three main motivations for government involvement:

1. Reducing carbon emissions contributes to reducing the economic, social and environmental costs of climate change.
2. Many low carbon technologies are currently at pre-commercial or supported commercial stages of development and may therefore require some form of government support to facilitate their wider adoption.
3. Early investment in technologies that are likely to be of more domestic importance in future may be worthwhile. Governments might also wish to gain competitive advantages in new technologies with a view to developing future export markets.

Government involvement is usually designed to overcome barriers to low carbon technology transfer. However, unless it is undertaken with proper awareness of the full range of issues highlighted in this summary, government involvement can also introduce new barriers to technology transfer. Government involvement requires initiatives at both the national and international level.

National level government initiatives

Domestic policy environment: Clearly defined and enforced domestic carbon emissions policies are integral to encouraging low carbon technology transfer. For example, the hybrid case study highlighted the fact that China's recent introduction of a strict policy limiting carbon emissions from new vehicles, together with processes for enforcing this policy, has led to Toyota to enter into a joint venture with a Chinese company to manufacture hybrid vehicles in China.

National systems of innovation: As mentioned above, national systems of innovation are integral to developing absorptive capacity among national firms. Governments have a clear role to play here in supporting and encouraging R&D initiatives, facilities and networks across both the public and private sectors. This will also benefit from governments' engagement with bilateral and multilateral information sharing activities such as the UNFCCC's TT:CLEAR initiative.

Intellectual property rights (IPRs): Insufficient protection of IPRs can be a deterrent to international firms transferring technologies. A well defined and enforced national IPR legal structure is therefore important to encourage transfer of some low carbon technologies.

Political stability: Political instability in some countries might act as a deterrent to foreign investors, particularly where new commercial technologies are concerned.

Enabling business environment: As well as political stability, there is also a linked need to focus on creating an enabling economic, social and business environment to encourage technology transfer. For example, certain large power station equipment manufacturers interviewed during this study highlighted a number of problems with doing business in India that made them reticent to engage in technology transfer activities.

Infrastructure: National governments have an important role to play in ensuring that the appropriate infrastructure is in place to foster technological development. For example, the intermittent or non-existent supply of electricity in many rural areas of India was cited as a key problem in rolling out biomass technologies in India.

Creating markets: Three of the four pre-commercial and supported commercial technology case studies (LEDs, biomass and hybrid vehicles) highlighted a need for national policy intervention to help create domestic markets for these technologies. As well as a clearly defined domestic policy environment as outlined above, this could also include government procurement initiatives and targeted information campaigns (aimed at, for example, the construction industry) that promote the use of these technologies.

Access to finance: For some smaller scale financing issues, there may be a role for national government intervention. For example, the biomass case study highlighted how investors in the technology often had problems with cash flow due to the seasonal nature of biomass availability. They were unable to overcome this by borrowing as biomass is traditionally viewed as waste and banks are unwilling to lend against it, even though banks are willing to lend against briquetting machinery which is viewed as a capital asset. Governments may therefore wish to intervene to try to address such misunderstandings in relation to novel new low carbon technologies.

International government initiatives

In the case of climate change, extensive institutional arrangements and funding provisions exist pursuant to the Convention to provide a framework for further action with the Expert Group on Technology Transfer (EGTT) play a focal role in this process. Since the Gleneagles Summit the role of other multilateral institutions such as the World Bank and IEA has also come to the fore. Although outside of the UNFCCC/Kyoto process, a number of supportive initiatives have also been established to further international technology development and transfer, such as the Asia-Pacific Partnership (Hoehne et. al.2006).

Collaborative R&D and technology demonstration and diffusion: One of the most important issues that this study has highlighted is the need for bilateral and multilateral collaboration between developed and developing countries on R&D, demonstration and diffusion (RDD&D) of low carbon technologies. This is central to developing technological capacity in developing countries through sharing knowledge and experiences in relation to specific low carbon technologies. For example, industry respondents to this study cited a lack of transparent information on international experience with coal based Integrated Gasification Combined Cycle (IGCC) power generation technologies as one key barrier to the use of this technology in India. This type of concern was also shared by briquetting companies who saw a lack of communication and information sharing as a key barrier to technological development. The biomass case study also demonstrated how collaborative R&D between an Indian briquette manufacturer and a Dutch University led to specific technological improvements. The LED case study also highlighted collaborative R&D as the central requirement for developing technological capacity in this industry in India.

The International Energy Agency's (IEA) implementing agreements provide one potential vehicle for achieving collaborative RDD&D, either bilaterally or multilaterally. There is, however, a need to revise the focus of the implementing agreements so that as well as fostering information sharing they are also able to deliver more output oriented projects as well as demonstration projects. They also need to focus on engaging developing countries. Energy R&D carried out under the European Union's Framework Programme could also provide a potential funding vehicle for collaborative R&D that includes developing countries such as India.

Intellectual property rights (IPRs): As noted above, lack of access to IPRs may act to prevent recipient countries from gaining access to the knowledge necessary to improve their technological capacity. There may therefore be a role for bilateral and multilateral government collaboration in R&D for low carbon technologies that are at very early stages of development with public ownership of IPRs and in fostering targeted initiatives that aim to bring together relevant stakeholders to address specific IPR problems. The potential for new kinds of global public/private partnerships, drawing on the experiences of global arrangements that have been agreed internationally to support access to anti-retroviral drugs for low income countries, have not been fully explored in the climate context. More detailed work analyzing the potential application of these approaches to the climate context, bearing in mind the unique features of climate change, might create a fresh approach to discussions.

High costs of new technologies: Many low carbon technologies are new or still being developed and therefore entail higher costs for acquiring and/or using/operating them. National governments as well as international governmental bodies may therefore play a role in financing initial uptake of these technologies. International financing initiatives to date have included the Global Environment Facility (GEF) and the Clean Development Mechanism (CDM).

Need for private sector involvement: Government intervention in technology transfer must recognise the central role that private investors play in the transfer process. Failure to engage with private companies has been a key issue in hampering the long term success of government led initiatives such as the Japanese Green Aid Plan.

Information barriers: Poor knowledge of available technologies and financing opportunities reduces demand for new technologies. Bilateral and multilateral information sharing initiatives such as TT:CLEAR have an important role to play in overcoming these barriers. The success of such initiatives does, however, rely on national governments to properly engage with them, for example through the submission of technology needs assessments which are a central part of the TT:CLEAR initiative. As mentioned above, information sharing was seen as a central barrier to the transfer of LED and IGCC technologies. It was also seen as important for helping thermal power plants and boiler manufacturers to optimise the performance of thermal power plants in India.

Markets for carbon: Creating prices for carbon through economic instruments has the potential to enable the carbon reduction benefits of low carbon technologies to be reflected in the market. Although the EU ETS and CDM are playing an important role in providing a price signal, globally the incorporation of the social costs of carbon is still at an early stage. The inclusion of the social cost of carbon emissions within market prices will support the financing of some low carbon technologies by helping to make these more competitive relative to less environmentally sound technologies. However, there are many institutional and regulatory barriers that also need to be examined if the full suite of low carbon technologies is to be taken up in developing countries.

Under the Kyoto Protocol to the UNFCC, the Clean Development Mechanism (CDM) is provides a market price for carbon in the context of developing countries. It allows investors from industrialised countries listed in Annex I of the Convention to generate Certified Emissions Reductions (CERs) by investing in projects that reduce greenhouse gases in developing countries. Current analysis of technology transfer aspects of CDM projects show that some technology transfer is happening in developing countries but perhaps less than might be expected. Countries can try to rectify this by focusing on the kinds of technology they wish to promote and through policy towards CDM projects and programmes. The low number of registered CDM projects that intend to transfer technology in India as compared to other developing countries such as China suggests, however, that there may be some India-specific barriers to technology transfer via the CDM. Examination of India’s CDM national approval processes in comparison with those of other countries, and the extent to which these might address this problem requires further study.

Multilateral institutions such as the World Bank have a particularly important role to play. The Bank has recently outlined some additional multilateral finance mechanisms that could be implemented. Following Gleneagles, the World Bank and Regional Development Banks are working on an energy investment framework that aims to address cost, risk, institutional and information barriers to scaling up public and private investment in low carbon technology.

Options that have been put forward include a Clean Energy Financing Vehicle that would blend carbon finance and capital grants for highly efficient technologies. They also include proposals to help upgrade the efficiency of existing capital equipment, to provide venture capital, and to develop candidate projects for financing via other mechanisms. As outlined above, the success of such mechanisms will depend on a range of domestic factors such as absorptive capacity, supportive institutional and regulatory frameworks as well on the availability of the technologies in question. There is also an inherent need to ensure that any technology transfer activities that are financed under such mechanisms are aimed at moving beyond just the demonstration of low carbon technologies. Rather they need to be carefully structured to respond to the issues outlined in this report with the explicit aim of contributing to long-term low carbon technological capacity building in developing countries.

1. Introduction

There is growing awareness that a transition to a sustainable energy economy is one of the main challenges facing us in the 21st Century. One of the main drivers for this transition is climate change. The evidence that human-induced climate change is already underway has strengthened in recent years. This has been coupled with indications that the impacts will be more serious and far-reaching than those suggested by early predictions.

The scientific consensus about climate change has led to an increasing emphasis on low carbon energy technologies to mitigate emissions of carbon dioxide, which is the most important greenhouse gas. Both governments and private sector organisations have engaged in new programmes to develop and deploy these technologies. While a number of these technologies are already at an advanced stage in the commercialisation process, many others are still being developed and tested. Furthermore, the uptake of many low carbon energy technologies has been slow because they are less economically attractive than conventional technologies.

Most new carbon abatement technologies are being developed in industrialised countries. However, much of the potential for these technologies to make significant reductions in emissions is in developing countries where fossil fuel consumption is increasing rapidly – particularly in India and China. Thus, the migration of global energy systems to lower carbon pathways depends upon the successful transfer and absorption of these low carbon technologies within developing country economies.

At Gleneagles in July 2005, the G8 highlighted the importance of strengthening technology cooperation to develop low carbon energy options. Many developing countries pressed for a new approach to international cooperation in the area of clean energy technologies. As a follow-up to this, the UK Government and the Government of India have decided to collaborate on a study to assess the barriers to the transfer of low carbon energy technology between developed and developing countries.

This is the final report for this study. The aim of the study is to facilitate technological co-operation between developed and developing countries. It is envisaged that the study will help to inform intergovernmental discussions about the development and transfer of low carbon energy technologies. Of particular importance are discussions under the auspices of the UN Framework Convention on Climate Change (UNFCCC) and the Gleneagles Dialogue, clean energy and sustainable development and climate change. The study focuses primarily on technology transfer to India. It is, however, hoped that the insights provided by the study might provide the basis for informing more general discussions on low carbon technology transfer to developing countries.

The study was approached in three stages. Firstly, a review of the literature on technology transfer was undertaken. This provided an overview of key insights arising from the literature on technology transfer. In particular, the analysis carried out during this review focused on building upon the literature on technological change and technology transfer in a way that highlighted a series of specific considerations for low carbon technology transfer. The results of the literature review are presented in Section 2 of this report. The study then examined five case studies of low carbon technologies that covered different sectors and different stages of commercialisation. The case studies that were examined are outlined in Table 1.1 and are presented in detail in Section 3 of this report. For each case study, Table 1.1 also provides an indication of which of the partner organisations that collaborated on this study were responsible for the analysis. The case study findings were presented to a number of industry representatives and academic researchers at a workshop in New Delhi in September 2006 in order to elicit industry feedback on the findings and ensure that the analysis properly reflected people's experience of technology transfer in India. The final stage of the study, once the case studies were complete, was to analyse the findings of the literature review alongside the findings of the case studies. This enabled recommendations to be made on different actions that can be taken in order to better facilitate the transfer of low carbon technologies to developing countries. These recommendations are presented in Section 4 of this report.

Table 1.1: Low carbon technologies for case studies

	Status of technology		
Sectors	**Pre-commercial**	**Supported commercial**	**Commercial but slow diffusion**
Low-carbon power generation technologies	Coal gasification including IGCC (SPRU)	Biomass including fuel supply chain issues (TERI)	Improving combustion efficiency (TERI)
Network/ infrastructure technologies			
Low carbon end use technologies	LED lighting (TERI)	Hybrid vehicles (SPRU)	

2. Literature review

As part of this study, this literature review aims to provide a brief overview of some of the key issues related to low carbon technology transfer to developing countries. It begins with a contextual outline of the need for low carbon technology transfer and the specific need for such technology in India. It then goes on to discuss how processes of technological change are understood to occur, and then to define and explore processes of technology transfer. Some of the barriers that might prevent successful technology transfer are then discussed. The literature review concludes with a summary of nine key issues that this study will then explore through several technology case studies.

2.1 The need for low carbon technologies in India

India is the second most populous country in the world. Occupying 2.4% of the world's geographical area it is home to nearly 17% of the global population (Jung et al. 2005). With 250 million people living on less than US$1 per day and about 550 million people without access to electricity (Jung et al. 2005) India's per capita contribution to global greenhouse gas (GHG) emissions is relatively low at present. In 2002, for example, India's per capita carbon emissions (tonnes of carbon per capita) from fuel combustion were estimated at 0.97 compared to global per capita carbon emissions of 3.89, or the EU's 8.41 and US' 19.66 (OECD and IEA 2004, TERI 2006b, p.xiii). This is also reflected in India's relatively low per capita ecological footprint of 0.8 global hectares next to 4.7 global hectares in Europe and 9.7 in the US (Worldwatch 2006, p.16). India is, however, a rapidly developing nation and continued population and economic growth is likely to drive significant increases in future energy demand and associated carbon emissions.

In line with its economic development, India has a rapidly expanding middle and higher income population. As the country works towards the eradication of poverty under its Tenth Five Year Plan (2002-7) and the UN's Millennium Development Goals (MDGs), it is hoped that the standard of living in the country will continue to increase. Whilst the eradication of poverty and achieving real improvements in the standard of living is of utmost importance for India, this also implies important future challenges as demand for energy continues to rapidly increase. Between 1990 and 2004, for example, India saw an 88% increase in total carbon emissions compared to increases of 67% in China, 19% in the US and 6% in Europe (Worldwatch 2006, p.9). Assuming sustained economic growth and continued reliance on domestic coal, business as usual predictions suggest economy-wide energy related carbon emissions in India will increase to 688 million tonnes by 2030 (ALGAS 1998) compared to 204 million tonnes in 1994 (GoI 2004, TERI 2006b, p.55). Total commercial energy demand is projected to increase to 7.4 times its current rate by 2031/32 (TERI 2006b, p.2). The adoption of low carbon technology in India therefore has an important potential role to play as part of global efforts to mitigate climate change.

Due, amongst other things, to its heavy reliance on agriculture, India is one of the nations likely to be most heavily effected by future climate change. This provides additional impetus for India to engage with global efforts to reduce GHG emissions. India has ratified the UNFCCC, but, as a developing country, has no obligations under the convention to reduce GHG emissions. It has, however, opted to introduce a number of policies aimed at reducing carbon emissions. Whilst these policies have had some success (Jung et al. 2005), Indian industry is still considerably more energy intensive than many developed countries (Chandler et al. 2002).

India has large domestic coal reserves which currently meet 52% of its domestic energy needs (Jung et al. 2005). Coal production in India grew to more than 328 million tonnes in 2001/02 rendering it the third-largest producer of coal after China and the USA. The increasing trend in the use of coal in India is set to continue into the future with an estimated doubling of domestic coal production and increasing coal imports over the next 30 years (TERI 2006b, p.2). Indian coal also has high levels of impurities thus requiring additional energy for transport and processing. India has seen marked success in initiatives aimed at transferring certain renewable energy technologies, especially wind and solar power (IPCC 2000, p.425). But with the abundance of domestic coal reserves, coal is likely to remain the mainstay of the Indian energy sector making the development of advanced clean coal technologies a central concern (TERI 2006b, p.1).

There is also high dependence on biomass, for example from trees and woody shrubs, for domestic energy production in India, especially in rural areas (Jung et al. 2005, TERI 2006b). This can represent a carbon neutral source of energy as the carbon released during combustion is equal to that sequestered by the biomass during its growth and, once released during burning, may subsequently be sequestered by other woody biomass. As with many other natural resources that are traditionally communally managed, however, forests and woodlands are subject to increasing pressures, such as drives towards privatisation, which can erode the traditional management regimes that previously ensured their sustainable management (Lovett et al. 2006). The breakdown of traditional management regime can lead to unsustainable levels of biomass extraction meaning this biomass no longer represents a carbon neutral source of energy. This highlights the need for adoption of advanced biomass technologies in India.

Due to its reliance on coal and biomass, energy production in India is very carbon intensive at present. Another concern in terms of carbon emissions in India is its transport sector. India's transport sector is predicted to show the highest growth in energy demand out of any sector over the next 30 years (TERI 2006b, p.2). Introducing policies and technologies that can mitigate carbon emissions related to this sector are therefore also important. As India's energy demands increase in future, minimising carbon emissions will represent key challenges for the nation and the broader international community. Low carbon technology transfer therefore has a high potential role to play in addressing these challenges.

The UNFCCC has introduced an initiative known as TT:CLEAR as part of its technology sub programme. Under Article 4.5 of the Convention, the technology sub programme has the main goal of improving the flow of, access to and quality of information relating to the development and transfer of environmentally sound technologies (ESTs). TT:CLEAR essentially acts as a clearing house for information on the availability of environmentally sound technologies. Activities currently being undertaken as part of TT:CLEAR include (UNFCCC 2005):

- Working to develop current understanding of enabling environments for technology transfer, which includes cooperating with business, industry and public–private partnerships to organise sector-specific workshops.
- Developing innovative financing options for increasing developing countries' capacities for undertaking technology needs assessments and developing project proposals.
- Exploring possible ways to enhance synergy with other global conventions and processes where technology transfer and capacity-building for technology transfer are considered, including the Convention on Biological Diversity (CBD), the United Nations Convention to Combat Desertification, and the Montreal Protocol.
- Working to develop innovative options to finance the development and transfer of technologies.
- Working to understand key issues relating to technologies for adaptation to climate change.

A central objective of TT:CLEAR has been to work with developing countries (non-Annex I Parties from the perspective of the UNFCCC) to produce individual Technology Needs Assessments. These are country-driven assessments of perceived technological needs for mitigating and responding to climate change. Whilst India has provided some information on perceived technology needs to the UNFCCC as part of its initial national communication, it has not yet produced a full Technology Needs Assessment (UNFCCC 2006).

2.2 Processes of technological change

The aim of encouraging the transfer of low carbon technology to developing countries is to assist developing countries in their efforts to reduce carbon emissions by adopting low carbon technologies. This adoption process has two aspects – the development of new innovative capacity in low carbon technologies and the diffusion of these technologies in the market. In order to understand how transferred low carbon technology is likely to impact overall on the technology used in developing countries, it is first necessary to briefly outline how technological change occurs.

2.3 Individual and aggregate level technological change

Gallagher (2006) highlights Freeman's (1992) identification of four types of technological change:

1. Incremental innovations
2. Radical innovations
3. Changes of technological systems
4. Changes of techno-economic paradigm

This list can usefully be divided into two types of individual technological changes and two different aggregations of multiple technological changes (Bell 2006, personal communication). The two types of individual technological changes are incremental and radical innovations. Incremental innovations are seen as occurring more or less continuously as industries strive to improve quality, design and performance. This emphasises the importance of learning by using, doing and interaction between suppliers and users of technology (Lundvall 1988, Freeman 1992, p.77). Radical innovations, on the other hand, occur when new inventions emerge, often as a result of deliberate R&D that leads to a radical departure from previous production practice. An example of this could be hybrid cars. Whilst hybrid cars utilise two existing technologies, the internal combustion engine and battery-driven electric motors, the combination of these technologies in the production of a new, significantly more energy efficient vehicle could be seen as representing a radical innovation (Gallagher 2006).

The two different categories of aggregated changes are changes in technological systems and changes in the techno-economic paradigm. Changes in technological systems occur when a cluster of innovations impact on several branches of an economy. An example would be the sort of systems changes that might be observed as a result of the widespread introduction of hydrogen fuel-cell vehicles. The constellation of innovations that lead to the widespread application of synthetic materials in the mid 20th century would be another example of changes in technological systems. Changes in the overall techno-economic paradigm, on the other hand, reflect a more extensive impact where innovations are pervasive enough to affect every other branch of an economy. Examples include the impact of advances in information technology over the last two decades (Gallagher 2006) and innovations such as steam and electricity. An important aspect of both these types of aggregate level technological changes is that they could result from either a series of incremental or radical innovations, or a combination of both. This makes it inherently difficult to differentiate between the two categories of aggregated technological changes on the basis of *ex ante* empirical observation (Bell 2006, personal communication). It is, perhaps, only possible to distinguish between them on the basis of historical observations. The pervasive impact of ICT, for example, was probably not predictable when computers were first developed.

2.4 Leapfrogging

One idea that attracted a lot of attention in the past is the concept of 'leapfrogging' as outlined by Goldemberg (1998). The idea of leapfrogging is simply that developing countries can leapfrog over the resource and energy intensive steps to industrialisation taken by developed countries by adopting modern, energy efficient technologies. Rather than going through a series of incremental technology changes, they could move straight forward into adopting the most advanced available technologies. Leapfrogging could occur at the level of both processes and products, such as the adoption of energy efficient light bulbs powered by photovoltaic solar panels (Gallagher 2006). It is also argued that leapfrogging can help to avoid the long term environmental costs associated with industrial activities if a developing economy moved directly to the use of more advanced, low polluting technologies. This would contrast with most developed countries whose industrial development initially relied heavily on high polluting technologies with cleaner technologies being introduced much later in the cycle of industrialisation.

Gallagher (2006) identifies two types of leapfrogging depending on the level of technology adopted by developing countries. The first type involves skipping generations of technology such as the widespread adoption of mobile phones in China prior to the common availability of landlines. This example is returned to further below. The second type of leapfrogging involves developing countries leaping further ahead of developed countries to become technology leaders. The Korean steel industry provides an example of this second type of leapfrogging. Here, the Korean steel industry not only leapfrogged up to current levels of advanced technology but eventually developed beyond the technological capabilities of other steel producing nations to become technology leaders in the industry.

The concept of leapfrogging, however, has attracted a large degree of scepticism as the empirical evidence on technological change tends to lend more support to the idea of incremental technological change (Freeman 1992, p.77). Returning to the example of the Korean steel industry, the process that lead to Korea overtaking the technological capabilities of more developed economies in this industry lasted nearly forty years and consisted of a long line of continuous incremental innovations (M. Bell 2006, personal communication). Accordingly, the literature on technology transfer to developing countries emphasises the necessity of a more incremental, or assimilative process in ensuring the generation of new, long-term technological capacity in developing countries. One highly cited focus for analysis on issues of technology transfer, for example, has been the case of the Asian economic boom, or Asian Tiger Economies. Here, the available evidence does not tend to support a notion of leapfrogging. Instead it lends itself better to supporting the more evolutionary idea that underpins assimilation theories of technology transfer (as discussed below) with the success of Asian economies being the result of a difficult, long-term technological learning process (Nelson and Pack 1999). Gallagher (2006) examines the case of US-Chinese joint ventures in the Chinese automotive industry and demonstrates that here also no leapfrogging occurred until the late 1990s. Gallagher cites the need for recipient countries to go through a process of developing the capabilities to produce or integrate advanced technologies by themselves before any leapfrogging is possible. This emphasises the fundamental necessity for developing countries, as part of the technology transfer process, to develop capacities in terms of the knowledge necessary for long term technological innovation. This issue is explored in more detail below.

It is worth noting that, whilst leapfrogging may have been widely discredited in terms of its ability to reflect the reality of processes of technological change, there is another way of interpreting the idea of leapfrogging in the context of low carbon technology transfer that might provide an attractive potential goal. This relates back to Gallagher's (2006) first type of leapfrogging referred to above where generations of technology are skipped, as in the widespread adoption of mobile phones in China prior to widespread adoption of land lines. In the context of low carbon technologies, leapfrogging in this sense would essentially involve developing economies moving consciously to adopt the most advanced available low carbon product technologies. So, for example, all new housing stock could be built to the highest possible standards of energy efficiency and integrate micro-generation technologies such as solar and wind. Combining this with technologies such as solar hot water systems and energy efficient electrical goods may have the potential to greatly reduce future energy demands and associated carbon emissions. It is likely that this would involve a high degree of government engagement aimed at providing effective incentives to catalyse such a scenario. Nevertheless, the need for rapid adoption of low carbon technologies may well be seen as a desirable outcome in terms of reducing carbon emissions. It might also enable the development of an industrial economy already well adjusted to meet the low carbon requirements and associated economic perturbations that could characterise the global economy under future climate change scenarios.

The idea of 'leapfrogging' onto a low carbon pathway to development highlights the centrality of understanding timescale as an issue in technological change. Bell (in press) emphasises that technological learning is a dynamic process that happens over time. Little empirical work, however, has been done to date that adequately addresses the different time-scales that can be involved in technological learning or why such differences exist. Bell therefore asserts that a new focus is required within the research and funding of research in this area in order to develop a better understanding of time-centred issues in technological learning. This is important from the point of view of strategic management in terms of knowing how quickly returns might be seen from investments in skills and knowledge development, which, as is explored in more detail below, are central to developing new technological capacity in developing countries.

Having discussed various ideas of technological change, in which transferred technologies play a part, we now turn to focus directly on the idea of technology transfer. This includes discussion of different types of technology transfer, the kind of mechanisms that are used in order to undertake such transfer and the various barriers that might exist to the transfer of low carbon technologies.

2.5 Technology transfer

The term 'technology transfer' can mean many different things. It has been defined and measured in many different ways and assessed against a wide range of criteria (Schnepp et al. 1990, p.2). Technology transfer has therefore attracted attention from a broad range of perspectives including business, law, finance, microeconomics, international trade, international political economy, environment, geography, anthropology, education, communication, and labour studies (IPCC 2000, pp.16-17). This has produced an equally wide range of frameworks and models of technology transfer, but to date no overarching theories have emerged. In his review of research and theory on technology transfer, Bozeman (2000, p.627), states that:

> "In the study of technology transfer, the neophyte and the veteran researcher are easily distinguished. The neophyte is the one who is not confused. Anyone studying technology transfer understands just how complicated it can be."

Nevertheless, there are several key definitions, distinctions and insights that have emerged from the broader literature on technology transfer that are relevant when considering the transfer of low carbon technologies between developed and developing countries.

Schnepp et al. (1990, p.3) define technology transfer as "… a process by which expertise or knowledge related to some aspect of technology is passed from one user to another for the purpose of economic gain." Technology transfer is a term that relates to any type of technology, not just low carbon technology. Within the current climate of environmental concern, however, the economic gain that Schnepp et al. speak about in their definition of technological transfer can be interpreted in a wider context that includes the economic benefits provided by the environment as a source of natural resources that feed into the economic process and a sink for emissions that result from the economic process. In the case of the transfer of low carbon technology, these economic benefits are associated with the mitigation of the future costs associated with climate change (see Ockwell and Lovett 2005). As with any technology transfer, however, low carbon technologies may also yield financial benefits to the companies involved in the transfer process.

2.6 Types of technology transfer

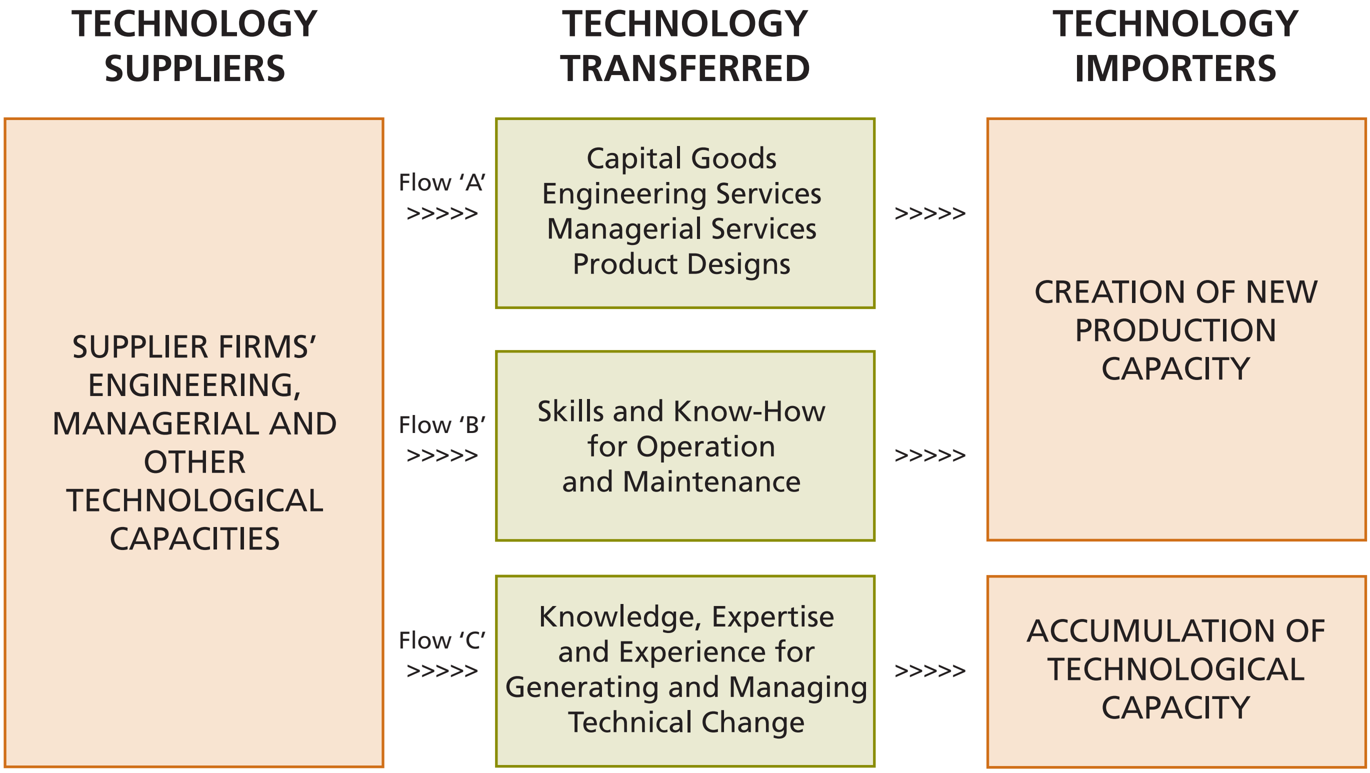
One important distinction in the literature on technology transfer is between vertical technology transfer (the transfer of technologies from the R&D stage through to commercialisation) and horizontal technology transfer (the transfer from one geographical location to another). Schnepp et al.'s (1990, p.3) definition quoted above refers to horizontal technology transfer. In reality, this distinction between horizontal and vertical technological transfer is unlikely to be so distinct. In the case of low carbon technology transfer between developed and developing countries, which this study is primarily interested in, there is likely to be elements of both. The transfer of technology from one country to the next represents horizontal transfer. But this transfer may also involve a degree of vertical transfer as many low carbon technologies are currently pre-commercial or supported technologies and undergo development towards commercialisation within the new country context.

Technology transfer may also take the form of internalised or externalised transfers by trans-national companies (Ivarsson and Alvstam 2005). Internalised transfers usually form part of a package of foreign direct investment (FDI) where access is provided to a range of technological, organisational and knowledge assets as well as marketing experience and brand names. Externalised transfers are those made to firms outside of the direct ownership or control of the company transferring the technology. This occurs through initiatives such as minority joint ventures, franchising, distribution agreements, sales of capital goods, licenses, sub-contracting, or original-equipment-manufacturing arrangements. Research and development (R&D) can also generate beneficial external linkages within recipient countries but is dependent on the availability of adequate R&D facilities.

2.7 The centrality of knowledge transfer

A key insight to emerge from the literature is that technology transfer is not just a process of capital equipment supply from one firm to another. Comprehensive technology transfer also includes the transfer of skills and know-how for operating and maintaining technology hardware, and knowledge for understanding this technology so that further independent innovation is possible by recipient firms (Bell 1990). This flow of technology between technology supplier in industrialised countries and technology importers in developing countries is illustrated in Figure 2.1 as conceptualised by Bell (1990).

Figure 2.1: The technological content of international technology transfer



Source: Bell (1990)

Figure 2.1 can be broken down into two stages. The first stage is the supply of technology to recipient countries. As Figure 2.1 illustrates, this can be split into three separate technology flows, namely:

A. Capital goods and equipment
B. Skills and know-how for operating and maintaining equipment
C. Knowledge and expertise for generating and managing technological change

The second stage involves building on these three technology flows to develop new capacity within the recipient country. This capacity consists of both new production capacity and new technological capacity. It is this new capacity for production and technological innovation that is most likely to ensure successful technology transfer and long term advances in technology development in recipient countries (Worrell et al. 2001).

Within the economics literature there is a divide between two different schools of thought concerning how technology transfer translates into new technological capacity within recipient countries. Both schools of thought accept the long term importance of knowledge for developing new capacity within technology importing countries. They are, however, divided as to how this knowledge is generated. Traditionally, commentators tended to base their ideas around neo-classical 'accumulation theories' of technology transfer (Nelson and Pack 1999, Ivarsson and Alvstam 2005). This approach assumed that the learning that underpins capacity building within developing countries automatically followed capital investments. In this view, capacity building in developing countries would be encouraged by increased capital investment facilitated, for example, by a more competitive economic policy environment.

More recently, however, 'assimilation theories' of technology transfer have tended to gain greater support from the analysis of empirical evidence on technology transfer (Nelson and Pack 1999, Worrell et al. 2001, Ivarsson and Alvstam 2005). Assimilation theories take a more evolutionary view of the technology transfer process and stress that learning is a key factor in making capital investments successful. Knowledge transfer therefore becomes central to ensuring that technology supply leads to successful capacity building in recipient countries. Whilst accumulation theories would focus only on the supply of flow A in Figure 2.1, assimilation theories highlight the essential role of flows B and C. The availability of knowledge as part of the technology transfer process is not, however, enough on its own. Assimilation theorists also stress the importance of risk taking and entrepreneurship on behalf of firms in recipient countries to facilitate learning. The generation of inter-firm linkages through regular local production by foreign operators is also seen as integral to knowledge generation with external linkages resulting in technological upgrading among local suppliers. In this sense, external technology transfers are more likely to generate new technological capacity in recipient countries than internal transfers which might simply exploit low labour costs (Ivarsson and Alvstam 2005). Competing in international export markets may also be an issue here in driving awareness of international standards and contracting with developed country firms who demand and facilitate high standards (Nelson and Pack 1999).

As well as highlighting the importance of using local suppliers, the assimilation view of technology transfer implies that all three flows of technology illustrated in Figure 2.1 (flows A, B and C) are important for enabling recipient countries to develop their own technological capabilities. This has been problematic in the past as the predominant type of technology supply to developing countries has tended to be capital goods and equipment as characterised by flow A in Figure 2.1 (Bell 1997, Watson 1999). For example, a database of international aid to China's energy sector compiled by Evans (1999a) showed that 80% was focussed on funding construction of new thermal and hydro-power plants. The primary aim of this aid was to finance the export of equipment supplied by foreign firms (Watson 1999). Saad and Zawdie (2005) also point out how the transfer of plant and equipment to developing countries have often been based on 'turnkey' and 'product-in-hand' contracts that focused on boosting industrial growth rather than fostering innovation. They also highlight the fact that restrictive terms of contracts between trans-national companies and firms based in developing countries have limited the scope for fostering innovation through 'reverse engineering'. Moreover, technology transfer has often conformed to a linear model of relationships between technology suppliers and importers, which precludes knowledge sharing across the economic spectrum. From the perspective of encouraging the long-term adoption of low carbon technologies in developing countries, it is therefore important that technology transfer includes flows of skills and knowledge as well as capital goods and equipment. Successful examples of purely knowledge-based technology do exist. For example, a joint initiative between China and the Netherlands which established an intelligent transport systems training centre in China is reported to have made a promising initial impact on tackling congestion in Shanghai (van Zuylen and Chen 2003).

As highlighted by the IPCC's (2000, section 1.4) report on technology transfer, this increasing awareness of the centrality of developing knowledge-based capacity within developing countries has led many people to feel uncomfortable with the term "technology transfer". They argue that it encourages a view of technology as an object and transfer as a one off transaction that maintains dependency on host country suppliers. Suggested alternative terms include 'technology cooperation' (Heaton et al. 1994, Martinot et al. 1997), 'technology diffusion' (Grubler and Nakicenovic 1991) and 'technology communication' (Robinson 1991).

These tend to emphasise technology transfer as a more dispersed, uncoordinated process that occurs over time with a central emphasis on a two-way relationship between technology suppliers and importers (IPCC 2000, Section 1.4).

2.8 Measuring technology transfer

An important point to note is the inherent difficulty of measuring technology transfer (Bozeman 2000). This is particularly true of skills and knowledge within the technology transfer process. Indicators such as the level of FDI might, for example, be used to give some indication of the extent of capital goods and equipment being supplied to developing countries (although, as Chung et al. (2003) show, FDI does not necessarily imply any technology transfer). It cannot, however, be taken as an indication of the level of skills and knowledge that have been transferred alongside of such capital investment. Moreover, even if it were possible to measure these flows of technology transfer, measuring their impact in terms of capacity building would remain problematic.

2.9 Mechanisms for low carbon technology transfer

Before discussing the various barriers that can hinder the transfer of low carbon technology transfer, it is first useful to clarify the different mechanisms by which technology is transferred. There are two reasons for attending to different mechanisms for technology transfer. Firstly, there is a link made in some of the literature between different transfer mechanisms and the outcome of the transfer process in terms of the impact on recipient country capacities (the far right column, column C, in Figure 2.1 in Section 2.4 above). Secondly, clarification of different transfer mechanisms is also necessary in order for governments or other actors to understand how they might intervene if they wish to encourage the transfer of low carbon technologies.

2.10 Actors and motivations

The first point to note is that technology transfer tends to involve a range of different actors (IPCC 2000, p.17). These vary according to sector, country circumstances and type of technology involved. Table 2.1 identifies some key actors and their motivations and concerns within the technology transfer process. Table 2.1 shows that the actors involved in technology transfer processes have a variety of motivations. In some cases, there will be a significant degree of agreement about the purpose of technology transfer. However, there is also scope for disagreement or conflicts of interest. These conflicts have the potential to pose important challenges to the transfer process.

Table 2.1: Key factors and their motivations and concerns

Stakeholder	**Motivations and concerns**
Transnational and multinational corporations	Seek international sales, market share, and cheaper production costs through equipment transfers and foreign direct investment. Primarily concerned with profits, acceptable risks and protection of intellectual property
Recipient-country firms	Seek to: • Minimise costs (as with transnational corporations) • Increase technical capabilities to improve quality or reduce cost • Improve technological status • Access managerial and marketing expertise • Access sources of capital • Access to export markets • Access new distribution networks.
Recipient governments	Seek to: • Increase capabilities for domestic technology-development • Promote foreign investment • Improve living standards and environment via appropriate technologies
Provider or donor governments	Seek to support development and political goals. Also interested in expanding foreign markets and increasing exports for their national firms.
Multilateral agencies	These include agencies with development goals (e.g. World Bank, United Nations Development Programme (UNDP), Regional Development Banks and Regional Organisations) and environment goals (e.g. Global Environment Facility – GEF). • Agencies with development goals seek to support development and achieve desired economic and policy reforms. • Agencies with environmental goals, aim to transfer of environmentally sustainable technologies by catalysing markets and enabling private sector involvement in the transfer of these technologies. The adoption of the principal of sustainable development by many such agencies implies that development and environmental goals ought to be approached as mutually reliant.
Non-governmental organisations (NGOs)	Tend to promote issue of technology choice and "appropriateness" of technologies transferred through development assistance and commercial channels. Also central in highlighting social and cultural impacts of transfers, and need for technology adaptation to suit local conditions and minimise unwanted impacts.

Source: (IPCC 2000, p.56)

2.11 Mechanisms

The mechanisms by which low carbon technology transfer occurs are no different to the mechanisms that are routinely used for the transfer of other kinds of technology. Several sources in the literature, including the work of the IPCC (IPCC 2000, pp.17 & 57) on low carbon technology transfer, tend to produce somewhat confusing lists of different mechanisms involved in technology transfer. Here we present an attempt at a more internally coherent framework of transfer mechanisms produced by Martin Bell (2006, personal communication).

An initial distinction that needs to be made is between different kinds of 'organisational arrangement' for technology transfer. These include:

- Transfer within the context of ***arm's length relationships*** between parties (transfer mediated by 'pure' market relationships)
- Transfer undertaken within ***joint venture relationships*** between the parties
- Transfer undertaken in association with ***foreign direct investment (FDI) relationships*** between parent companies and wholly owned subsidiaries

The literature has also seen the emergence of a body of work that addresses knowledge flows within value chains between customers and suppliers within original equipment manufacture relationships (see, for example, Hobday 2000, Gereffi 2001, Gereffi et al. 2001, Humphrey and Schmitz 2001, 2002, Gereffi et al. 2005, Hobday et al. 2005). This work highlights another category of organisational arrangement:

- Transfer undertaken within the organisational framework of ***customer-supplier contractual relationships*** (e.g. original equipment manufacture supply agreements)

The above forms of organisational arrangement for technology transfer are all between private sector actors. There is also the possibility of organisational arrangements involving government actors (although it should be noted that this is distinct from any form of 'government influence' on technology transfer which is addressed below). Two forms of government-linked organisational arrangement are:

- Transfer involving ***public sector business enterprises as recipients or suppliers***
- Transfer involving ***public research and technology organisations as recipients or suppliers***

This results in a five-fold typology of organisational arrangements for technology transfer, namely:

1. Private sector arm's length relationships
2. Private sector joint venture relationships
3. Private sector FDI relationships
4. Private sector customer-supplier contractual relationships
5. Public sector business enterprise as recipient or supplier
6. Public research and technology organisation as recipient or supplier

Within any of these organisational contexts, a number of transfer-related activities might take place. These include activities such as:

- The sale/purchase of capital goods and related services for investment projects,
- The licensing/sale of designs and know-how
- The execution of collaborative research, development, design or pilot plant activities

- The exchange of scientific and technical personnel
- The education and training of personnel
- The acquisition of knowledge via conferences, shows, visits, open literature

These two lists of organisational contexts and transfer-related activities can therefore be combined into a matrix form, as in Table 2.2, which provides a useful heuristic approach to conceptualise what might be involved in the technology transfer process. In Table 2.2, organisational contexts are listed on the vertical axis (rows 1-6) and transfer-related activities are listed along the horizontal axis (columns A-F). Essentially, any cell within the matrix in Table 2.2 could characterise a mechanism by which technology is transferred.

As the IPCC (2000, p.57) notes, these mechanisms tend to involve cooperation between different actors, but there are also situations where technology transfer occurs without any interaction between actors, usually without the consent of the technology provider. These include industrial espionage, end-user or third country diversions and reverse engineering.

Another issue that is important in characterising technology transfer mechanisms is the degree of integration involved. This refers to the extent to which supplier companies integrate the different flows involved in the transfer process (flows A-C in Figure 2.1 in Section 2.4 above). The differences in this dimension cut across all other distinctions made in Table 2.2. For example, in column A which deals with the sale/purchase of capital goods and related services:

- The transfer of technology via the sale/purchase of capital goods in the context of private arms length relationships (cell A1) might be highly integrated (e.g. involving some form/degree of turnkey project), or it might be highly disintegrated (e.g. via the acquisition of different items of plant from a wide range of different host country suppliers).
- The same kind of difference might also arise in, for example, cell A3 such as when oil companies setting up new refineries in wholly owned subsidiaries differ between using turnkey-type contracts or much more ‘unpackaged’ arrangements that externally source the inputs of equipment and related investment services.

As highlighted in the discussion of assimilation theories of technology transfer in Section 2.4 of this literature review, issues of integration could have significant impacts in terms of the production and technological capacity of the recipient country (this is the capacity illustrated by the far right column, column C, in Figure 2.1 in Section 2.4 above). For example, if the generation of inter-firm linkages through regular local production by foreign operators is integral to knowledge generation among local suppliers, then a high level of integration of transfer activities is unlikely to enhance developing country capacity.

Table 2.2: Mechanisms for technology transfer

Organisational context for transfer	**Main transfer activities**					
	The sale /purchase of capital goods and related services for investment projects	The licensing/sale of designs and know-how	The execution of collaborative research, development, design or pilot plant activities	The exchange of scientific and technical personnel	The education and training of personnel	The acquisition of knowledge via conferences, shows, visits, open literature
	A	B	C	D	E	F
Private sector arm's length relationships 1						
Private sector joint venture relationships 2						
Private sector FDI relationship 3						
Private sector customer-supplier contractual relationships 4						
Public sector enterprise as recipient or supplier 5						
Public RTO as recipient or supplier 6						

Source: (IPCC 2000, p.56)

Some literature has, however, tended to focus more on choice of organisational arrangement (the vertical axis in Table 2.2) as defining the degree of integration of transfer activities. In particular, the difference between private sector joint venture relationships (row 2 in Table 2.2) and private sector FDI relationships in the form of wholly owned subsidiaries (row 3 in Table 2.2) has been implicated as influencing the benefits to recipient countries in terms of capacity development. The assumption here is that joint venture relationships are likely to involve more cooperation and knowledge sharing than wholly owned subsidiaries. This choice of organisational vehicle for entry into foreign markets has been highlighted as one of the most important decisions a firm makes during its decision to invest in foreign markets (Datta et al. 2002, Tsang 2005).

As the IPCC (2000, p.57) highlight, in the past, wholly owned subsidiaries tended to represent the dominant organisational context for technology transfer. Since the 1980s, however, joint ventures have become more common. This may be due to a number of factors. These include the requirement of governments in recipient countries for foreign investors to form joint ventures and the realisation by foreign investors of the value of the local knowledge of host country firms (Datta 1988). In these ways, joint ventures might also reduce transaction costs, which may be a key determinant of a firm's choice of foreign investment approach (Kogut 1988). This has lead to the development of theoretical frameworks, such as that tested in the context of China by Pan (1996) and later tested in the context of Vietnam by Tsang (2005), which focus on transaction costs and the bargaining power of foreign firms and host country governments as key determinants of ownership levels in joint ventures and entry mode choices. As Tsang (2005) highlights, however, there are still important disagreements in the literature as to what drives the choice of organisational arrangement for foreign investment. In his study of Vietnam, for example, Tsang (2005) found that his findings contradicted with the consistent findings of other studies, as highlighted by Datta et al. (2002), that greater cultural distance between the company and the target country is associated with entry choices that involve lower degrees of ownership for recipient countries (e.g. suppliers would opt for wholly owned subsidiaries over joint ventures or licensing agreements). For a critical review of research to date in this area see Datta et al. (2002). Table 2.3 provides a summary of some of the key issues that the IPCC (2000, p.57) identifies as affecting technology supplier firms' choice between certain organisational contexts and activities for technology transfer.

A final issue of particular relevance to low carbon technology transfer is the issue of government influence on the transfer process. In the case of low carbon technology transfer, governments from both supplier and recipient countries are likely to play important roles. There are several reasons that might motivate greater government involvement in the transfer of low carbon technology transfer relative to other technologies. Firstly, an increasing level of political will exists to take positive action to move towards low carbon economies as reflected in the commissioning of studies such as this one. This is largely related to this existence of ancillary benefits to individual countries from mitigating future economic impacts of climate change. Secondly, many low carbon technologies are currently at pre-commercial or supported commercial stages of development and may therefore require some form of government support in order to facilitate their wider adoption. A third motivation for government involvement may be a desire to move toward early investment in technologies that are likely to be of more domestic importance in future. Governments might also take a view towards gaining relative advantages in promising new technology with a view to future export markets.

Table 2.3: Issues affecting firms' choice of organisational context and activities during technology transfer

Organisational context	**Issues affecting choice**
Wholly owned subsidiaries	• Acceptable financial risks • Foreign investment policies of government • Expected size of domestic market • Export duties • Repatriation of profits
Joint ventures	• Acceptable financial risks • Ensuring protection of intellectual property • Expected size of domestic market • Product adaptation • Partner identification, appraisal and negotiations • Foreign investment policies of government • Export duties • Repatriation of profits
Transfer activity	**Issues affecting choice**
Direct sales	• Import duties • Advertising • Product compatibility • Standards and certification • After-sales service and training • Distributor capabilities • Degree of system integration required before use by final user • Insurance and product liabilities
Turn-key contracts	• Domestic technological capabilities • International competitive bidding • Import duties • Buyer training • Corruption

Source: (IPCC 2000, p.56)

Transfer activity	**Issues affecting choice**
Licensing agreements	• Intellectual property protection • Future domestic market and strategic interests of multinational company • Acceptable financial risk
Twinning, conferences, symposia and other person-to-person pathways	• Ability to attend conferences and symposia • Availability of counterpart resources • Access to information and communication means • Intellectual property protection

Based on IPCC (2000, p.57)

Such government influence may be involved across any of the cells in Table 2.2. Table 2.4 summarises the issues that the IPCC (2000, p.57) identifies as affecting government's choice between different approaches to finance when intervening in the technology transfer process.

Table 2.4: Issues affecting governments' choice of finance approach during intervention in technology transfer

Finance approach	**Issues affecting choice**
Multilateral development lending	• Need for and viability of carrying out structural economic reforms • Guarantees and credit worthiness of government and borrowers • Economic and financial rates of return from investments • Procurement procedures
Development aid and other grant financing	• Donor country political agenda • Multilateral agency priorities • Recipient country capacity to make informed choices • Range of stakeholders' involvement in recipient country

Based on IPCC (2000, p.57)

Based on Bell's analysis presented in this section, mechanisms for technology transfer can therefore be thought of in terms of four key levels of differentiation:

1. Alternative organisational arrangements for transfer (the vertical axis in Table 2.2)
2. Alternative transfer activities (the horizontal axis in Table 2.2)
3. Alternative degrees and patterns of integration in the execution of the activities
4. Alternative forms of government influence in shaping the transfer process

2.12 Stages in the technology transfer process

In general, as technology transfer is often led by the private sector, the process is likely to be driven by the interests of individual firms. Therefore, the process of technology transfer is not implemented using a standardised approach. By contrast, the discussion of government-driven pathways for low carbon technology transfer emphasises a more structured process. Some authors, including the IPCC (2000, p.57) and Kathuria (2002), have found it useful to outline a series of stages, or steps, that could usefully characterise the process of technology transfer.

Within her India-specific review of technology transfer, Kathuria (2002) sets out seven steps:

1. Assessment of technology needs

This involves a country-specific assessment of low carbon technology needs. In countries like India, for example, where there is heavy reliance on coal and biomass this might include cleaner coal and advanced biomass technologies. This is what the UNFCCC is trying to achieve by encouraging non-Annex I countries to submit technology needs assessments.

2. Selection of technologies

The selection of technologies is also a function of resource availability. For both purchasers and suppliers of technology, this process of selection can be subject to a high degree of uncertainty due to a lack of information. Suppliers may not have access to adequate data on conditions within target countries and purchasers may not be able to gain a full picture of the softer, knowledge based aspects of a prospective technology. This often results in reliance on imperfect approaches to selecting technology, such as advertising, well-known brand names or existing contacts.

3. Mechanisms for technology import

This step involves the choice of an appropriate mechanism for importing/exporting technology. As explored above, the choice of mechanism has important implications for the impact of technology transfer on overall technological capacity within the recipient country.

4. Operating technology at its designed capacity

Kathuria suggests that where operating technology at its designed capacity is not explicitly addressed by firms in developing countries, capacity utilisation rates, product quality and general technological efficiency tend to be relatively low.

5. Adapting technology to local conditions

This step relates to the need to adapt imported technology to local conditions such as physical or climate factors. Kathuria, however, fails to highlight another important factor, namely the need to adapt to local cultural conditions whereby technology usage and applications varies between cultures. This may particularly be true in the context of cultural differences between developed and developing countries. Dawkins and Daniel (1998), for example, demonstrate that differences in driver behaviour between the US and Jamaica render US traffic control technologies unsuitable.

6. Improving installed equipment

This step builds on steps 4 and 5 to improve elements such as quality and material/energy requirements of an imported technology once installed. Kathuria cites this kind of 'capacity stretching' as forming the predominant kind of technological improvement in Latin American countries.

7. Development of technology

Developing technology tends to be where countries can add the most domestic value. Whilst there may be limited scope for developing countries to become technology leaders at an aggregate level, there may still be opportunities to develop niche technologies such as in the successful examples of the software industry in India and machine tool industry in Taiwan.

In contrast to Kathuria's seven steps, the IPCC (2000, p.57) state that "Some observers have suggested that along any pathway, technology transfer follows five 'stages'". They list these as:

1. Assessment (including identification of needs)
2. Agreement
3. Implementation
4. Evaluation and adjustment
5. Replication

The IPCC do not comment on these stages in any detail, nor do they cite which observers suggest them. It is, however, clear that they follow a similar rationale to Kathuria's (2002) seven steps with 'replication' alluding to the development of technology within recipient countries. A useful observation made by the IPCC is that the actors involved and the decisions and actions taken at each different stage will vary considerably depending on which technology transfer pathway is chosen (government-driven, private-sector-driven or community-driven).

2.13 Barriers to low carbon technology transfer

The central focus of this study is on understanding how developed and developing countries might best cooperate in order to facilitate the transfer of low carbon technologies. As well as understanding processes of technological change and technology transfer, it is also necessary to understand what barriers exist to low carbon technology transfer.

A number of analyses of barriers to technology transfer have been produced in the past, such as that presented by TERI in a recent report on climate change and technology transfer for the British High Commission in India (TERI 2006a). In this section we discuss barriers to technology transfer within the context of two key frameworks already introduced in this review. The first is Bell's (2006 personal communication) four-fold typology of mechanisms for technology transfer (see Section 2.5 above), namely:

1. Alternative organisational arrangements for transfer (the vertical axis in Table 2.2)
2. Alternative transfer activities (the horizontal axis in Table 2.2)
3. Alternative degrees and patterns of integration in the execution of the activities
4. Alternative forms of government influence in shaping the transfer/acquisition process.

The second is Bell's (1990) conceptualisation of the three different flows that categorise the technology transfer process (see Figure 2.1 in Section 2.4 above), namely:

A. Capital goods and equipment

B. Skills and know-how for operating and maintaining equipment

C. Knowledge and expertise for generating and managing technological change

The barriers discussed in this section can be summarised as:

1. Transfer of capital goods and equipment:

- *Financial barriers:* Lack of funds to aid technology transfer to developing countries and the added cost of pre-commercial and supported commercial low carbon technologies.
- *Political barriers:* Political instability and the need for clearly defined and clearly enforced policy.

2. Transfer of skills and know-how:

- *Management of projects:* Failure to include training in the operation and maintenance of transferred technology as part of the transfer process.

3. Transfer of knowledge and expertise:

- *Degree of integration of transfer activities:* High levels of integration during the transfer process (e.g. turnkey projects) can prevent recipient firms from gaining knowledge and expertise.
- *Absorptive capacity:* Where absorptive capacity of recipient firms is weak they are less able to take advantage of collaborations with foreign firms.
- *National systems of innovation:* Weak national systems of innovation often lead to weak absorptive capacity among national firms.
- *Micro-level management of transfer projects:* Acquiring knowledge as part of the transfer process requires a proactive, strategic approach by recipient firms to obtain new knowledge during technology transfer projects.
- *Intellectual property rights (IPRs):* Protection of IPRs can prevent recipient firms from gaining access to the knowledge necessary to imitate and then innovate on the basis of new technologies.

4. Demand for technology transfer:

- *Preference for conventional technologies:* Investors often-associate higher risks with new technologies.
- *High costs of new technologies:* New technologies often entail higher costs for acquiring and/or using/operating them.
- *Cultural barriers:* Differences in perceived acceptability and appropriateness of particular technologies can impact on demand.
- *Information barriers:* Poor knowledge of available technologies and financing opportunities reduces demand for new technologies.

5. Status of technology development:

- *Risks and uncertainties related to stage of commercialisation:* Barriers to technology transfer may be less pronounced as technologies become more widely commercially available. This is particularly important for many low carbon technologies that are either pre-commercial, supported commercial or commercial but slowly diffusing.

6. Government intervention in technology transfer:

- *Policy environment:* Lack of a clearly defined and enforced policy environment can deter investment in low carbon technology.
- *Markets for carbon:* The failure of the market to recognise the cost of carbon is a key barrier to the transfer of low carbon technology. Governments have a central role to play in creating markets for carbon.
- *Need for private sector involvement:* Many government interventions in the technology transfer process have failed to recognise the central role of private investors in the transfer process.

7. The role of interests and power:

- *Interests and power:* Low carbon technology transfer involves many different actors with strong vested interests in the technology itself as well as the distributional outcomes of the transfer process. Understanding the role of interests and power in both vertical and horizontal technology transfer represents a key gap in current research.

These barriers are discussed in more detail below. We begin by discussing barriers to each of these flows (A, B and C) individually with reference to the first three elements of Bell's mechanisms typology. We then discuss the influence of demand for technology and the stage of commercial development of individual technologies. Barriers are then discussed in the context of the fourth element of Bell's mechanisms typology, namely government influence on the transfer process. Finally, we highlight the importance of interests and power in the transfer process.

Barriers to transfer of capital goods and equipment (Flow A)

The transfer of capital goods and equipment (flow A) is facilitated via any of the mechanisms defined by the cells in Table 2.2 in Section 2.5 above. Barriers to this flow of transfer are likely to be primarily financial. These relate to a lack of funds within developing countries to aid technology transfer and/or the absence of international mechanisms for finance. This issue may also be exacerbated by the increased expense associated with implementing new large-scale industrial technologies relative to achieving incremental improvements to existing technologies. One example would be the expense of installing new supercritical boilers within coal fired power plants as opposed to increasing the efficiency of existing plant by improving its operation (Watson 1999). The pre-commercial and supported commercial nature of many low carbon technologies may also increase their associated costs relative to established technologies. This is discussed further below.

There may also be political barriers to the transfer of capital goods and equipment. Political barriers often include the potential for political instability in developing countries or perceived weaknesses in enforcing policy, which might act as a deterrent to foreign investment in the absence of strong policy intervention. This is of particular importance for low carbon technologies, the development of which is often incentivised by strong environmental policy. This is linked to the idea of institutional barriers that stem from inadequate economic, legal and regulatory frameworks in developing countries. There may also be political barriers to the transfer of specific technologies, such as nuclear technology, where this is perceived as posing a threat to international security.

Barriers to transfer of skills and know-how (Flow B)

As illustrated in 2.1 in Section 2.4 above, an essential part of developing new production capacity within recipient countries through technology transfer is the transfer of the skills and know-how for operating the technology (Flow B in Figure 2.1). Barriers to Flow B are likely to arise as a result of the management of transfer projects. This essentially relies on whether the process of technology transfer is managed on the basis of supplying proper training and support for host country recipients to enable them to optimally operate the technology. A lack of sufficient training on skills and know-how has, for example, often been observed following the transfer of power generation plants supplied as turnkey projects. This has resulted in many power plants in developing countries being operated at sub-optimal capacity.

Barriers to transfer of knowledge and expertise (flow C)

As noted in Section 2.4 of this literature review, the development of new technological capacity in developing countries is crucial if technology transfer is to be successful in the longer-term (Bell 1990). This relies on the transfer of knowledge and expertise necessary for generating and managing innovation and technological change (flow C). There is a range of complex issues at play here that may constitute barriers to the transfer of this particular flow.

One important barrier to the transfer of knowledge and expertise is related to the degree and pattern of integration of transfer activities (i.e. the third element of the four-fold typology for categorising mechanisms). In this sense, according to assimilation theories discussed in Section 2.4 above, barriers to the transfer of flow

C are likely to arise as a result of highly integrated transfer strategies adopted by supplier firms (e.g. turnkey projects). Lower levels of integration where, for example, local companies are used as suppliers are more likely to have positive knock-on effects in terms of diffusing knowledge throughout the economy.

A related issue is the extent of existing technological capacity within a recipient country, which is directly related to firms' ability to absorb new technology. This is referred to in the literature as 'absorptive capacity'. If absorptive capacity is weak amongst recipient firms, they are less able to take advantage of collaborations with international technology suppliers. Essentially, a dialectical relationship exists between technology transfer and absorptive capacity (Bell 2006, personal communication). On the one hand, the level of absorptive capacity amongst recipient firms can have an important *influence on* the outcomes from technology transfer (the greater the absorptive capacity, the greater the potential for transfer to contribute to further developing capacity amongst recipient firms). On the other hand, the absorptive capacity of recipient firms can be significantly *influenced by* the outcomes of technology transfer projects.

In terms of low carbon technology transfer, this essentially implies a need to focus on developing absorptive capacity within developing country firms. There is, however, an inherent tension here. Measures to strengthen absorptive capacity may lead to greater concern amongst technology suppliers that technology transfer might eventually 'boomerang', leading to the creation of new lower cost competitors (Watson 2002). This, in turn, can lead to reluctance to engage in deeper knowledge transfer and a predisposition to engage in capital equipment transfer augmented by some training and management co-operation.

Whilst technology transfer can aid the development of a country's technological capacity, the literature notes that this is a much broader issue that requires a national approach. The national system of innovation (Freeman 1987) in a developing country can have an important influence on the capacity of firms and other actors to absorb new technologies and to engage in independent innovation. National systems of innovation encompass a complex mixture of actors, institutions, policies and relationships within a country. The overall purpose of this term is to capture a country's ability to accumulate technological knowledge and to use this knowledge to gain competitive advantage. Great emphasis is placed on the provision of a collective technology infrastructure to strengthen this ability (IPCC 2000).

The barriers to technology transfer that stem from weaknesses in national systems of innovation vary from country to country. For example, a number of studies have identified a general lack of co-ordination including weak linkages between research institutions and equipment manufacturers as an important barrier to technology transfer to China (Watson 2002). For India, a number of issues have been identified by previous studies. These include a study of the steel industry that identifies fragmentation as a barrier to overcoming lock-in to old, inefficient technologies (D'Costa 1998). The literature also includes a broader indicator-based analysis of the Indian innovation system, which notes that a historical barrier to innovation has been prolonged, inappropriate forms of government intervention and a lack of liberalisation in Indian industry (Mani 2004). This study also points to the positive impacts of recent reforms in tackling these perceived weaknesses. Such observation raises interesting questions in relation to the level of political liberalisation in China relative to India and the relative success of technology transfer processes in each country. It is important to note, however, that more empirical analysis would be required before such observations could substantiate any broad generalisations with regard to national systems of innovation and technology transfer.

One issue that has been highlighted as particularly important in developing the knowledge and expertise necessary for innovation is the micro-level management of technology transfer projects by recipient firms. This essentially refers to the practices of managers within the recipient firms. For example, Kim (1998) demonstrates how managers within Hyundai proactively took a strategic approach to acquiring migratory knowledge during the acquisition of foreign technology in order to expand the firm's existing knowledge base. This is seen as having been instrumental in intensifying Hyundai's organisational learning and shifting the company's learning orientation from imitation to innovation.

Another important barrier to the flow of knowledge and expertise is the concern of firms negotiating the transfer of non-hardware elements of technology with the protection of their intellectual property rights (IPR). IPR protection has become an increasingly important issue in international negotiations on a variety of issues including public health, biotechnology, trade and food security (UK Commission on Intellectual Property Rights (CIPR), 2002, ICTSD and UNCTAD 2003). IPRs have positive and negative impacts on technology transfer. A joint study by UNCTAD and the International Centre for Trade and Sustainable Development (2003, p.85) notes that:

> "It is fair to say that stronger IPRs reduce the scope for informal technology transfer via imitation, which was an important form of learning and technical change in such economies as Japan and the Republic of Korea (not to mention the United States). TRIPS [Trade-Related Intellectual Property Rights] has narrowed the options in this regard and raised the costs of imitation. At the same time, stronger patents, trademarks and trade secrets should reduce the costs of achieving formal technology transfer and expand such flows. However, evidence on this is not conclusive."

The study concludes that there is a lot of uncertainty about the impact of intellectual property protection on technology transfer. There is evidence that the effect depends on a number of factors including how developed a country is, what technologies are being transferred and the capacity and structure within the industry concerned (ICTSD and UNCTAD 2003). Furthermore, the extent of IPR protection has an influence on the kind of technology transfer mechanism that is likely to be favoured by international firms. Strong IPR regimes tend to encourage technology licensing and joint ventures whereas weaker regimes lend themselves to foreign direct investment (Maskus 2000). This is a similar point to the discussion in Section 2.5 above on the influence of cultural differences on the choice of mechanism for technology transfer and the level of ownership this implies for supplier firms.

The study concludes that there is a lot of uncertainty about the impact of intellectual property protection on technology transfer. There is evidence that the effect depends on a number of factors including how developed a country is, what technologies are being transferred and the capacity and structure within the industry concerned (ICTSD and UNCTAD 2003). Furthermore, the extent of IPR protection has an influence on the kind of technology transfer mechanism that is likely to be favoured by international firms. Strong IPR regimes, tend to encourage technology licensing and joint ventures whereas weaker regimes lend themselves to foreign direct investment (Maskus 2000). The adoption of the TRIPs agreement has encouraged stronger IPR regimes in developing countries similar to those in developed countries (UK CIPR, 2002). There is also a shift globally from an open science model towards stronger management of IPRs based on a licensing model. (Sathaye, J. A., De La Rue, S., and Holt, 2005).

Some have argued that one way to overcome IPR barriers is for governments to make patents for important technologies publicly available through compulsory licensing or the purchase of licenses with public funds (ICTSD and UNCTAD 2003). A recent Ministerial Indaba on climate action notes that 'a Multilateral Technology Acquisition Fund could be structured to buy-out intellectual property rights (IPR's) and make privately-owned, climate-friendly technologies available for deployment in developing countries' (van Schalkwyk 2006) or in a "limited public domain" (Ghosh, 2006).

However, it has also been noted that access to key patents by developing country firms is not a sufficient condition for effective technology transfer. Much of the knowledge relevant to working a patent is tacit. Full use of a patent is likely to require access to a variety of related information sources that are not fully explained in the patent.

Whilst a number of studies have examined IPR related barriers in the field of biotechnology, agriculture and public health (UK CIPR, 2002, Yamin, 2002), the literature on the specific nature of IPR barriers in the context of climate change is sparse. This may, in part, be due to the fact that IPRs play a less central role in encouraging innovation within the context of low carbon technology than, for example, in the pharmaceutical industry. This suggests a need to question whether a strategy involving government intervention in the form of compulsory licensing would be as suited to low carbon technology as it is to other industries such as pharmaceuticals (Taylor, 2006, personal contribution).

Lack of demand for technology transfer

There are several issues highlighted in frameworks such as that developed by TERI (2006a) which do not necessary impact on technology transfer *per se*, rather they affect the demand for particular technologies (Bell 2006, personal communication). The above discussion of barriers tends to assume a situation where demand exists for particular technologies but barriers exist to their transfer. There are, however, some issues that act to reduce demand for technology transfer and therefore act as indirect barriers. Issues impacting on the demand for technologies might include, for example:

- A preference for conventional technologies. This might include shying away from pre-commercial technologies, which is of particular importance for low carbon technologies. This might also be affected by a lack of industry standards for new technologies as is observed in many new timber-based construction materials.
- High costs of some new technologies. This might relate either to the high cost of acquiring or the high cost of using/operating them.
- Cultural barriers. In a north/south context this might relate to differences between the views of developed countries and those of developing country populations about the acceptability and appropriateness of particular technologies.
- Information barriers that lead to poor knowledge of available technologies and financing opportunities. This could be influenced by a reluctance by some technology suppliers to share information due to IPR concerns or concerns with maintaining international competitiveness.

Status of technology development

This literature review has already touched on the fact that many low carbon technologies are still at pre-commercial and supported commercial stages in their development, which is one reason that government intervention might have an important role to play in encouraging their adoption. There is, however, an inherent connection that warrants discussion here between the stage of development of a particular technology and the importance of different barriers to its transfer and wider adoption (Bell, 2006, personal communication).

Within this study, we have identified three key stages of technology development in order to assist in the selection of relevant low carbon technology case studies. These stages cover different parts of the innovation spectrum from pre-commercial technologies undergoing R&D and demonstration through to commercial technologies that are nevertheless diffusing slowly in developing countries. The three stages are:

1. Pre-commercial – Technologies that are not commercial in either developed or developing countries and are still undergoing significant demonstration and R&D e.g. LED lighting
2. Supported commercial – Technologies that are starting to be deployed in supported markets, but that are making slower progress in developing countries e.g. hybrid vehicles
3. Commercial but slow diffusion – Technologies that are in common commercial usage in developed countries, but that have a slow rate of diffusion in developing countries e.g. techniques for improving power station combustion efficiency

There are important issues related to the level of development of a technology in terms of both its cost effectiveness and the risks that private investors are likely to associate with investing in it. For example, pre-commercial technologies (stage 1 in the above typology) are more likely to be subject to higher costs of initial investment than existing commercial technologies (stage 3). This may be because, as in the example of hydrogen fuel cells, in order for technologies to become cost effective, significant economies of scale must be achieved through large-scale production. Often, the pre-commercial statues of such technologies may also mean that the costs associated with their adoption are subject to a high degree of uncertainty. This is also linked to the level of demand for a new technology, which is affected by the issues discussed above. This can result in a catch twenty two situation. For example, private investors are unlikely to invest in large-scale production of hydrogen fuel cells in the absence of sufficient demand. Such demand is, however, unlikely to develop unless fuel cells are available at lower prices, which, in turn, cannot be achieved without large-scale production.

In line with uncertainties relating to the costs of pre-commercial and supported commercial technologies, the risks that private investors associate with investing in such technologies are also likely to be higher at earlier stages in technology development. The risks that private investors associate with different technologies can act as significant barriers to their adoption and transfer. It is therefore important to be aware of the fact that the barriers to the transfer of low carbon technologies are likely to vary according to the stage of development of these technologies. In the case of pre-commercial technologies such as hydrogen fuel cells, this might require governments to take a lead in helping to finance commercial production in order to reach some level of cost effectiveness and reduce the risks faced by potential private investors. Supported commercial technologies on the other hand, such as hybrid cars for example, might require less direct incentives, such as technology neutral taxation of emissions to favour low carbon emitting vehicles.

At the stage of slow diffusing existing commercial technologies, intervention would focus more on addressing the barriers to horizontal technology transfer that are discussed above. This raises an important point of relevance to this study. The aim of the study is to understand how to overcome barriers to the transfer of low carbon technologies to India and other developing countries. However, the pre-commercial and supported commercial status of many low carbon technologies means that many of these technologies have not been widely adopted in developed countries. The barriers faced to the transfer of these technologies to developing countries are therefore similar to the barriers to their adoption within developed countries. In the language introduced in Section 2.4 of this literature review, for those technologies that are further from market, technology transfer will therefore have a strong vertical (commercialisation) component as well as a horizontal (geographical transfer) component. This is, however, complicated when developers of new low carbon technologies are based in developed countries. In this case the barriers to horizontal transfer discussed above become relevant. Pre-commercial and supported commercial technologies are, however, more likely than commercially available technologies to be affected by barriers such as IPRs and a desire to 'guard' the underlying knowledge. In such cases, whilst firms may well be willing to manufacture and market the technology in developing countries, they may opt to pursue strategies that involve a higher degree of integration in the production process in order to retain the tacit knowledge upon which the technological innovation is based.

Government intervention in technology transfer

Government intervention (the fourth element of Bell's four-fold typology of mechanisms for technology transfer) is likely to play a key role in facilitating low carbon technology transfer through the development of suitable policy frameworks and institutions. However, whilst government involvement is usually designed to overcome barriers to low carbon technology transfer, this involvement can also introduce new barriers to transfer As discussed earlier in this literature review, government intervention in the transfer process may be of particular relevance in the context of low carbon technology transfer relative to many other technologies. This is due to a range of issues including increasing political will to act to mitigate climate change, the pre-commercial or supported commercial status of much low carbon technology, a desire to move toward early investment in technologies that are likely to be of more domestic importance in future and gaining relative advantages in promising new technology with a view to future export markets.

As noted above, political barriers could also exist to technology transfer due to political instability in developing countries or perceived weaknesses in enforcing policy. This can act to deter foreign investment and requires strong government intervention to implement adequate economic, legal and regulatory frameworks in developing countries. Another important issue for many low carbon technologies is their pre-commercial and supported commercial status as discussed above. This essentially implies that they will not be transferred under normal commercial conditions because they are perceived as risky or uneconomic. One of the reasons that many low carbon technologies are uneconomic under current conditions is that the externality they are designed to address – i.e. climate change – is not priced. Whilst the inclusion of the environmental and social cost for carbon emissions will not be enough to finance all low carbon technologies, the lack of a carbon price presents an important barrier to their overall development and deployment. The UK sponsored Stern Review on the Economics of Climate Change, due to report in October 2006, is considering the economic, social and environmental consequences of climate change, including extreme events and may provide some additional guidance on the issue of carbon pricing.

The use of economic instruments such as taxes and tradable permits to price carbon has been considerably boosted by the creation in 2005 of the European Union Emissions Trading Scheme (EU ETS) and the functioning of mechanisms under the Kyoto Protocol, in particular, the Clean Development Mechanism (CDM) (Yamin, 2005).

The CDM has an ambitious remit. It allows investors from Annex I countries to generate Certified Emissions Reductions (CERs) by investing in projects that reduce greenhouse gases in developing countries. The CDM does not have an explicit technology transfer remit but it is recognised that it might facilitate technology transfer to developing countries where emissions reduction projects involve technologies not currently available in host countries. An analysis of all 860 registered CDM projects to date by Haites et al. (2006) demonstrates that around a third of these projects intend to include the transfer of either equipment or hardware or both and that. These projects account for around two thirds of emissions reductions achieved under the CDM. The plans for technology transfer vary significantly by project type and host country. In India, for example, only 7.3% of CDM projects plan to involve some element of technology transfer compared to 55.1% in China and much as 83.3% in Malaysia (see Table 2.5). This suggests that host country approval processes can increase the rate of technology transfer under the CDM. These results also suggest that local technology is preferred for some types of emission reduction projects. Given the expanding role of the CDM in the future climate regime, particularly for countries like India, more detailed analysis of host country approval processes for CDM may provide useful insights on how the CDM can deliver more technology transfer.

Table 2.5: Technology transfer for CDM projects in selected host countries

Host country	**Number of projects**	**Estimated emission reductions (ktCO$_2$e/yr)**	**Average project size (ktCO$_2$e/yr)**	**Technology claims as number of projects**	**Transfer per cent of annual emission reductions**
Argentina	9	3,579	398	77.8%	99.4%
Brazil	160	20,471	128	33.1%	74.1%
Chile	23	3,720	162	17.4%	44.8%
China	69	52,996	768	55.1%	75.9%
Honduras	19	446	23	57.9%	57.5%
India	329	26,595	81	7.3%	34.4%
South Korea	12	12,556	1,046	50.0%	88.2%
Malaysia	18	2,343	130	83.3%	94.8%
Mexico	54	7,305	135	85.2%	91.4%
Nigeria	2	4,044	2,022	0%	0%
Philippines	22	388	18	63.6%	72.8%
Other host countries	137	14,930	109	49.6%	50.9%
Total	**854**	**149,369**	**175**	**33.5%**	**65.5%**

Source: Haites et al. (2006)

Irrespective of the CDM's impact on technology transfer, it is already widely recognised that this mechanism will not finance all of the potential low carbon technology deployment in developing countries. A range of national and international routes for additional finance have been developed which include a mix of public and private initiatives (TERI 2006a). Multilateral institutions such as the World Bank are thought to have a particularly important role to play. The Bank has recently outlined some of the additional multilateral finance mechanisms that could be implemented (World Bank 2006). It is working on an energy investment framework under the Gleneagles Dialogue that aims to address cost, risk, institutional and information barriers. Options that have been put forward include a Clean Energy Financing Vehicle that would blend carbon finance and capital grants for highly efficient technologies. They also include proposals to help upgrade the efficiency of existing capital equipment, to provide venture capital, and to develop candidate projects for financing via other mechanisms. Additional analytical work is needed to understand better the factors and circumstance under which these mechanisms might be implemented most effectively.

In addition to developing market frameworks and financial mechanisms that favour low carbon technologies, governments often seek to exert more direct influence over technology transfer processes. As noted towards the end of Section 2.5 above, government-led transfer of low carbon technologies is often described as a managed process with a number of distinct stages. This underplays the fact that governments can only intervene to set policy frameworks that support technology transfer. The transfer process itself will usually be undertaken by private firms via the mechanisms characterised by Table 2.2 in Section 2.4 above.

Muchie clearly describes the problems with this lack of clarity about the roles and interests of the different actors involved. He observes that 'the international dialogue ... suggests that as a matter of responsibility and commitment to the environment, technology proprietors from countries with strong systems of innovation can be enjoined to transfer [technologies] on "favourable terms" to developing countries' (Muchie 2000, p.203). OECD country governments, which are the source of the majority of bilateral and multilateral aid flows, have numerous agendas including regional security, poverty alleviation and trade (Evans 1999b). Trade agendas include the protection of domestic commercial interests, gaining access to developing economies and a cautious approach to WTO trade liberalisation rounds. Whilst there is often an alignment of interests between donor Governments that use aid as a device for trade promotion and multinational companies, these companies will only transfer technology if it is in their commercial interest to do so.

The difficulties of government-driven technology transfer are illustrated by practical experience. The Japanese Green Aid Plan is a good example (Evans 1999b, Watson 2002). It supported a range of demonstration projects in several Asian developing countries as well as supporting activities such as personnel exchanges and training. Despite the large amount of money spent on the Plan, it was only partly successful in facilitating technology transfer. One of the most fundamental problems was the lack of follow-on orders for the equipment used in the demonstration projects. This was partly due to the high cost of imported Japanese equipment. It was also caused by the structure of the Green Aid Plan that targeted equipment transfer, training and design co-operation at user industries (e.g. steel and cement). The manufacturing firms in recipient countries that were best placed to absorb and further develop the technologies concerned were excluded from the process.

A second example shows how a different approach, this time by a multilateral institution, was also beset by problems. The China Efficient Industrial Boiler Project was funded by the World Bank through the Global Environmental Facility (GEF). This project aimed to subsidise the acquisition of technology licences for new industrial boiler technologies by Chinese firms (Watson 2002). It took six years to identify suitable technology licensors, mainly due to the reluctance of major international firms to take part in the project on the GEF's terms. Whilst the specifications for boiler efficiency and emissions were very closely defined, the coal to be used was not characterised in sufficient detail for the bidding companies to produce a suitable design with performance guarantees. Furthermore, many international boiler-makers were not convinced that their intellectual property would be respected since the Ministry of Machinery wanted the license to cover the whole of China. Some of the projects eventually went ahead with smaller boiler suppliers. In an evaluation, the GEF concluded that the purchase of licenses had little direct impact on technology transfer, but that there may have been positive benefits of an indirect kind. The GEF believes that the existence of the project accelerated the Chinese government's normal process of regulation under which inefficient boiler designs are discontinued (Birner and Martinot 2002).

Understanding the role of interests and power

One important, but largely unexplored, issue of relevance to a discussion of barriers to technology transfer is the influence of interests and power. As the IPCC special report (2000, P.57) notes, the barriers to technology transfer differ on a case by case basis. Each case will involve a range of different actors whether from the private, public or not-for-profit sector. The involvement of public and not-for-profit actors is especially likely in the case of low carbon technologies due to the associated social benefits of reducing carbon emissions. With a large range of powerful vested interested involved, such as the oil lobby, and the often associated trade offs between economic and environmental concerns, the inter-play of interests and power in the technology transfer process is likely to play an integral part in presenting or dissolving barriers to successful transfer. The IPCC hint at this by stating that 'by analysing the interests and influences of different stakeholders … it is possible to determine how various barriers to technology transfer might be overcome' (IPCC 2000, P.57). They do not, however, develop this any further in terms of their analysis. This is clearly an area that warrants further research.

2.14. Implications for UK-India study

This literature review has briefly outlined some of the key issues for the study of barriers to low carbon technology transfer to India. It has discussed technology transfer from a perspective that is explicitly grounded in the innovation literature. An overview of technical change has been followed by an analysis of technology transfer processes and the barriers that often hinder attempts to put them into practice. An important distinction has been made between capital investment in developing countries and development of technological capacity that can be realised via deeper processes of knowledge transfer. Due to its particular relevance in the case of low carbon technology transfer, the analysis of barriers has also sought to explicitly address the potential role of government intervention in the transfer process.

As agreed at this project's initial steering group meeting, the next step is the analysis of five technological case studies. These are summarised in Table 2.6 together with the institution that is leading the analysis for each:

Table 2.6: Low carbon technologies for case studies

	Status of technology		
Sectors	**Pre-commercial**	**Supported commercial**	**Commercial but slow diffusion**
Low-carbon power generation technologies	Coal gasification – including IGCC (SPRU)	Biomass including fuel supply chain issues (TERI)	Improving combustion efficiency (TERI)
Network/ infrastructure technologies			
Low carbon end use technologies	LED lighting (TERI)	Hybrid vehicles (SPRU)	

The insights that have been highlighted in this literature review have raised a number of key issues for these case studies:

1. Processes of technological change. Evidence from the literature tends to support the idea that technological change occurs as a result of a process of incremental innovations. As a result, the idea of leapfrogging has been largely discredited. Nevertheless, whilst process-based leapfrogging may not be a realistic goal for low carbon technological change, product-based leapfrogging could be. The need for rapid adoption of low carbon technologies could drive product based 'leapfrogging' where developing countries move directly to the adoption of the most advanced low carbon product technologies during future development. India's earlier stage of development relative to some OECD countries implies the potential for widespread deployment of some technologies at earlier stages of development more quickly than was observed during the process of industrialisation in many OECD countries

2. Levels of integration in the transfer process. The level of integration within the technology transfer process is likely to impact on the long-term benefits to recipient countries. High levels of integration, such as turnkey projects, are less likely to contribute towards developing capacity for innovation in recipient countries than less integrated approaches such as joint ventures and the sourcing of components from local suppliers.

3. Supplier/recipient strategies. The level of integration in the transfer process is often a direct result of strategies adopted by supplier firms. In the same way that this has an impact on the outcome of the transfer process, the strategies adopted by recipient firms may be equally important. Recipient firms that strategically aim to obtain technological know-how and the knowledge necessary for innovation as opposed to imitation are more likely to be able to develop their capacity as a result of the transfer process.

4. Absorptive capacity. A dialectical relationship exists with regard to the absorptive capacity of recipient firms. Absorptive capacity *impacts on* the outcome of technology transfer (higher absorptive capacity implies a higher propensity to develop further capacity as a result of transfer). It is also *influenced by* technology transfer in that transfer activities have the potential to increase recipient firms' absorptive capacity depending on what flows are included in the transfer process (flows of hardware, know-how and knowledge for innovation). Developing national systems of innovation may have an important role to play in developing absorptive capacity. Of particular interest to the Government of India is the potential for international R&D co-operation to strengthen capacity (Sethi 2006). The case studies may be able to draw on past policies to develop 'NSI institutions' such as the establishment of the India Renewable Energy Development Agency.

5. Intellectual Property Rights (IPR). It is clear that both the Government of India and the international dialogue under the UNFCCC are interested in ways to increase access to IPRs for low carbon technologies within developing countries (Sethi 2006, van Schalkwyk 2006). The literature shows that, whilst this may be desirable, it is unlikely to be sufficient for Indian firms to develop new technological capacity. This review has raised a number of broader issues, such as tacit knowledge, that are also necessary to address. Furthermore, there is a complex relationship between the strength of the IPR regime in a country and the extent to which this fosters technology transfer**.** It is clear that both the Government of India and various channels of international dialogue related to the UNFCCC and Kyoto are interested in ways to increase access to IPRs for low carbon technologies within developing countries (Sathaye et al 205, Sethi 2006, van Schalkwyk 2006, Ghosh 2006). This literature shows that progress on this issue is far more likely if IPR issues are not framed narrowly in terms of access but also address other factors and barriers, such as tacit knowledge and absorptive capacity. As these factors differ by country, technology and sectors, a case by case approach may yield more useful insight in how to address IPR related barriers.

6. Status of technology development. The barriers to successful technology transfer are likely to vary according to the stage of technology development. The early stage of development (pre-commercial and supported commercial) of many low carbon technologies implies a need to focus on barriers to both vertical (commercialisation) technology transfer as well as a horizontal (geographical) transfer. In some cases this may mean that similar barriers exist to the adoption of low carbon technologies at early stages of development in developing and developed countries. However, where these technologies are owned by companies based in developed countries, generic barriers to technology transfer between developed and developing countries may still need to be addressed.

7. Government involvement. Government involvement is likely to play a key role in facilitating low carbon technology transfer. The lessons from past government-driven technology transfer are mixed at best. Therefore, the remainder of the study will consider how governments can act as facilitators of technology transfer by setting appropriate policy frameworks, but without over-prescribing the process to the extent that private sector actors are unable to fulfil their roles.

8. Carbon markets and finance. Carbon markets and other economic instruments such as taxes can play a major role in supporting the development and transfer of low carbon technology transfer. The main market mechanism for developing countries under the Protocol, the CDM, can help to facilitate this transfer. The strengths and weaknesses of this aspect of the CDM will need closer study as projects are implemented. Other market based opportunities for technology transfer are likely to be discussed as part of the UNFCCC Dialogue. Other private and public financing mechanisms such as those now being pursued by the World Bank and International Energy Agency pursuant to the Gleneagles Summit will also play a significant role. The important questions for this study are the extent to which these mechanisms and initiatives facilitate technology transfer as well as technology deployment and the way in which approaches to finance might need to vary for different low carbon technologies.

9. Interests and power. The interests and political and economic power of the different actors involved in the technology transfer process is likely to have significant bearing on the barriers to and outcomes of technology transfer processes. This may be of particular relevance in the case of low carbon technologies where a wide range of dominant interests stand to be affected. This is an area that remains relatively unexplored within the literature but that warrants further investigation.

3.1 Coal gasification (SPRU)[2]

3.1.1. Introduction

Gasification is a process that can convert a range of energy sources such as coal, biomass and petroleum products into a synthetic gas (syngas). The syngas can be used to produce power and other products such as fertilizers. The main focus of this case study is on gasification of coal for power generation, particularly Integrated Gasification Combined Cycle (IGCC). In India there is also the potential for underground coal gasification (UCG). Whilst this is outside of the scope of this study, future investigation of UCG technology transfer to India would be worthwhile.

3.1.2 Contribution to reducing carbon emissions

India has large reserves of coal relative to its current production levels with a reserves-to-production, R/P, ratio of 217. This compares favourably with India's R/P for crude oil which is 20.7 and its R/P for natural gas which is 36.2 (BP 2005). One limitation of Indian coal is its high ash content (around 50%). This adds additional energy requirements in terms of cleaning and transporting coal for power generation. Coal meets around 60% of commercial energy needs and around 70% of electricity generated in India comes from coal (TERI 1998). As with China, this implies that coal is likely to play an important part in India's energy mix in the short to medium term. The introduction of technologies that can reduce CO_2 emissions from coal is therefore important in reducing carbon emissions.

Gasification technology can make both incremental and radical reductions in carbon emissions from power plants and industrial processes such as fertiliser production. Incrementally, the use of state-of-the-art IGCC could be more efficient than alternative power plants – hence producing lower carbon emissions per kWh of electricity. Other emissions also benefit from reductions through IGCC. IGCC can also offer low emissions of other pollutants such as SO_2 and NOx (see Table 3.1.2 in Section 3.1.9 below). Similarly, the application of the best international gasifier designs to industrial processes could significantly improve the efficiency (and hence the emissions per unit of output) of industrial applications such as ammonia or urea production for fertilisers. Some analysts believe that first-generation IGCC without carbon capture in India has the potential to reduce CO_2 emissions by a tenth compared to emissions from supercritical pulverised coal (PC) and by a fifth compared to less efficient subcritical PC technologies (Ghosh 2005). Other commentators, however, believe that supercritical power stations and IGCC will offer broadly similar improvements. Furthermore, the reliability of IGCC technology burning coal still falls short of commercial requirements (Watson 2006).

For more radical cuts in carbon emissions, gasification needs to be combined with carbon capture technology as a pre-combustion carbon capture process. This involves separating the 'syngas' (synthetic gas) generated from gasifying coal into a hydrogen-rich gas that can be burned and a stream of CO_2 that can be extracted. The CO_2 then needs to be transported to a suitable site (saline aquifer or depleted hydrocarbon field), injected and stored. This has been partly achieved, for example at the Great Plains synfuels plant in the USA. However, it has not yet been combined with commercial-scale power generation using the syngas.

3.1.3 Description of technology

Gasification as an industrial process

Gasification as an industrial process is an established technology with many applications. These include steam, chemicals (e.g. ammonia, methanol, acetic acid), fertilizers, clean fuels and hydrogen. Most basic products produced from refineries or from oil or natural gas conversion can also be produced by gasification.

There are three main types of gasification technologies currently available. These are:

- *Fixed bed gasifiers*: These haven't worked well with high ash Indian coal as the ash and hydrocarbons tend to collect in the bed.
- *Fluidised bed gasifiers*: This technology is widely believed to be most appropriate for Indian coal.
- *En-trained flow gasifiers*: These require the coal to be ground up and injected as small particles. This technology hasn't worked well with Indian coal as the ash had to be burnt off which resulted in too much energy loss from the coal. The ash is also highly abrasive which has resulted in it damaging the grinding equipment.

IGCC for power generation

The Integrated Gasification Combined Cycle (IGCC) is an outgrowth of the gas-fired Combined Cycle Gas Turbine (CCGT), the technology which has dominated global power plant orders in recent years. The basic difference between these two technologies stems from the presence of a gasifier and gas clean up equipment in an IGCC. This allows it to burn synthetic gas (or syngas) produced from coal or other fuels such as heavy oil residues or biomass instead of using natural gas.

Underground coal gasification

Underground coal gasification (UCG) is the in-situ gasification of coal in the seam. It is achieved by injecting oxidants, gasifying the coal and bringing the product gas to surface through boreholes drilled from the surface. This is an attractive technology for India due to the very high ash content (around 50%) of much of India's coal reserves. Gasification of raw, unwashed coal via UCG can therefore avoid the high financial and environmental costs of washing and transporting Indian coal. Two locations in India, one in Rajastan and another in Bengal-Bihar, have previously been identified as potential sites for UCG. As mentioned above, this case study focuses on IGCC and does not cover UCG.

3.1.4 Identification of firms owning relevant technologies

The current technology leaders in gasification are Shell and Texaco (the latter having been bought by GE with an ambition to sell turnkey IGCC plants). Shell and Texaco/GE's gasifiers are mainly en-trained flow gasifiers.

Capabilities also exist in specific component technologies. For example, British Gas and Lurgi have developed their own gasifier technology.

In addition to the above, some capabilities exist in other countries including India (see below) and China. In China, indigenous technology lags behind the international state of the art. New gasifiers are currently being implemented in China in partnership with Shell which had 14 current gasification projects ongoing in China in 2005 (Shell 2005).

3.1.5 Identification of firms in India

BHEL, the largest power plant equipment manufacturer in India, has a range of capabilities and a long history of collaboration and licensing agreements with international firms such as GE and Siemens. They have built a small scale fluidised bed gasifier for testing purposes (6.2MW) using Indian coal. Some independent observers who have studied BHEL's gasifier have been quite positive about its potential viability.

BHEL have made an important contribution in researching the use of high ash Indian coal in the gasification process. BHEL has also developed a Hot Gas Cleanup System (HGCS) using a granular bed filter system coupled to a 6 tonne per day (tpd) Pressurised Fluidised Bed Combustion (PFBC) system. Hot gas cleaning within the gasification process has, for many years, been one of the greatest challenges – particularly if the gas is to be burned in a modern gas turbine. Advanced gas turbines are very sensitive – impurities in the fuel gas mean that failures are more likely and more frequent maintenance is required.

Consultation undertaken during this study suggests that BHEL have been talking to NTPC (National Thermal Power Corp) – the national utility – and the Indian Planning Commission about taking this work forward. Their ultimate aim is to build a 125MW IGCC demonstration at the Auraiya power plant (BHEL 2006).

NTPC, the Indian national power company, have also been thinking about gasification. Whilst, as noted above, NTPC are talking to BHEL about IGCC, it would appear that they are mainly focussing on the possibility of collaboration with US based organisations. In the past NTPC have received funding from USAID to carry out a feasibility study for a planned IGCC facility at its Dadri facility (BusinessLine 2002). This includes testing of Indian coal in US labs such as the Gas Research Institute in Chicago.

More generally, the US is perceived to be working to persuade India to engage with it on gasification. This includes a bilateral US initiative to form a multi-funded energy programme that includes gasification in which India has invested US$10m, as well as a more multi-lateral approach via the Asia Pacific Partnership which the US is viewed to be coordinating.

3.1.6 Other relevant institutions

Other important institutions identified as playing a role in IGCC in India include:

- The Planning Commission: In India the Planning Commission has a key role to play in negotiating and granting permission for building gasification plants.
- USAID: USAID has, in the past, also played a role by funding a BHEL IGCC feasibility study. The US is fairly active more generally in lobbying developing countries such as China and India to consider IGCC. This is generally perceived as an effort on the US' behalf to recover the money that the US government has invested in IGCC demonstration.

3.1.7 Current commercial status of technology

Although the first coal-fired IGCC plant went into operation twenty years ago, this technology is still in its demonstration phase. Coal-fired IGCCs have been constructed at several sites in the USA and Europe. Table 3.1.1 below gives details of the five main 'utility-scale' demonstration plants which have been built in the last decade or so. All have been supported by public funding – in this case from EU Framework Programmes and the US Clean Coal Programme.

Table 3.1.1: Capital Costs of Coal-fired IGCC Plants

Plant	**Year(1)**	**Capacity**	**Equipment . . . Gas Turbines**	**Gasifier(2)**	**Capital Cost(3)**
Buggenum, Holland	1994	253MW	Siemens V94.2	Shell OB	\$600m (\$2400/kW)
Wabash River, USA	1995	262MW	GE 7FA	Destec OB	\$438m (\$1670/kW)
Tampa Electric, USA	1996	250MW	GE 7FA	Texaco OB	\$510m (\$2040/kW)
Puertollano, Spain	1997	300MW	Siemens V94.3	Prenflow OB	\$600m (\$2000/kW)(4)
Pinon Pine, USA	1998	100MW	GE 6FA	KRW AB	\$335m (\$3360/kW)

(1) First full operation on coal gas.

(2) Gasifiers are either oxygen-blown (OB) or air-blown (AB).

(3) Costs are in money of the day. All of these plants have been subsidised. The US Department of Energy contributed \$219m to Wabash River, \$150m to Tampa Electric and \$167m to Pinon Pine. So far, Puertollano has received 52.7mECU (approx. \$65m) from the EU Thermie programme.

(4) Puertollano's capital cost rose to \$2900/kW due to interest charges during a prolonged construction period.

Source: Various manufacturer and government publications.

3.1.8 Cost structure of the technology

The figures in Table 3.1.1 show that the capital costs of new IGCC plants are substantial in some cases. In general, financial performance has been slightly better in the USA than in Europe. Apart from the relatively small Pinon Pine project, the costs of constructing an IGCC plant in the USA are closer to the \$1400/kW-\$1700/kW (circa. £900-£1100/kW) range which was often quoted at the time they were constructed (e.g. Simbeck and Karp, 1996). In Europe, the limited evidence suggests that capital costs were at least 20% higher.

Recent experience with the gas-fired CCGT suggests that competition between gas turbine and gasifier suppliers could deliver lower costs for fully commercial plant. The figures in the table from the UK Energy Review report assume that a UK-based IGCC would cost £1000/kW (DTI 2006). Other assessments are more optimistic on costs. One desk study by a British research team a few years ago estimated costs of around 1100 Euros/kW (circa. £700/kW) (McMullan et al. 2001).

It is notable that even the more expensive DTI estimate is only slightly higher than estimates given for a UK-based supercritical Pulverised Fuel (PF) plant. It is also important to emphasise that the accuracy of these estimates has not yet been tested. No commercial coal-fired IGCC plants have been built anywhere in the world, let alone in the UK.

A key cost consideration in the context of India arises from the high ash content of Indian coal. In order to take advantage of en-trained flow gasifiers, Indian coal must be combined with better quality imported coal or petroleum coke. Combing the coal with other feed stock is also necessary in order to produce a syngas of high enough quality to produce fertilizers. This implies that gasification for fertilizer production in India is a more expensive process than it might be for power generation. The higher cost might, however, be offset by higher margins on selling fertilizer relative to electricity.

As well as capital costs, operation and management (O&M) costs can also be high for IGCC plants. O&M may also require considerable investments in training and skills development, particularly in the context of technology transfer initiatives.

3.1.9 Perceptions among actors of main risks attached to technology

The two key risks associated with IGCC are high capital costs and the lack of reliable operational history. The risks associated with high capital cost are amplified by the limited operational history and the new nature of this particular application of gasification.

In terms of reliability, availability figures show some evidence of improvement during demonstration programmes. For example, Wabash River improved from an initial availability of 40% in 1995 to between 65% and 75% during 1997. Similarly, Tampa Electric's overall availability improved from 33% in 1996 to around 80% in its final three years of operation from 1999-2001 (TEC 2002). At Buggenum in Holland, availability has improved from initial low levels, and was quoted at 65-75% in 2002 and 2003. By contrast, the worst performer was the Pinon Pine plant in the USA which has now closed. Its coal gasification system was only operated for a total of 128 hours.

According to a more recent assessment by the Electric Power Research Institute (Holt 2003), none of the demonstration plants have achieved their target availability level of 85%. This assessment suggests that the main challenges for IGCC include system integration (getting a combined cycle plant and a gasification plant to work together) gas clean-up (making synthetic gas clean enough for modern gas turbines), and gas turbine reliability (particularly the case for European plants that used Siemens gas turbines).

Some of the published figures for the environmental performance of IGCC are summarised in Table 3.1.2.

Table 3.1.2: Environmental Performance of Existing IGCC Plants

Plant	LHV efficiency	SO_2 emissions	NO_x emissions
Buggenum, Holland	43.0%	<0.22g/kWh	<0.62g/kWh
Wabash River, USA	41.2%	0.05-0.16g/kWh	0.34g/kWh
Tampa Electric, USA	38.9%	97% removal	0.32g/kWh
Puertollano, Spain	42.2%	unknown	unknown

Source: As Table 3.1.1, except LHV efficiency figures which are from Holt (2003).

The figures in Table 3.1.2 show that the environmental performance of IGCC technology has lived up to expectations. In terms of thermal efficiency, sulphur dioxide and nitrogen oxides IGCC performance is at least as good as other cleaner coal options such as PFBC and supercritical PF. It is interesting to note that the US plants have lower thermal efficiencies than those in Europe. In the case of Wabash River, this can be explained by the fact that an old steam turbine has been repowered with a new gasifier and gas turbine.

Since the construction of the five demonstration plants listed in Table 3.1.2, no further coal-fired IGCC plants have been built. However, at least two US utilities (Cinergy and American Electric Power) have announced their intention to construct new coal-fired IGCC plants in the next few years. Two further IGCC plants have been given the go-ahead under the clean coal programme's successor, President Bush's Clean Coal Power Initiative. Provisions for subsidising such new plants were included in the recently passed US Energy Policy Act of 2005, making the chances of implementation high (Neff 2005). In Japan, concrete IGCC development plans are also underway. A new 250MW demonstration plant is due to begin operating in 2008. It is being developed by a consortium of Japanese utilities with support from the Japanese government.

The combination of IGCC and carbon capture technologies introduces further risks and uncertainties. The process for removing carbon dioxide from syngas is already in use – for example, the Great Plains synfuels plant in the USA does so on a scale suitable for power generation applications. However, the technical advances necessary to allow hydrogen to be burned in a gas turbine have not yet been made. Whilst General Electric has one gas turbine plant in Germany that burns syngas containing 60% hydrogen, pure hydrogen combustion presents challenges for materials, emissions control etc. An alternative to this would be to use the hydrogen directly in a fuel cell.

Although pre-combustion carbon capture in a power station has yet to be demonstrated, a number of government and industry R&D initiatives are underway. Perhaps the most notable is the US Department of Energy's FutureGen project. This $1bn project aims to design, construct and test a 275MW IGCC electricity and hydrogen plant. The plant was originally scheduled to be in operation by 2011, though this is now subject to delay due to difficulties in securing funding from Congress (Platts 2005).

In an Indian context, another technological risk exists in relation to the limited amount of testing of IGCC that has been done with Indian grade coal. All IGCC demonstration plants to date have been based on coals with different characteristics to Indian coal, especially ash content and ash fusion temperature. There is therefore limited existing empirical data on how these technologies would perform if applied to Indian coals. Some Indian respondents to this study have expressed frustration with a lack of international information sharing on IGCC which hampers their ability to consider domestic applications of the technology.

3.1.10 Analysis of incentives and policy interventions

Incentives to reduce the risks associated with IGCC need to be targeted both at overcoming problems with high capital costs and increasing the level of operational experience with IGCC. A central consideration in the context of India is the limited existing empirical data on IGCC and Indian coals. This implies a need for indigenous R&D and possibly full-scale demonstration before commercial plants would be viable. The work of BHEL on testing IGCC with Indian coal is therefore of vital importance here. This may be further assisted by engaging in collaborative, cross-industry, international initiatives to share information on advanced coal technologies, which would offer a means to reduce the risks and future costs associated with IGCC. One example of such an initiative is the US Electric Power Research Institute (EPRI)'s CoalFleet study. EPRI are open to non-US participants so it may be worthwhile for India to investigate the feasibility of engaging with this study.

One possible approach to overcoming the risks of high capital costs is for government to share the funding of demonstration activities with industry. This is the approach taken by the U.S. Department of Energy for the Clean Coal Technology Program (known as the CCT program) where industry met 65% of the cost. The approach involved demonstration plants being set up at commercial scale by industry at their own privately owned premises and with industry retaining intellectual property rights. The Government's share in the cost of the project is then repaid by the industry only upon commercialisation of the technology (WEC 2005). It should, however, be noted that very little has in fact been paid back due to a lack of commercialisation among the existing demonstration plants.

The capital subsidies approach applied in the US and Europe does not seem to have been successful in encouraging the commercialisation of IGCC to date. Whilst capital subsidies are good for financing one-off demonstrations to explore a range of new technologies, they do not provide an incentive for operators to maximise performance and reliability. One alternative approach might be to offer support for IGCC on a performance basis. This could involve governments entering into agreements to grant carbon credits to IGCC plants on the basis of emissions targets that must be met or exceeded during operation. Alternatively, IGCC plants could be allowed to sell their electricity at a higher price than commercial technologies.

Valuing carbon emissions from power generation through taxes or emissions trading is one approach that could improve the relative cost competitiveness of IGCC for investors. Evidence from analysis carried out by Ghosh (2005) suggests that IGCC becomes competitive with supercritical pulverised coal only under a considerably high penalty level of $200/ton of carbon and higher. If, however, carbon capture and storage can be achieved, IGCC competitiveness is significantly enhanced with the break-even tax level at which IGCC emerges as an economic choice over supercritical pulverised coal being around $75 per ton of carbon (Ghosh 2005).

This analysis should, however, be treated with caution. Operational experience to date suggests that supercritical and IGCC technologies have broadly similar performance (Watson, 2006). In the absence of carbon capture, IGCC will not have a clear economic advantage at any carbon price. With carbon capture, there is an expectation that IGCC will be cheaper if carbon prices are significant. However, this is based on theoretical predictions that the addition of carbon capture equipment to IGCC can be achieved at a lower energy penalty than addition to supercritical technology. This reinforces the need for further R&D and demonstration of IGCC technology – both within India and internationally.

3.1.11 Interventions with more medium/long term implications

The interventions suggested in Section 10 above are all important in terms of long term technological capacity building in the field of IGCC. There are, however, some additional interventions that would be beneficial in the long term.

The analysis presented in the literature review for this study highlights the fact that the long-term success of technology transfer in technologies such as gasification relies on building technological capacity within recipient countries. As well as developing the absorptive capacity Indian firms by improving national systems of innovation, this also relies on working with firms to encourage lower levels of integration in transfer activities and encouraging them to adopt specific, strategic approaches to acquiring knowledge as part of the transfer process.

Participation in international initiatives to share information on technology, such as the UNFCCC's TT:CLEAR, also has a clear role to play in encouraging technology transfer and developing India's technological capacity in IGCC. India's engagement with the Cleaner Fossil Fuels Taskforce of the Asia-Pacific Partnership on Clean Development and Climate represents another potential approach to information sharing that may yield useful opportunities for sharing and developing technological expertise. There may also be other opportunities such as participation in demonstration projects outside India – though careful thought should be given to the potential usefulness of these given the particular characteristics of Indian coal. A Chinese utility (China Huaneng Group) has already joined the FutureGen alliance that is planning to build a zero emission IGCC-based plant in the USA.

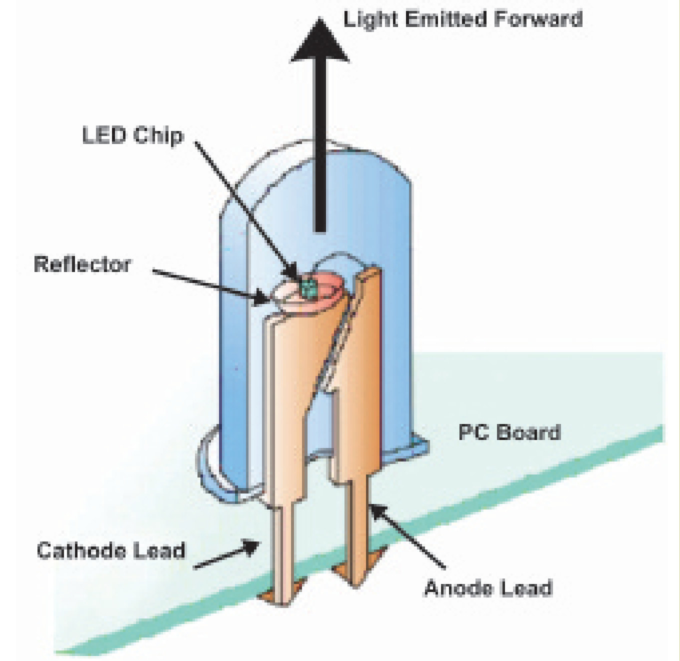
A clearly defined and properly enforced policy in relation to carbon emissions from power generation and industrial processes will also have a key role to play in creating the necessary conditions to encourage investment in low carbon technologies, including IGCC.

3.2 LED lighting (TERI)

3.2.1 Introduction

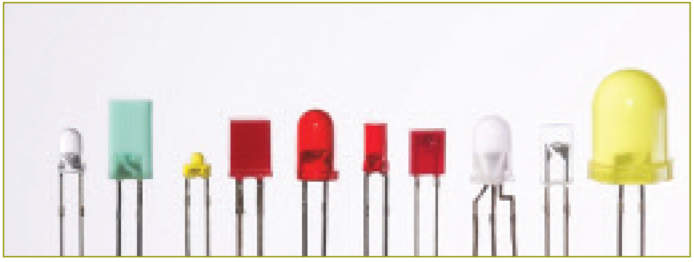
A Light Emitting Diode (LED) is semiconductor diode (p-n junction diode) formed by a semi-conducting element, which emits light when a forward voltage is applied to the p-n junction.

Figure 3.2.1: Structure of a typical LED



The material used in the semi-conducting element of an LED determines its colour. Conventional LEDs (red, green and blue) are made from a variety of inorganic semiconductor materials as shown in Figure 3.2.2.

Figure 3.2.2: Various types of LEDs



As far as the technological advancement of various types of LEDs is concerned, red LEDs were developed first followed by green and blue LEDs (as shown in Box 1). LED development began with red devices made with gallium arsenide. In due course, advances in material research made it possible to produce devices with shorter wavelength, producing light in a variety of colours.

Box-1:

Historical development of LEDs

1962:	First LED in the Lab
Late 1960:	Low output red LED (<1 mcd), used for commercial application as an indicator
Mid 70s:	Green LED
Early 90s:	Blue (Nakamura)
Late 90s:	Commercialisation of high brightness LEDs

Although LEDs (red and green) were first developed in the 1960s, they were mainly used for coloured light applications such as indicators. They were only recently used for various general lighting applications when white LEDs were developed in 1993[3] and became widely available in the late 1990s.

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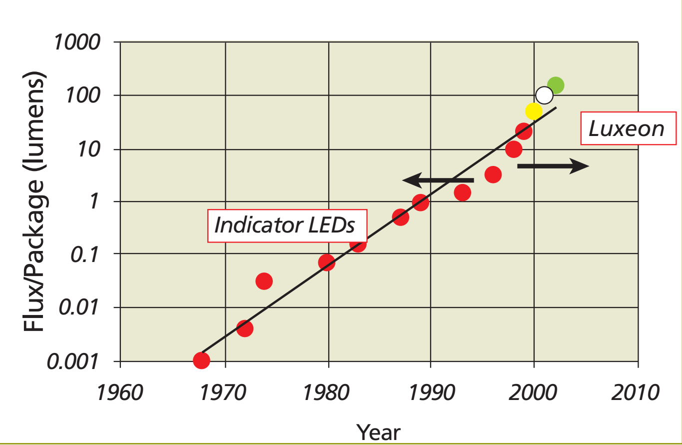
[3] By Shuji Nakamura while working at Nichia Corporation in Japan.

Figure 3.2.3 Evolution in LED

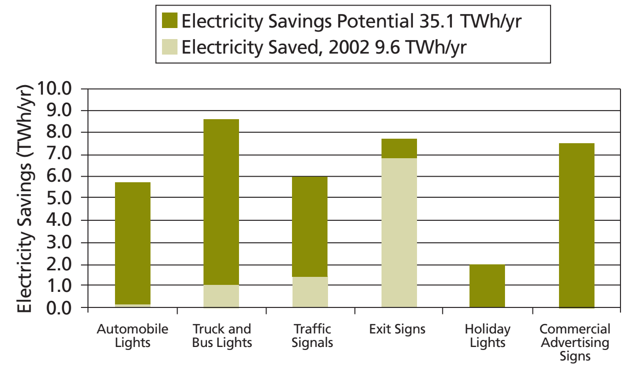


As the focus of this study is on low carbon end-use technology, this case study focuses on LEDs for general lighting applications, or white LEDs.

3.2.2 Contribution to reducing carbon emissions

A major part of the electrical energy consumed in domestic or commercial building sectors is for lighting applications. Electricity consumption for lighting can be drastically reduced by using more efficient lighting devices. LED lamps are seen as one of the most efficient future lighting sources due to their long life and low power consumption. The International Energy Agency (IEA) has reported that the total power consumed by lighting equipment cost about USD 230 billion worldwide in 1998 and this power generation created about 410 million tons of carbon emissions. In this context, the excellent power saving opportunities from using LEDs can help in reducing power consumption and carbon emissions. Figure 3.2.4 shows the energy saving potential of LEDs in different lighting applications.

Figure 3.2.4: Energy saving potential of LEDs in niche lighting applications



Data from:
"Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications"
U.S. Department of Energy
November 2003

One US energy study has concluded that solid-state lighting in the foreseeable future could save 3.5 quadrillion BTUs of electricity. Additionally, global carbon emissions from future power plants could be reduced by 300 million tons/year if LED-based lighting takes hold in the next decade, according to another US estimate. (Sandia National Laboratories, Next-Generation Lighting Initiative (NGLI).

3.2.3 Description of technology

The first step for finding out the scope for technology transfer is to understand the different processes involved in LED manufacturing and the gaps (if any) that exist between worldwide manufacturers and Indian LED producers. The following sections therefore discuss the status of the technology and various barriers that might exist for transferring of LED technologies to India.

Processes involved in LED manufacturing

Manufacturing LED products involves the following steps:

Semi-conducting material development

The first step in LED manufacturing is to develop the semi-conducting material. The two semi-conducting materials presently used for LED lighting systems are:

- Aluminium gallium indium phosphide (AlGaInP) alloys for red, orange and yellow LEDs
- Indium gallium nitride (InGaN) alloys for green, blue and white LEDs.

Slight changes in the composition of these alloys changes the colour of the light emitted. The majority of the GaN based LED manufacturers worldwide use large-scale reactors as the next generation mass production tool for blue, green and white LEDs.

LED chip manufacturing

LED chip manufacturing involves several processes such as wafering, polishing, epitaxial deposition, fabrication and testing.

The lumen output of LED chips produced by the world leading manufacturers has been increased significantly by adopting different techniques. One such technique is improving the surface area for maximum collection of light (as shown in Figure 3.2.5).

LED packaging

Once the LED chip is manufactured, it undergoes several packaging processes such as dia- bond, wire bond, encapsulation and testing. The performance of LEDs depends upon ambient temperature, the current passing through the LED, the amount of heat sinking material, the type of optics used etc. These issues can be addressed during packaging. The overall performance (optical, maximum light extraction, electrical and thermal performance) of the LED output depends largely upon its packaging.

There are no white LED chips as such, the white LED is mainly produced from conventional LEDs (Red, Green or Blue) or UV LED during the packaging process.

Figure 3.2.5: Different shaping of LED chip

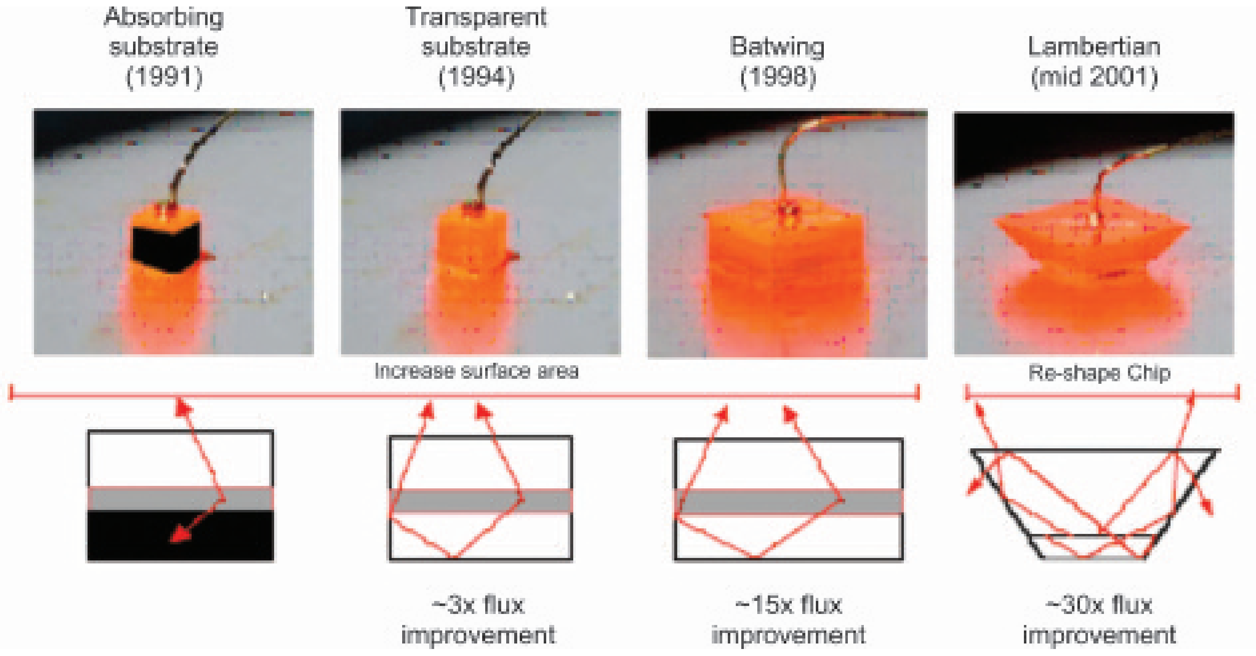
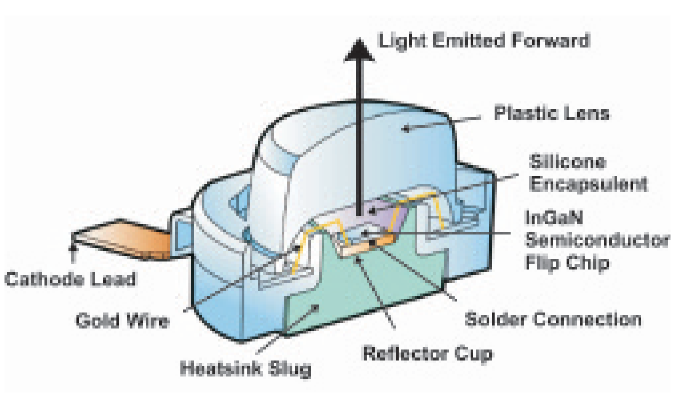


Figure 3.2.6: Cross section of a typical LED



White LEDs
There are two approaches to creating white light with LEDs:

Mixed colour white light
Mixing of light from several coloured LEDs to create a spectral power distribution that appears white in colour

Phosphor converted white light
Generating white light through the use of phosphors together with a short wavelength LED. For example, when one phosphor material coated LED is illuminated by blue light it emits yellow light as it has a fairly broad spectral power distribution. Therefore, incorporating such phosphors into the body of a blue LED produces yellow light by converting some of the blue light. The rest of the blue light is mixed with the yellow light to produce white light.

The advantages of mixed colour white LEDs are (i) higher overall luminous efficacy (ii) good colour rendering properties. The difficulty is maintaining colour stability over the life of the LED and at different operating conditions including dimming.

On the other hand, the advantage of phosphor converted white LEDs is that they have a single, compact white light source. However, the efficacy is less than mixed coloured white LEDs.

Photovoltaic (PV) integrated white LED based lighting systems are one of the most feasible and cost effective options for rural lighting applications.

3.2.4 Identification of firms owning relevant technologies

Worldwide, there are several LED chip manufacturers (some of those manufacturers are listed below) and packaging units. Table 3.2.1 shows the profile of the firms owning LED technology.

Table 3.2.1: Profile of firms owning LED technology

Manufacturers	**Company profile**
1: Cree, Inc, USA	Established in 1987, Cree develops and manufacturers semiconductor materials and devices based on silicon carbide (SiC), and gallium nitride (GaN), which is the basis for developing LEDs. Cree's LED chip products include blue, green and near UV devices made from GaN and related materials grown on SiC substrate. Cree LED chip manufacturing involves 6 processes: SiC crystal growth, wafering, polishing, epitaxial deposition, fabrication and testing. Cree is also involved in packaging some high-powered LEDs. However, the majority of its LEDs are sold in chip form to several customers who then package it for various applications.

Table 3.2.1: Profile of firms owning LED technology *(continued)*

Manufacturers	**Company profile**
2: Lumileds Lighting, LLC,California	Lumileds is headquartered in San Jose, California, with operations in the Netherlands, Japan and Malaysia and sales offices throughout the world. Lumileds began as the opto-electronics division in Hewlett-Packard (HP) almost 40 years ago. In the late 1990's, recognizing the potential for solid-state lighting, HP and Philips, one of the world's leading lighting companies, began exploring how they could work together and deliver a new solid-state lighting solution to the market. In 1999 HP split its company into two, and the opto-electronics group was assigned to the new Agilent Technologies. In November of the same year, recognizing the enormous potential for LEDs, Agilent Technologies and Philips (NYSE:PHG) formed Lumileds and assigned it the responsibility of developing and marketing the world's brightest LEDs and enabling a new world of light. In 2005, Philips acquired Agilent Technologies' interest in Lumileds. The company supplies core LED material and LED packaging. It manufactures billions of LEDs annually, and ranks as the producer of the world's brightest red, amber, blue, green and white LEDs. Lumiled has few LED distributors in India (one of the distributors is Future Electronics in Mumbai)
3: Nichia Corporation, Japan	Established in 1956, Nichia has grown in the field of manufacturing and sales of fine chemicals, particularly inorganic luminescent materials (phosphors). In the process of the challenging pursuit of brighter luminescent and light-emitting materials, it succeeded in developing and commercialising the super high brightness Blue LED in 1993. Its Head quarters are in Japan with subsidiary locations in Taiwan (Hsinchu), America (Lancaster, Detroit, California), Malaysia (Selangor), The Netherlands (Amsterdam), Germany (Kronberg, Nürnberg), China (Shanghai, Hong Kong), Singapore, Korea (Seoul) , India (New Delhi), Thailand (Bangkok)

Table 3.2.1: Profile of firms owning LED technology *(continued)*

Manufacturers	**Company profile**
4: OSRAM Opto Semiconductors, Germany	Osram Opto Semiconductors GmbH is one of the world's two largest manufacturers of optical semiconductors in the lighting, sensor and visualisation sectors. The company has more than thirty years of experience in the development and manufacture of optical semiconductor components and combines extensive know-how in semiconductors, converter materials and packages under one roof. Its expertise is evidenced by more than 2000 patents in various areas of semiconductor technology. The company has its headquarters in Regensburg, Germany and development and production sites in San José (California) and Penang (Malaysia) and employs more than 3500 people throughout the world. Osram Opto Semiconductors has a far-reaching presence in the optical semiconductor market with visible and infra-red LEDs, organic LEDs (OLEDs) and lasers and offers semiconductor components in various sizes, brightness levels and package formats – from mini chips with edge lengths less than 0.1 mm to high-power chips with outputs up to 2W, mains for surface mounted technology (SMT) packages. In keeping with the trend toward smaller and smaller light sources with greater and greater luminous efficacy the company has developed various LEDs including Micro SideLED, ChipLED and PointLED. OSRAM has several LED suppliers in India.
Gelcore, USA	GELcore, formed in 1999, was previously a joint venture between GE and the Emcore Corporation of Somerset, NJ. Owned by GE and supported by Nichia, GELcore combine strong lighting industry leadership and brand recognition with a deep understanding and broad expertise in semiconductor material development. Standing at the forefront of today's global LED revolution, GELcore offers a wide range of world-class, environmentally friendly LED solutions and systems for signage, architectural, transportation, display lighting and general illumination applications. General Electric says it will invest $100 million to buy out Emcore's interest in its joint venture GELcore, which makes energy-efficient LED lighting for outdoor and transportation-related signs.

There are number of LED packaging units[4] across the world that purchase LED chips. The chip manufacturers have several packaging vendors, with whom they have the technical/supply tie up.

Box No – 2: LED chip manufacturing – A very capital intensive process

Discussion with Nithi M Nithipalan, President & CEO, TEKCORE, a leading LED chip manufacturing unit in Taiwan raised the issue that chip manufacturing requires a minimum investment of around 200 million USD, which is capital intensive. They are not keen on establishing any chip manufacturing unit in India as at present they have not found any potential market. However, they have shown interest in some joint collaboration with packaging units.

3.2.5 Identification of Indian firm owning relevant technology

To date there is no LED chip manufacturer in India. There is only one approved Packaging unit in India – Kwality Photonics, located at Hyderabad[5].

Company profile of Kwality Photonics:

Established in 1966, Kwality Group of Industries includes Kwality Electronic Industries and Kwality Photonics Pvt. Ltd. which is India's only packaging unit and producer of LEDs, LED Displays & Opto Electronic Products. Kwality offers over 600 types of LEDs, LED Displays & Opto-electronic Products and obtained ISO 9001:2000. The raw materials used for manufacture are sourced from vendors in Japan, Taiwan and the USA. The work force is mostly post-ITI and is trained on a continuous basis to produce consistently high quality products. There are several LED system integrators and suppliers in India.

Box No – 3: Creating a market for LEDs in India is the first step towards technology transfer and government investment is required in R&D

The summary of discussions with CEO, Kwality Photonics is as follows:

- Kwality has not tied up with anyone and packaging is a self-taught technique. Only raw materials (LED chips, material for phosphors etc) are imported from outside.
- At present the company does not have any long term arrangement with any specific chip manufacturers and imports chips from Japan, Taiwan, USA and china
- In his view, chip making is a multimillion-dollar business and lots of strength in R&D is required whereas packaging can easily be done in India. He explained that out of the 4 processes required for packaging, all processes apart from wire bond can be done manually. Therefore, if raw material stocking and indigenous manufacturing of wire bond can be done, then packaging could be a potential business in India.
- He also mentioned that the market needs first to be created in India. In his view, Government has to take the initiative and must have a million-dollar LED programme in order to attract world leaders to invest in India.
- Besides that, Government investment is required in R&D.

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[4] Interaction with Nithi M. Nithipalan, President and CEO of TEKCORE CO Ltd (A chip manufacturing unit in Taiwan revealed that there are around 600 LED packaging units in Taiwan alone.

[5] Personal discussions with CEO of Kwality Photonics took place on 19th July, 2006 on the technology transfer issues.

Box No – 4: Market has to be created in India for LED

Discussion with Future Electronics (a distributor of Lumiled LEDs) raised the following points:

- Lumiled is mainly looking for the market potential that exists in India for LED products. At present, as the market does not exist in India (or is not very clear), Lumiled does not have any huge plan of investing.
- As India is already far behind than rest of the world in the field of LED (although there exists large opportunities/potential), Government initiatives, collaborative efforts (University-industry collaboration) are required without any further delay.

Box No – 5 Solar PV based White LED systems under Ministry of Non Conventional Energy Sources (MNES)

Recently LED based solar Home Lighting systems and Street Lighting systems have been developed and undertaken by the Ministry. But at present there is no specific programme related to LEDs. It is expected that the recently developed systems would be demonstrated in some of the rural villages and subsequently a programme can be formulated.

Box No – 6 Market development for white LED based lighting systems by Light up the World Foundation (LUWF)

'Light up the World Foundation' (LUWF), a humanitarian organization, is involved in disseminating the White LED (WLED) based lighting system to several homes in the developing world. LUWF disseminate the systems through projects and local entrepreneurial means. Some of the ways followed by LUWF in order to create the demand include:

- ✓ Raising awareness of the practical use of WLED for home, task and mobile lighting on a broad scale to a number of market segments
- ✓ Micro enterprise development
- ✓ Drive down the cost through innovative designs and preferential supply chain relationships: LUFW has partnership with Lumileds and can source Lumiled products (Luxeons) to local businesses and social organizations in developing world markets. In addition, one of the future strategies is to bring prospective battery and solar module manufacturers into the supply chain.
- ✓ Adopting effective delivery mechanisms: To increase the capacity to deliver, LUTW is securing additional partnerships with strong, capable and committed in-country social organizations such as Centre for Rural Technology (CRT) in Nepal and Agricultural Development Authority in Sri Lanka.

LUFW has local business partners in several countries such as Geetanjali Solar in India. LUWF is planning an ambitious large-scale multi-stage project involving up to 1500 villages through Rotary Clubs in India over the next few years. LUWF, through its work in Sri-Lanka, has become an accredited commercial partner of the World Bank.

Box No – 7 Installation of WLED based small solar PV system in Nepal

A number of white LED based PV systems having capacity less than 10Wp are installed in Nepal. At present there is no provision of subsidies for such small systems. Some NGOs and private manufacturing/installation companies have been promoting the system in different rural areas. The Center for Renewable Energy (CRE) has installed 78 such systems on a pilot project basis supported by different funding agencies. Some private companies such as Solar Electricity Company, Bionic energy, SEC Energy and Swogun Energy etc are promoting WLED based small systems on their own.

3.2.6 Identification of other relevant institutions involved in LED technology

In India, very few institutions are involved in LED technology. These include Tata Institute of Fundamental Research (TIFR), Mumbai , CREE, Pilani, Indian Institute of Technology(IIT) Madras, IIT Kanpur. TIFR and CREE are producing GaN material at the lab-scale. Their perception on major risks involved with LED technology is that no commercial manufacturer who manufactures the semi-conducting material[6] in India. Although a few institutions such as IIT Madras, Indian Association for Cultivation of Science (IACS) are involved in different approaches to phosphor converted white light (White LED), it is not fully commercialized.

Box No – 8: LED Development in India – A lesson on catching the bus on time'

Summary of discussion with IIT Kanpur:

Timely investments in R&D are important if the country wishes to develop indigenous capacity in new technologies. As an example, take the case of LEDs for lighting applications. Innovations in solid-state lighting (SSL are at the threshold of bringing about a revolution in energy efficient white lighting systems. DOE (Department of Energy), US have been supporting a series of R&D projects amongst manufacturers and universities in the US since the mid-1990s. No such support was forthcoming from DST (Department of Science and Technology), India around that time although some consultation, visits and workshops did take place.

The proactive attitude adopted by DOE has helped US lighting firms like Lumileds and the University of California, Santa Barbara to establish a head start in SSL technology.

Technology development is a high cost and high risk exercise. In most sectors, home grown Indian firms seldom take such risks. The government must play a major role in supporting R&D in new cutting-edge technologies, preferably through private-public partnership projects.

Technology transfer is a business to business (B2B) transaction. A manufacturing process often consists of several discrete components or steps. For example LED chip manufacturing involves seven or eight steps. A certain level of indigenous R&D capability is required in a new technology even if a firm wishes to negotiate transfer of a part of the manufacturing technology where there are gaps. Complete transfer of manufacturing technologies can happen only in the case of technologies which have reached maturation and where R&D costs have been received by the sale of the product.

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[6] Personal discussion with Prof. Deepak Gupta, IIT Kanpur

Box No – 8: LED Development in India – A lesson on catching the bus on time' *(continued)*

Technology transfer barriers are sometimes a function of geographical country of origin. For example, in OLED technology, it has been found that Japanese firms are more wary of exporting technologies to India compared to European or US firms. The reason for this needs further investigation and probably some help through diplomatic channels.

Technology transfer issues

No home grown R&D on gallium nitride in India. Recently, TIFR & CEERI, Pilani have imported reactors for dye making and have nascent R&D programs in LEDs

Dye making technology will not be transferred to India until costs are recovered by leading manufacturers

There are serious IPR issues regarding technology transfers

Box No – 9: Import of LED is much easier and cheaper than to manufacture it because of IPR issues

Discussion with Prof. N Narendran, Director of Research, Lighting research center, New York highlighted the following:

- In his view the market transformation activities are already in place in the USA and there are joint collaborative efforts from research institutions, manufacturers, social researchers etc that aim to transform the LED system for the end-users.
- In India there is no clear indication about the type of market that exists for LEDs . The first step is to create the market in India. He also expressed the opinion that, in the field of LED, India stands far from other parts of the world. Unless and until the market is created there is little scope for development in the field of LEDs in India.

Box No – 9: continued

- On technology transfer issues, he mentioned that it is easier and much cheaper to import the discrete LEDs than manufacturing and packaging them (especially for India, where the market itself is not very large). As there are a number of patents associated with each process and almost all manufacturers sue each other over patents it is really difficult to resolve the IPR issues.

Box No – 10: Collaborative efforts between universities/research institutions and industry needs to be established.

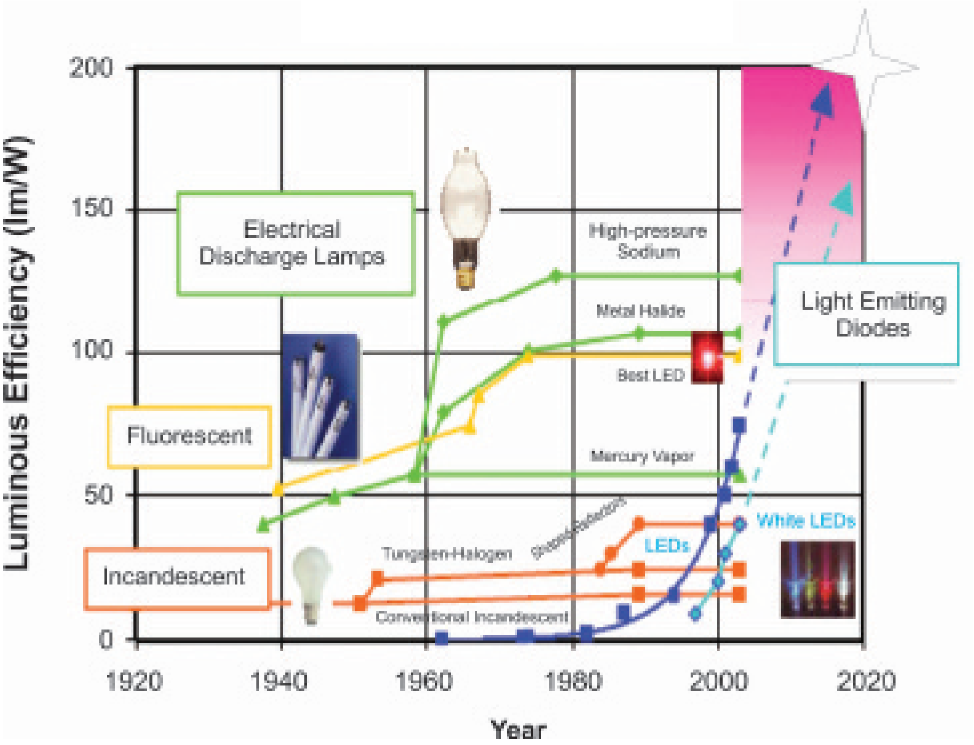
Discussion with Dr M M.K Samy, Material Science Research Centre, IIT Madras highlighted the following:

- IIT Madras in mainly involved in developing different phosphors (including nano-phosphors) for producing white light.
- In Dr Samy's view, the business relationship between the research organizations and the manufacturing unit has to be established. He explained that, at present, the research work in India is project based and confined to a particular institution. As there are no collaborative efforts between institutions and manufacturers, the technology/technique developed at the lab scale is not converted to manufacturing. Institute-Manufacturing collaboration has to be established at the beginning and sufficient funds allocated for the entire process.

3.2.7 Commercial status

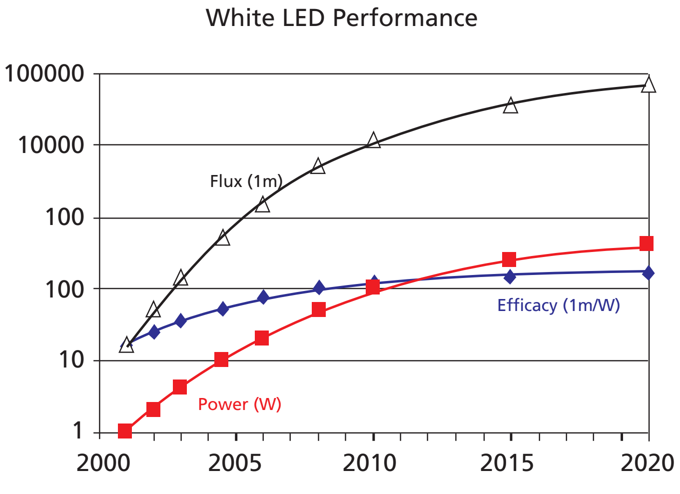
Figure 3.2.7 shows the performance of different lighting systems (commercially available) including LEDs. Worldwide, luminous efficiency of around 100 lm/W has already been achieved by the best type of LEDs.

Figure 3.2.7: Evolution of Lighting systems



However, as far as the commercial white LEDs are concerned, for a single chip the efficacy is 60-80 lm/W (as shown in figure 3.2.8).

Figure 3.2.8: White LED performance



Design evolution of LED packaging

LEDs consisting of a single element will not exceed the light output of conventional lighting sources in the near future. Therefore *currently* LEDs are available with multiple elements packaged together into a single device. This method is already able to reach a lumen output comparable to some of the low wattage incandescent lamps and such future products are likely to continue to offer greater light output.

Packaging during early systems had arrays of many LEDs whereas later products used fewer high output LEDs with lenses to shape the resulting distribution. More recently devices use even fewer LEDs with a combination of reflections, diffusers and lenses to get the higher output. In order to make white LEDs, in recent years the more commonly used approach is phosphor converted white light. The prime focus is to increase the overall luminous efficacy with more flexibility for achieving a range of colour properties based on phosphor availability. Figure 3.2.9 shows the comparison of Indian and international status for various steps of LED technology.

Figure 3.2.9: Comparison between Indian and international status in various steps of LED technology

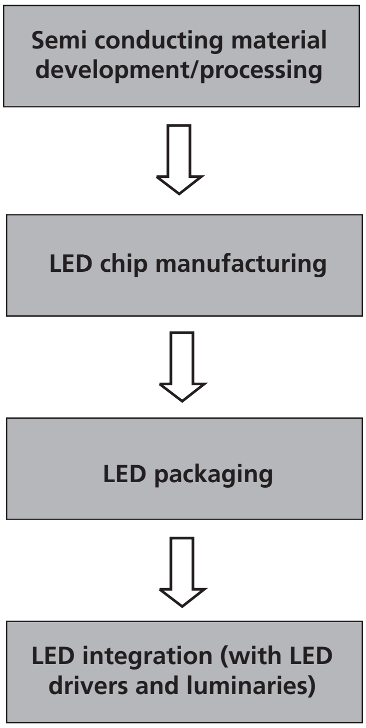
Indian status:

Material development:
Tata Institute of Fundamental Research (TIFR) is involved in producing Gallium nitride material at the lab scale by using AIXTRON mass production reactor. Semi conducting material used for LED chip manufacturing is not commercially manufactured in India.

Wafer and LED chip manufacturing:
There is no wafer or LED chip manufacturer in India.

LED Packaging:
Research in India on LEDs is mainly on developing different phosphors for producing highly efficient white LEDs. There is only one known LED-packaging unit in India i.e Kwality Photonics

LED system integration:
A number of LED system providers exist who import discrete LEDs, integrate them into LED arrays and include the appropriate LED driver circuit as per the requirement for various applications.



International status:

Material development:
USA and Japan are the world leaders in material development.

Wafer and LED chip manufacturing
USA, Japan, China & Taiwan are world leaders in LED chip manufacturing. Nichia Corporation, Cree Inc, Lumiled Lighting, OSRAM Opto semiconductors are the leading LED manufacturers owning relevant technologies.

LED packaging:
There are a number of LED packaging units across the world who purchase LED chips and package them into discrete LEDs. They may have technical tie ups with their LED chip supplier or have their own technique. Packaging units are more established in China, Taiwan and Japan.

LED system integration:
Several LED system integrators exist across the world.

3.2.8 Cost structure of the technology

Chip manufacturing is a very capital intensive technology and costs up to 200 million USD. The average sale price of white LED has been declining 20% per year and projection by the Opto-electronics Industry Development Association anticipates that "Life time ownership cost s of LED lighting systems will be less than incandescent bulb by 2007 and lower than fluorescent lamp by 2012."

3.2.9 Barriers

The main barriers to the transfer of LED technology are as follows:

Financial barriers:

LED chip manufacturing requires several processes. Each process involves energy as well as capital-intensive equipment.[7] The existing players in India are relatively smaller in size and are not ready/capable of investing huge amounts for LED chip manufacturing.

Financial barriers also exist for transfer of capital goods and equipments. Material production requires high investment in procuring the equipment and raw materials. Financial barriers also exist to sourcing raw materials. Sourcing of raw material is a critical issue.[8]

Policy barriers:

Intellectual Property Rights (IPR) issues: Another barrier relates to the IPR issue associated with LED manufacturing. It is a highly protected technology. As there are various processes involved in manufacturing LED chips, each process is patented and requires huge investment. At present the cost of investing in both chip manufacturing and resolving the IPR issues is substantially high compared to importing the chips. Therefore in India, the chips are imported primarily from China, Taiwan, Japan, the US and other countries.

Lack of intervention: There is no clearly defined policy environment for LED chip manufacturing.

Technology barriers:

Limited market size: The leading players worldwide are not considering India as a potential region for investment as they do not see any market in India at present. Unless and until the market is created in India for LEDs they may not consider India for any joint venture/technology transfer.

Lack of skills and know–how: Although the technical competency in India exists in the fields of material science, engineering, control electronics and other relevant fields, they have to be nurtured in the context of LED technology.

3.2.10 Key actors and their perceptions of risks

Technology transfer involves different actors and each actor has a degree of concern about the risks involved with the technology. Table 3.2.2 shows the perception of each key actor on major risks involved with LED technology.

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[7] Interaction with Nithi M. Nithipalan, President and CEO of TEKCORE CO Ltd (A chip manufacturing unit in Taiwan and Mr Vijay Gupta, CEO, Kwality photonics, the only one LED packaging unit in India

[8] Discussion with Prof. Deepak Gupta, IIT Kanpur

Table 3.2.2: Perception on major risks involved with LED technology

Stakeholder	**Perception on major risks involved with LED technology**
Manufacturers owning the technology	***Motivation:*** Expanding network of sale, market share, low cost of end product due to lower man power cost ***Risks:*** *Regulatory risk:* Protection of IPR *Technology risk:* Cost of LEDs is still very high compared to other lighting products. Probability of less acceptance of this technology in the field. *Financial risk:* Huge capital investment is required. Direct investment in India might not be profitable at this stage as there is no market driven initiatives.
Indian firms	***Motivation:*** Access to latest LED technologies Enhancing technical capabilities Ease of sourcing of raw material ***Risks:*** *Regulatory risk:* Maintaining environmental and other norms *Technology risk:* Probability of less acceptance of this technology in the field. *Financial risk:* Huge capital investment is required with less return on investment.
Government	***Motivation:*** Capacity building for domestic technology development Promoting foreign investment Achieving economic and policy reform Promoting LED based PV integrated lighting systems for rural lighting applications ***Risks:*** *Regulatory risk:* Maintaining environmental and other norms *Financial risk:* Specific budget allocation

Table 3.2.2: Perception on major risks involved with LED technology *(continued)*

Stakeholder	**Perception on major risks involved with LED technology**
Universities/Research institutions	***Motivation:*** Capacity building for domestic technology development Sharing of knowledge about the latest technological development across the world Possibilities of joint collaboration ***Risks:*** *Technology risk:* R&D might not result in viable end-product as per the requirements of the community
Multilateral agencies	***Motivation:*** Achieving developmental goals Enabling public-private involvement

3.2.11 Scope for technology transfer and intervention required

As outlined in the literature review of this report, technology transfer can be of two types, vertical (transfer of technology from R&D stage to commercialisation) and horizontal (technology transfer from one geographical region to another). In India, as far as LEDs are concerned, only horizontal transfer is relevant.

The technology transfer between world leading manufacturers (owning relevant LED technologies) and Indian firms would be possible with several arrangements for technology transfer such as:

Joint ventures between manufacturers
Foreign direct investment
On a contractual basis

Interventions required

- Indigenous capacity (technical, managerial etc) is to be developed quickly so that when technology is transferred it can be taken up
- A road map, from market potential assessment to actual implementation of the system, is necessary. A government programme (such as PV roof top programme in Japan and Germany) could be initiated to develop the market, which might also attract foreign investors.
- A clearly defined policy framework on investment opportunities including private sectors involvement needs to be established. This should include several kinds of incentives for encouraging manufacturing/technology transfer (some of the incentive are already in place such as reduction of import duty on raw materials for manufacturing).
- As Government is already promoting PV integrated energy efficient lighting systems for rural lighting applications, incentives could be provided for LED based PV integrated systems.

- Collaborative efforts between research institutions, manufacturers, system developers and providers should be encouraged to facilitate faster uptake of technology.
- A dedicated Technology Development Fund (TDF) could be created to fund R&D and small and medium enterprises (SMEs).

3.3 Biomass (TERI)

3.3.1 Introduction

Biomass materials include all land and water based vegetation such as trees, agricultural residues, forestry residues and organic wastes. Biomass can be burnt directly or converted into liquid or gaseous fuel.

As India's economy and population grow, the country is seeking domestic and renewable energy resources to meet the growing energy demand. Biomass is a plentiful resource in India, and about one quarter of the nation's 400-500 million tonnes of biomass resources remain unused (IREDA 1997, MNES 2006). Biomass briquetting is a link between agriculture and fuel supply and use (Eriksson 1990). Although briquetting of biomass does not add to its heat value, briquettes are easier to transport and store. Briquettes are six to ten times denser than loose biomass, burn more efficiently, and create less pollution. Since biomass briquetting provides additional income to farmers and creates jobs it also serves a social function as well.

The transportation and storage advantages, environmental benefits and ease of burning have resulted in a healthy demand for briquettes in India. In 1987, the government of India instituted a financial incentive program to encourage biomass densification plants throughout the country. Administered by the Indian Renewable Energy and Development Agency (IREDA), the loan program spurred the development of the briquetting industry in a number of Indian states. The briquetting industry experienced gradual growth until the mid-1990s as entrepreneurs signed onto IREDA's program or invested independently in briquetting machines (Grover 1996). By the late 1990s most of the IREDA-supported plants had failed to meet expectations and IREDA ended the loan program for biomass briquetting start-ups.

Meanwhile, biomass densification, in the form of pellets, has proven successful in Europe. The market has expanded over the last ten years and is now growing quickly as a result of aggressive government policies and incentives for green energy and successful commercialization of attendant technologies. This case study explores the gap between Indian and European performance in the biomass densification industry and identifies barriers to successful technology transfer between industrialized countries and India. Lastly, the case study identifies incentives and policy interventions that may be able to overcome the barriers that have impeded commercialization of biomass densification technologies in India.

3.3.2 Contribution to reducing carbon emissions

Biomass is a renewable and carbon neutral source of energy. Biomass combustion releases carbon dioxide into the atmosphere but at the same time an equivalent quantity of carbon dioxide is also consumed by the biomass as it grows. Hence the same amount of carbon dioxide is absorbed from the atmosphere as is released when biomass is burnt. This closed carbon cycle makes biomass fuel 'carbon neutral'.

When used as a substitute for coal or other fossil fuels, briquettes help reduce local pollution and greenhouse gas emissions. Burning biomass briquettes does not release sulphur or nitrogen oxide into the atmosphere. Biomass briquettes also have much less ash compared to coal. Briquetting of agricultural waste products instead of wood also helps prevent deforestation.

3.3.3 Technology

Two biomass briquetting technologies dominate the Indian market: the ram and die machine and the screw machine. These two machines use different processes to densify sawdust and agricultural waste, and the end products also have different densities and shapes. A third kind of press, the hydraulic press has not been used in India and is considered unsuitable for Indian raw materials (Naidu 1995).

Ram and Die Press

The ram and die press, also called the piston press, produces cylindrical briquettes. The biomass is transported from outside the plant to the briquetting machine by a large horizontal screw. The ram and the die are the two essential pieces of the machine. As biomass drops in from above, the ram pushes the biomass through the die at high temperature and pressure. The high temperature creates a self-binder around the briquettes, which are then cooled as they leave the machine.

Screw Press

The screw press produces cylindrical briquettes with a hole through the centre of the cylinder. The machine uses a large screw to grind the biomass into briquettes that are of uniform composition. The briquettes produced by a screw press have some advantages over those produced using the ram and die press, such as better combustion due to the centre hole and carbonized outer layer. However, there are some disadvantages of the screw press viz., higher operating power and maintenance costs. Because of these disadvantages, the screw press has not been particularly successful in India.

3.3.4 Firms owning relevant technology in Europe

Europe's biomass fuel sector has been promoted by European governments and the European Union. Screw presses are commonly utilised in Europe to briquette sawdust. There are several manufacturers of biomass briquetting machines in Europe. Names of some European manufacturers of briquetting machines are Schimanda, Netherlands, Pini & Kay, Germany, Biomass Development Europe, Belgium and ATS, Switzerland.

In Europe, however, the dominant biomass fuel is pellets and not briquettes. Pellets are shorter and narrower compared to briquettes. They burn continuously with a heat profile similar to gas or oil. Just like a gas boiler, pellet boilers are fully automated in Europe, and the low ash in biomass requires less cleaning frequency. Pellets can be made from various biomass materials like sawdust, wood, crop residues or even straw. There are hundreds of plants producing pellets in Europe. Pellets are in good demand in households, small businesses and hospitals. The growth of the pellet market in Europe has some implications for technology transfer to developing countries like India.

3.3.5 Firms owning relevant technology in India

Biomass briquettes are used in many industries in India, including tea factories, chemical plants, pharmaceutical companies, tobacco companies, oil operations, rubber factories, distilleries, ceramic factories, textile and dye operations, kitchens, and other heat intensive businesses.

While there is no reliable data on the number of briquetting plants operating in India, estimates range from 250 to 300. The number of operating briquetting machines is about twice the number, since many plant operators run more than one briquetting machine. Around two dozen briquetting machines are sold annually in India.

In the 1980s, European briquetting manufacturers used to market their products in India. Now almost all biomass briquetting machines are of local make. The essential difference between Indian-made machines and non-Indian machines is that Indian manufacturers make, almost exclusively, the ram and die design, whereas European machines mostly use the screw design.

Four Indian biomass briquetting machine suppliers were studied and interviewed for this case study – Hi Tech Agro, Radhe Engineering, N.S.Y. Energy Engineering and Sree Engineering. Hi Tech Agro, based near Delhi, sells the most number of machines in India, primarily for producing 60mm and 45mm briquettes. Hi Tech also supplies dryers and is engaged in some research related to changing the size of briquettes produced. Radhe Engineering manufactures larger briquetting machines, which produces 90mm briquettes. The company sells about 10 machines per year. N.S.Y. Energy Engineering used to produce about 5-6 briquetting machines per year until 2003 but now sells just 2-3 machines. Sree Engineering produces about a dozen screw and ram and die briquetting machines annually.

Sree Enginneering is the only company producing screw briquetting machines in India. Screw briquetting presses offer an operational advantage for only one raw material available in India – the coffee husk, which gives the machines less wear and tear than other raw materials. Sree sells small capacity (100-220 kg/hr) 80mm screw machines to coffee husk briquetters located mainly in the state of Karnataka where coffee husk is abundant.

To varying degrees, all of the Indian manufacturers are exporting their briquetting machines. Importing countries include Uganda, Ghana, Ethiopia, Kenya, Malaysia, Indonesia and Vietnam.

3.3.6 Identification of other stakeholders involved in transfer activities

In 1995, the University of Twente, Netherlands partnered with the Indian Institute of Technology (IIT), Delhi as well as an Indian manufacturing company (Hi-Tech) to investigate the potential for overcoming the potential problems of screw presses in India, viz. to lessen the wear on the screw, lower the energy needs, and increase the types of raw material. A screw press was imported from Schimanda for demonstration and adaptation to local conditions. The collaborative project succeeded in prolonging the life of the screw by hard facing the screw for wear resistance. The research team lowered the energy needs of the screw press by 20 to 40 percent by preheating the raw material. Overall, the adjustments resulted in a 30 percent increase in production for the screw briquetting press, but the preparation process added extra costs and wear and tear on the screw still required frequent replacements (Grover pers. comm.).

While the imported technology was successfully adapted to Indian conditions through the collaborative R&D project, it did not result in commercialization of the screw press in India. One of the reasons was that the improvements suggested would be costly to implement, but a more significant obstacle was that as long as ram and die machines were selling and operating at an acceptable level, manufacturers were not willing to begin a new endeavour that carried with it some measure of uncertainty.

3.3.7 Current commercial status of the technology

In India, coal is the primary competitor to biomass briquettes. The price, availability, and quality of coal vary widely within the country. In east India, where coal is available locally and its cost is low (Rs 1500-2000 or US $ 33-44 per tonne) no briquetting plants have been established. In western parts of India, where coal prices are higher (Rs 3200 or US $ 70 per tonne) industries are seriously considering switching to biomass briquettes. In southern India where coal costs are quite high (Rs 4000-4500 or US $ 87-98 per tonne) use of biomass briquettes are quite competitive for the industry.

Firewood is a serious competitor to biomass briquettes. Wood is cheaper than briquettes and has a similar calorific value. Wood is collected from public and private lands, some legally and some illegally, and used to fuel many small-scale industries all over India. For domestic heating applications, gas and oil are preferred because of the convenience of availability and use, even though they are the most expensive options.

Screw presses are utilized in Japan and much of Europe and provide high quality briquettes made of sawdust in those countries. The sawdust in those areas is generally uncontaminated, low in moisture, and has low dust content, unlike the sawdust in most parts of India. In addition, sawdust is a waste product in Europe and in many areas "there is quite a cost for getting rid of the sawdust, so people (saw-mills) pay to take the sawdust; he charges less than it takes to go to the dump" (Clancy, personal communication). The raw material situation is quite different in India, where sawdust is a commodity rather than a waste product and is in fact widely used, unprocessed, as a cooking fuel.

If screw briquettes were to be produced in India they would probably find a steady consumer in the gasification industry, where screw briquettes burn more satisfactorily than ram and die briquettes because the outer surface can be carbonized. Despite the attempts made in 1995 to make imported screw presses compatible with Indian conditions, its higher capital cost is a barrier to its dissemination in India.

3.3.8 Cost structure of the technology

According to interviews and published information, the capital cost of a biomass briquetting machines ranges between Rs 1,300,000 to 2,500,000 or U.S. $ 30,000 to $50,000. Prices vary between companies and machine capacities.

The major input costs for biomass briquetting plants are raw materials, electrical energy and transportation. Raw material is the most important constraint in the briquetting industry because it represents the greatest input cost to the entrepreneur and its availability on a sustainable basis remains a concern. When raw material supply is interrupted due to monsoons, excessive demand, or high prices, the entrepreneur's ability to provide her customers with a reliable supply of briquettes is compromised.

The briquette quality is directly related to the quality of biomass used. The quality of biomass, or its calorific value, depends mainly on the raw material. Calorific values of common biomass materials available in India range between 3,700 and 4,700 kcal/kg (see table 3.3.1)

Table 3.3.1 Calorific value and cost comparison of commonly available biomass

Biomass	**Calorific value (kcal/kg)**	**Price (Rs/tonne)***
Sawdust	4700	2000
Groundnut Shells	4500	1000-2200
Coffee Husks	4300	1200-1600
Mustard Stalks	3800	1000-2000
Rice Husk	3700	2000-2200

* (1 US $ = Rs 46)

Another major input cost is energy. A typical ram and die press briquetting machine available in India uses about 35 kWh/tonne. Assuming, an electricity cost of Rs 5/ kWh (US $ 0.11 per kWh), the direct energy cost of briquetting translates to about Rs 175 per tonne (US $ 3.8 per tonne). In addition there are other operating costs associated with preparatory activities such as chopping, pulverising and drying of the biomass, maintenance of the machines and manpower. The total operational cost of briquetting is estimated to be about Rs 380 per tonne (US $ 8.2 per tonne) in India.

Another important determinant of the net profitability of a briquetting plant is the volume of briquettes produced. The capacity utilization of the machine is the key figure, since no briquetting plant can operate 24 hours a day for all days of the year. Accepted capacity utilization rates range between 50 to 80 percent of rated capacity, with 300 days of production per year and a maximum of sixteen hours of operation per day—two eight hour labour shifts. At this capacity utilization rate, a plant with two 500 kg/hr machines or one 1,000 kg/hr machine should produce 4,800 tons of briquettes per year (IREDA 1997).

Given an average baseline price of Rs 1,500 per tonne (US $ 33.6 per tonne) of raw material, Rs 380 per tonne (US $ 8.2 per tonne) of operational cost, and Rs 500 per tonne (US $ 11 per tonne) to cover transportation expenses, the total cost of producing one tonne of biomass briquettes amounts to Rs 2380 (US $ 52.8). Assuming, the average selling price of biomass briquettes of Rs 3,000 per tonne (US $ 65 per tonne) the average profit margin is about Rs 620 per tonne (US $ 12 per tonne). In an area where the plant is running at full capacity and with no outer constraints, a plant running at 1,000 kg/hr capacity should net approximately Rs 3 million per year (US $65,000). Hence there is an attractive payback on investment of about one year in briquetting plants.

The above calculation does not take into account variations in biomass costs across regions, markets, transportation networks, freight prices seasons, and similar such variables. Also, this figure excludes interest payments on the machine and working capital and land costs.

3.3.9 Perception among actors of major risks

Though the standard interpretation of technology transfer involves a transfer of hardware, the barrier to commercialisation of the briquetting technology in India is not hardware related. The main barriers to commercialisation of the technology are system-related e.g. reliable supply and demand, reliability of related infrastructure and lack of technical expertise to maintain the machines operating in rural areas. Some of these aspects are discussed in this section.

Availability of raw material

The statistics about India's vast biomass resources and statements about the "virtually unlimited" supply of biomass in India can be misleading (Naidu 1995). Only a portion of the kinds of agro waste produced are compatible with current processing technologies, and much of this agro waste is already being used in rural areas without processing. Also, there is a large variation in quality of raw materials depending upon the species, growing conditions and climatic conditions.

In general, groundnut shell, coffee husks, sawdust, and mustard stalks have high heat values and work well in briquetting machines. Rice husk has also been briquetted in the past. The high ash content of 13 to 23 per cent in rice husk makes it a poor briquetting material. Most biomass raw materials have ash content under 5 per cent. Uncut cotton stalk and bagasse are also difficult to briquette due to long fibers that can interfere with the rotor. Tea waste is too powdery to briquette without something to bind the briquettes together, and coir waste (coconut fibers) is too moist. Some of these poorer materials may be briquetted at a high cost after they are heated, cut, ground, or otherwise processed, but it is important to remember that not all agro waste qualifies for briquetting. Competing uses for rice husk, coffee waste, bagasse, mustard stalks, and many other kinds of waste have caused the prices to rise dramatically.

Working capital constraints

Entrepreneurs and manufacturers alike identified working capital as a primary barrier to successful commercialization of briquettes. Because briquetting plant owners tend to extend credit to their customers but generally use cash to purchase raw material from farmers and brokers, the flow of money into and out of a briquetting plant is often uneven. In addition, because biomass is a seasonal commodity, entrepreneurs who own storage facilities generally stock up on biomass during the growing season for briquetting in the off season. Entrepreneurs will also buy large amounts of biomass when the price is low and buy less while the price is high. For these reasons, cash-flow handling is a critical component of any briquetting business.

Banks are reluctant to finance agro residue projects. These products have traditionally been viewed as waste, with no collateral value. While banks will finance the briquetting machines because they constitute concrete assets, they are reluctant to provide working capital loans for purchasing raw materials.

Lack of access to electricity

Another crucial energy cost is the opportunity cost of power outages at briquetting plants. In many regions of India, electricity from the grid cuts out for hours at a time. When power is lost for just one or two hours, the plant can usually resume operation without incident when power returns. However, if the power is off for more than two hours, the plant generally needs to be opened up and cleared of clogged biomass before briquetting continues.

Besides the power disruptions, the lack of accessibility to power presents problems. In India, where electricity connections are often unavailable in rural locales, the power requirement for briquetting machines could prove to be a major barrier to establishing plants in remote areas even if they are rich in agricultural waste products.

Maintenance aspects

In the early days of biomass briquetting, Indian machines experienced more breakdowns and required more maintenance than anticipated. Ram and die machines were expected to require significantly less maintenance and parts replacement compared to screw presses, but Indian entrepreneurs are experiencing high maintenance costs even with ram and die machines. In the last decade, however, the machines have improved and the breakdowns have decreased, though they do still need attentive supervision.

Three of the four briquetting machine manufacturing firms interviewed sent technicians along with the machines for three weeks to one month to train and educate the briquetting plant owners. Once the period of training is complete, the manufacturer is rarely called in to perform maintenance even though they may offer maintenance services; the manufacturers are generally far from the plants and therefore their services can be costly. Gradually the plant owners and their operators generally perform their own maintenance; the main costs associated with repairs are the cost of the spare parts and the opportunity cost of shutting down the machines. Based on 1995 field data, the shutdowns for repairs and maintenance amounted to 5 to 6 hours per day, or 30 per cent of total operating time (TERI 1995). The briquetting machines have improved over time and the estimated shutdown time has now reduced to about four hours per day.

3.3.10 Analysis of incentives and policy interventions

This section analyses some of the incentives aimed at promoting biomass briquetting and explores the possibility of diversification to biomass pelletisation in the future.

Financial incentives

IREDA, seeking to promote rural renewable energy and empower local economies to better utilize their biomass resources, provided soft loans for 28 biomass briquetting machines from 1987 to 1997 (Naidu 1995). IREDA provided low-interest loans to entrepreneurs who purchased briquetting machines, a large proportion of them in northern India. IREDA financed approximately 80 per cent of the initial cost of the machine, with an arrangement to have the money paid back at about 8 per cent interest. However, very few of the loans were repaid in full; the default rate was almost 80-90 percent.

Because of the low repayment record, briquetting has developed a poor reputation and been labelled as an irresponsible undertaking. Most stakeholders interviewed felt that subsidies are not the answer for the briquetting industry and that briquetting ventures will have to stand on their own.

Loans and grants for technological development

Technology Information, Forecasting, and Assessment Council (TIFAC) a part of Department of Science and Technology, Government of India has also financed three briquetting related projects in 1999-2000. Soft loans at 6 percent interest rate as well as some grants were provided to entrepreneurs for technological development. The projects had a provision of risk coverage, i.e. those that do not succeed in commercializing the target technology are not required to repay the loan.

Of the three projects financed by TIFAC, two were not repaid because they did not result in successful long term commercialization of the technology, and one was a grant. Even so, the technological development programs had some impact in terms of building of capacities among briquetting machine manufacturers. Interactions with the beneficiaries and others revealed that technology development support should be given preference over hardware subsidies in the future.

Ripple effect of collaborative R&D

It may be interesting to note that Hi Tech, the Indian briquetting manufacturer involved in the University of Twente – IIT, Delhi collaborative project, has benefited from the culture of experimentation around the project. Two technological improvements in the briquetting machine produced by them, viz., crankshaft improvement and the reduction of oil contamination, both occurred in 1995, when the collaborative research project was underway. Hi Tech also acknowledged that the R&D work on the screw briquetting press gave them ideas for making improvements to the ram and die press they were manufacturing. Clearly, collaborative R&D projects involving academia and industry have a ripple effect on the technology. Hence such projects need to be promoted in future.

Promoting biomass pelletizing in India

Europe's "pellet revolution" came about through a concerted collaboration between government, industry experts, academics, and consultants. A number of factors contributed to the rise and continuing success of pellets in Europe, and for pellets to succeed in India the industry must circumvent the barriers that have resulted in a stagnant briquetting industry.

A durable, energy-efficient pelletizing machine is crucial for success of pelletizing in India. It seems that the current small manufacturers of briquetting machines are not up to the task of developing an efficient, workable pelletizing machine. This is where technology transfer may prove extremely beneficial. Some experts believe that the highest chance of success lies with getting the involvement of a large Indian company "that is used to operating in the international environment" (Clancy pers. comm.) in the technology transfer project. Such a company would have the market power to develop high quality, efficient pelletizing machines and drive them into the mainstream market.

Government agencies are more open to funding pelletizing R&D than briquetting; IREDA is already involved in municipal solid waste pelletizing projects. Research institutions are also interested in the potential of this technology and are open to research opportunities.

3.3.11 Interventions with more medium/long term implications

Some longer term interventions that will help to mainstream biomass technologies in India are highlighted below.

National systems of innovation

R&D for biomass technologies can be done domestically if adequate government focus is given to this. The briquetting experience shows that local institutional capacity does not exist at the governmental or industrial level for such rural and decentralized industry. The present R&D efforts are restricted to the small-scale manufacturers of these technologies. Hence there is a need to strengthen the local R&D base in biomass technologies.

Information barriers

All the briquetting machine manufacturers felt that there is practically no collaboration or communication among them. The lack of networking and information sharing among the manufacturers is one of the greatest constraints to diffusion of technological developments in the sector. Hence projects aimed at promoting knowledge sharing among the manufacturers and users of biomass briquettes will be very useful for the sector.

IPRs

Intellectual property rights (IPRs) though not a very important issue in this sector, have created some friction between the European and Indian manufacturers of briquetting machines. Small-scale industries, such as briquetting machine manufactures, are typically 'copycat' businesses based on reverse engineering, first of European machines and then of machines made by Indian competitors. Copied machines, even though cheaper, are of inferior quality and plagued with technical problems. One of the ways to overcome the problem of IPR would be to get a few large private companies interested in biomass technologies.

Need for private sector involvement

As mentioned earlier, the present crop of small-scale manufacturers of briquetting machines are not poised to undertake R&D in biomass pelletization and subsequent mainstreaming of the technology. Hence efforts should be made to encourage a few large companies to get involved in biomass pelletization technologies. Involvement of large private companies would help to mainstream such technologies at a faster rate.

3.4 Hybrid vehicles (SPRU)

3.4.1 Introduction

In many developing countries, including India, increasing levels of personal wealth mean that private car ownership is rapidly increasing. Coupled with rapid processes of urbanisation, this has led to carbon emissions from cars becoming an increasing concern. Whilst current levels of car ownership in India are way below that of most developed nations, India's transport sector is predicted to show the highest level of growth in energy demand of any sector over the next 30 years (TERI 2006b, p.2). At a world level, fuel for transport accounts for some 32% of final energy use. Almost all of this energy is in the form of oil with transport accounting for 60% of total oil usage (IEA 2006). Introducing policies and technologies that can mitigate transport related carbon emissions are therefore a priority.

Hybrid vehicles are widely viewed as having a role to play in reducing the carbon emissions related to transport, especially buses and private passenger vehicles. Hybrid vehicles[9] combine a conventional internal combustion engine with battery-driven electric motors to achieve a significant reduction in fuel consumption and hence reduce carbon emissions. Before providing a more detailed description of hybrid technology, the potential contribution of this technology to reducing transport-related carbon emissions is first explored.

3.4.2 Contribution to reducing carbon emissions

Hybrid vehicles are estimated to be able to achieve reductions in fuel consumption and carbon emissions of anywhere between 20% and 50% relative to conventional vehicles. For example, In Hekkert et al. (2005) report CO_2 emissions of 153g/km for conventional diesel vehicles relative to 120g/km for hybrid diesel vehicles. This represents a reduction in CO_2 emissions of 21.6%. Looking at overall life-cycle energy use and greenhouse gas emissions, Weiss et al. (2003, p.11) report reductions of around 37% to 47% from hybrids relative to comparable conventional vehicles. With the projected exponential increases in car ownership in developing countries such as India and China this obviously implies that hybrid cars can make a significant contribution to reducing related increases in carbon emissions. There are, however, three key issues that policy makers need to consider in terms of the potential contribution

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[9] Reference to the term 'hybrid vehicle', 'hybrid car' or 'hybrid' in this report implies vehicles that utilise a combination of internal combustion engine and battery-driven electric motor as opposed to vehicles that combine a hydrogen fuel cell and electric motor, which are referred to as 'hybrid fuel cell' vehicles.

of hybrid vehicles to reducing future carbon emissions from the transport sector as a whole within an Indian context.

The first issue is the need for an integrated transport system. In terms of personal mobility, an efficient and affordable public transport system has an essential part to play in this by helping to avoid the negative environmental and economic impacts of road traffic congestion, particularly in large urban areas. In the UK, for example, problems with road traffic congestion are estimated to cost the economy around £12 billion (US$23 billion) per year (Devereux et al. 2004). Many commentators argue that such congestion is a direct result of a lack of an integrated and affordable bus and rail system in the UK. Buses play an even more important role in India accounting for between 60% and 80% of travel demand (CSE 2006). This highlights potential for applying hybrid technologies to buses in India. But it also suggests that there may be much to be gained from the horizontal technology transfer of flows of knowledge and expertise in developing integrated transport systems. For example, Transport for London managed to implement significant improvements to London's over congested transport system by buying in transport expertise from the US. India's work on its national urban transport policy is therefore of central importance to reducing transport related carbon emissions, as is it's engagement with the GEF UNDP-funded "Cleaner Mobility in Urban Areas" project.

The second key issue to bear in mind is that a significant number of passenger journeys in India are also made by two wheeler vehicles. In 2002, two wheeler vehicles accounted for roughly 70% of all registered vehicles in India with cars and taxis accounting for only 13% (Rawat 2004). Two wheeler vehicles in India often tend to have two stroke engines which make a large contribution to traffic related emissions of carbon, NOx and particulate matter (PMs[10]). At present there are no plans to develop any kind of hybrid technology for two wheelers. This highlights a need to address emissions from two wheel vehicles via other technologies and policy approaches, including an affordable and efficient public transport infrastructure.

Although they only accounted for 5% of registered vehicles in 2002 (Rawat 2004), three wheeler vehicles are also an important form of transport in India, especially in inner cities. Three wheelers, however, increasingly tend to run on four stroke engines which has made them amenable to conversion to run on CNG. Investment in developing hybrid drivetrains for three wheelers is also under way in India (see below).

The third issue to bear in mind when considering the contribution of hybrid vehicles to reducing carbon emissions is that this is only one of several technologies that may emerge to represent the dominant low carbon vehicle technology for in future. There are currently two other technologies that attract the widest interest as future alternatives to hybrids. One is clean diesel engines and the other is hydrogen fuel cells. At present, cars with small diesel engines compare favourably to hybrid cars in terms of fuel consumption and carbon emissions. They do, however, produce higher levels of other undesirable emissions such as NOx and PM_{10}s, which are a particular problem in many large urban areas. Hydrogen fuel cell vehicles, on the other hand, release no carbon during their operation (although, as with all vehicles, do have related carbon emissions during their manufacture and disposal). Hydrogen fuel cells are, however, at the pre-commercial stage of development and would require significant

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[10] "PM" stands for "particulate matter" and refers to small particles of matter emitted during the combustion of fossil fuels. "PM10" are particles smaller than 10 micrometres in diameter which are considered to be of high health risk due to their absorption into the lungs or even into the blood stream. This can cause cancer.

infrastructural changes before they become a viable option in both developed and developing countries. Nevertheless, many observers view hydrogen fuel cells as representing the dominant and most desirable technology in the long term.

Diesel engine cars are already commercially available which implies that focussing on hybrid vehicles would not distract from the development of clean diesel engines. Moreover, hybrid vehicles can also be based on diesel or petrol internal combustion engines implying that advances in clean diesel engine technology are of equal importance to the development of hybrid vehicles. Many commentators view hybrid technology as a stepping-stone that should be used in the medium term as fuel cell vehicles are developed (SAM and WRI 2003). Some observers have, however, raised concerns as to whether focussing on hybrid vehicles might distract from the long term goal of commercialising zero emission hydrogen fuel cell vehicles. For example, widespread adoption of hybrid vehicles would reduce the relative advantages, in terms of emissions and fuel efficiency, of adopting hydrogen fuel cell vehicles therefore potentially making fuel cell uptake less likely (Hekkert and van den Hoed 2006, p.58).

There are, however, two reasons why such concerns might not be warranted. Firstly, in order to maximise fuel efficiency, hydrogen fuel cells will also need to be hybridised by combining them with an electric motor in the same way that hybrid vehicles currently combine an internal combustion engine with an electric motor. The underlying technology that enables such hybridisation is therefore still important to develop. Secondly, the policy incentives required to promote the production and consumption of hybrid vehicles are fairly generic in terms of promoting the adoption of low carbon vehicles. The nature of these policy incentives is explored in more detail below.

Nevertheless, the system-wide technological changes that will be required to promote fuel cell vehicles may pose specific barriers to their uptake. This includes the need to develop sufficient infrastructure for the supply of hydrogen. Fuel cells are also likely to remain uneconomic unless they are manufactured at high volumes in order to utilise economies of scale and private manufactures are unlikely to undertake large scale manufacture in the absence of sufficient demand. Generating such demand might therefore require higher tax incentives for low carbon vehicles than might be necessary for promoting hybrid petrol or diesel vehicles that rely on existing infrastructure. It also implies a potential role for governments in subsidising initial fuel cell manufacture in order to reduce the risk to private investors and kick start production.

These discussions of future dominant low carbon vehicle technologies tend to ignore the possible contributions of electric vehicles as well as alternative fuels. These technologies should not, however, be discounted. Whilst consumers may be averse to the perceived limited range of electric vehicles, which have to be regularly recharged, research shows that in reality, in most applications, especially urban transport, the limited range of purely electric vehicles is not a problem. The issue lies more in consumer expectations of unlimited range for their vehicles (Gutmann 1999). It is also possible that advances in battery technologies via the development of hybrid vehicles could lead to the unexpected advancements in the range achievable by electric cars. Alternative fuels include fuels such as CNG which produces relatively minimal carbon emissions. India has been successful in encouraging the uptake of CNG buses, cars and taxis in cities such as Delhi and Mumbai (Rawat 2004). Alternative fuels also include carbon neutral fuels such as bioethanol. In Brazil, for example, the government took action in the 1970s to promote the use of carbon neutral ethanol distilled from sugar cane in response to concerns over oil security. Following this move by the Brazilian government, automotive manufacturers responded by adjusting technology to enable most vehicles to run on the ethanol (IPCC 2000, p.209).

This section highlights that, whilst hybrid technology is likely to play an important intermediate role in reducing carbon emissions from vehicles, it is also important to remain aware of the potential contribution of other technologies such as clean diesel, fuel cell vehicles, electric vehicles and alternative fuels. It is also essential to maintain an awareness of the need for affordable, efficient and integrated public transport systems.

3.4.3 Description of technology

Hybrid vehicles combine an internal combustion engine with a battery driven motor. This enables significant increases in fuel efficiency and is able to overcome the problem of limited range associated with battery powered electric vehicles, which must be regularly recharged. Importantly, the combination of existing technologies in hybrid vehicles could assist uptake of hybrid technology in developing countries where there is already familiarity with the component technologies (internal combustion engines and electric, battery driven motors).

Degrees of hybridisation

Hybrid vehicles can utilise a range of steps to achieve increased energy efficiency. This means that there are different degrees of hybridisation ranging from mild-hybridisation to full-hybridisation depending on the number of steps taken within any given vehicle to improve energy efficiency. Essentially there are four technological steps utilised in hybridising vehicles (UCS 2005) These are:

1. Idle-off capacity
2. Regenerative braking capacity
3. Power Assist and Engine downsizing
4. Electric-only drive

As illustrated in Figure 3.4.1, for a vehicle to qualify as a mild hybrid at least the first three steps must be fulfilled, to qualify as a full hybrid, all four steps must be fulfilled. These steps, based on information provided by the UCS (2005), are described in more detail below.

Figure 3.4.1 Difference between conventional vehicles, mild hybrids and full hybrids

	Vehicle classification		
Technology utilised	Conventional vehicle	Mild hybrid	Full hybrid
i. Idle-off capacity	X	X	X
ii. Regenerative braking capacity		X	X
iii. Power Assist and Engine downsizing		X	X
iv. Electric-only drive			X

Source: UCS (2005)

i. Idle-off capacity

Idle-off capacity refers to the capacity for a vehicle to switch off its engine when stationary. Hybrids use a fully functioning electric motor operating above 100 volts to achieve this. Some conventional vehicles, however, also achieve idle-off capacity via an enhanced 12 or 42 volt starter motor known as an integrated starter-generator. This ability alone does not, therefore, define a hybrid.

ii. Regenerative braking capacity

During braking, conventional cars convert the kinetic energy (movement energy) of the car into heat. Hybrids, on the other hand, use the electric motor to take over some of the slowing power of the brakes by operating as a generator and converting some of the kinetic energy into electricity and storing it in the battery. The energy can therefore later be used to propel the vehicle. This process is known as regenerative braking.

In order for regenerative braking to improve fuel economy, however, the vehicle must have an electric motor with high enough voltage to be able to capture braking energy and a battery pack with the capacity to store this energy. Some conventional vehicles with integrated starter-generators claim to have regenerative braking but, in fact, they do not have the capacity to recover enough energy to power the vehicle or improve fuel efficiency beyond what is achieved by their idle-off capability.

iii. Power assist and engine downsizing
This step involves the ability for a vehicle to use two methods of powering the wheels thus enabling an electric motor to share the load with an internal combustion engine. This step forms the basis for the most basic definition of a hybrid vehicle. In order to properly satisfy this requirement, the vehicle must have a large enough electric motor and battery pack for the electric motor to help the internal combustion engine during acceleration. By downsizing the size of the internal combustion engine and providing power assistance from the electric motor significant improvements in fuel economy are achieved. Vehicles satisfying these first three steps are categorised as ‘mild hybrids’.

iv. Electric-only drive
This step involves the ability to power the vehicle using only the electric motor with electricity supplied by the battery pack. This step characterises ‘full’ hybrids. This step enables the vehicle to use its internal combustion engine only when it is most efficient to do so. When starting out and when travelling at low speeds, the vehicle is powered only by the electric motor with electricity supplied by the battery. At higher speeds, both the internal combustion engine and the electric motor can power the car. At the same time, power can be supplied to recharge the battery.

Drivetrain set-up

Beyond the basic underlying technology that defines the degree of hybridisation, a further distinction can be made between different hybrid drivetrain set-ups. Essentially there are three different drivetrain set-ups utilised in hybrids: series drivetrain, parallel drivetrain, and series/parallel drivetrain.

Series drivetrain

This is the most straight forward drivetrain. In series hybrids only the electric motor is connected to the transmission. The electric motor receives electric power from either the battery pack or from a generator run by the internal combustion engine. A computer determines the amount of power drawn on from the battery or the internal combustion engine/generator set. Both the internal combustion engine/generator set and regenerative braking recharge the battery pack.

Due to the fact that the internal combustion engine is not connected to the wheels, series hybrids are optimal in stop-go driving conditions, as in inner city driving. This is because the internal combustion engine is not subject to the widely varying power demands of stop-go driving and can instead operate within a narrower power range at near optimal efficiency. The optimality of series drivetrains in stop-go conditions mean they are primarily being considered for buses and other urban vehicles.

The internal combustion engine in a series drivetrain is usually smaller than in parallel hybrids as it only has to meet average driving power demands; the battery pack, on the other hand, tends to be more powerful than in parallel drivetrains in order to provide remaining peak driving power needs. The larger battery and motor, along with the generator, increase the cost of series hybrids making them more expensive than parallel hybrids.

Parallel drivetrain

In a parallel hybrid, both the internal combustion engine and the electric motor are connected directly to the wheels. During acceleration, when power demand is high, parallel hybrids combine power from both the internal combustion engine *and* the battery-powered electric motor. In cruising conditions, however, they can draw on just the internal combustion engine, therefore eliminating the inefficiency of converting mechanical power to electricity and back. This usually means that parallel hybrids are more efficient for open road driving. In stop-start conditions, however, the direct connection between the internal combustion engine and the wheels reduces the stop-start efficiencies during urban driving conditions.

Parallel hybrids have smaller battery packs than series hybrids. They mostly rely on regenerative braking for recharging but can draw on the drive motor for supplementary charging in the same way as alternators in conventional vehicles work.

Series/parallel drivetrain
This drivetrain effectively attempts to merge the advantages of both types of drivetrain. The internal combustion engine can either drive the wheels directly (as in a parallel hybrid) or be disconnected from the wheels, which are then powered only by the electric motor (as in a series hybrid). This maximises the potential for the internal combustion engine to operate at near optimal efficiency. In stop-start conditions and at lower speeds the vehicle operates like a series hybrid and at higher speeds operates like a parallel hybrid. This combined system of drivetrain therefore achieves greater fuel efficiencies than either pure series or pure parallel drivetrains. Despite these increased efficiencies, however, a combined series/parallel drivetrain is more costly than a pure parallel hybrid because it requires a generator, a larger battery pack, and more computing power to control the combined system.

3.4.4 Firms owning relevant technologies

There are several companies that have begun to invest in hybrid technology. They tend, however, to vary in terms of the degree of hybridisation and drivetrains that they have developed. An important point to note is that the companies involved are not limited to automotive companies. Other companies, such as engineering companies and electrical equipment developers, have also been involved in developing hybrid drivetrains. This implies that, whilst there are a limited number of vehicle manufacturers in India, there is still scope for companies in other sectors to become involved in developing and manufacturing hybrid technology.

Mild hyrbids
Mild hybrids utilising parallel drivetrains are currently available from Honda. These include Honda’s hybrid versions of its Insight, Civic and Accord models. Honda refers to its underlying technology as ‘Integrated Motor Assist’ (IMA) technology.

There are also a number of mild hybrid technologies being utilised in buses. These are based on diesel fuelled internal combustion engines. Three companies are currently manufacturing hybrid bus technology:

- BAE Systems has developed a series hybrid system that they call ‘HybriDrive’.
- General Motors’ (GM) Allison Transmission has developed a parallel hybrid system which they call their ‘E^P System’ (this was developed as part of the US Department of Energy’s Advanced Heavy Hybrid Propulsion System, AH^{2}PS, Program). A unique aspect of GM Allison’s hybrid system is that it is a self contained unit that can effectively be bolted on to a variety of different types of internal combustion engines.
- ISE Corporation has developed a series hybrid system that they call ‘ThunderVolt’. ISE has partnered with Siemens in the production of their drivetrain, with Siemens supplying the electric motors, controllers, and generators. As well as their conventional diesel hybrid bus system, ISE have also produced a petrol hybrid with the benefits of lower emissions standards for NOx and PMs than their diesel hybrid buses or natural gas alternatives.

Full hybrids
Toyota is widely recognised as leading the field in full hybrid technology. Focussing on private passenger vehicles, it has developed a combined series/parallel drivetrain, which it calls its ‘Hybrid Synergy Drive’. Of particular interest to this study is the fact that in September 2005 Toyota entered into a joint venture with China’s leading car manufacturer, Sichuan FAW, and began production of the Prius in China.

Due to the high cost of R&D, a high level of cooperation has been observed between companies in both the research and manufacture of hybrid vehicles. For example, in collaboration with battery and fuel cell experts at Qinetiq, PSA Peugeot Citroen has also developed a diesel hybrid which they call the ‘Efficient-C’. The Efficient-C is reported to achieve a 30% improvement in fuel economy and emissions compared with a conventional diesel car and to be 15% more efficient than a petrol hybrid.

In autumn 2005, GM, DaimlerChrysler and BMW announced that they would be working together to develop GM Allison Transmission’s E^P System into a full hybrid system that can be used in cars rather than buses in order to be able to compete with Toyota. The companies call their cooperative research effort the Global Hybrid Cooperation (GCC 2006). The three companies hope to better Toyota due to the fact that the E^P System is a two-mode hybrid system whereas Toyota’s Hybrid Synergy Drive is only a one mode system (ENN 2006). This basically means that the GM Allison system has both low-speed and high-speed electric motors that are separately linked to the internal combustion engine. This enables it to switch between motors depending on driving requirements. Toyota’s system, on the other hand, relies on the electric motor alone during low speed driving and internal combustion engine and electric motor in parallel for high-speed driving. The two-mode nature of the GM Allison system means that it could potentially improve on Toyota’s system’s fuel efficiency. The fact that the GM Allison system is a self contained unit that can work with a range of internal combustion engines also raises the possibility of combining it with a diesel engine car which would be more fuel efficient that the petrol engine in the Toyota Prius.

The two-mode GM Allison system also requires smaller electric motors and hence a smaller battery pack and other related devices. This could mean that the GM Allison system might also compete favourably in terms of cost. Furthermore, the fact that the GM Allison system can be used with most existing internal combustion engines means that GM, DaimlerChrysler and BMW can package internal combustion engines with full hybrid transmissions more cost effectively and offer fuel efficiency savings across a wider range of vehicles (GCC 2006).

3.4.5 Indian firms with active interests/experience

This study has come across two Indian companies currently working to develop hybrid vehicles. TVS has developed a prototype three wheeler hybrid vehicle and Ashok Leyland has developed a prototype hybrid bus chassis. Informal contact with these companies has suggested that, at present, costs remain prohibitively high to allow commercial manufacture of hybrid vehicles.

3.4.6 Other relevant institutions actually or potentially involved in transfer activities

The actions of the automotive industry are principally defined by the market-driven activities of the private vehicle manufacturing companies (Nieuwenhuis and Wells 2003, p.16). The central concern of these companies is to maintain/increase market share. However, as Nieuwenhuis and Wells (2003, p.13) highlight, the increasing recognition of the need to reduce carbon emissions is now perceived to be the main agenda driving the car industry in Europe and East Asia. This has reinforced the gap between US manufacturers who service mainly the US market with the odd export being perceived as a bonus. It also emphasises the central role that increasing car use in developing economies such as India, China and Indonesia will play in defining levels of future vehicle-related carbon emissions.

Both manufacturers and independent observers now tend to view the ability of manufacturers to respond to the challenge of reducing carbon emissions as the central issue that will define their future profitability and ultimately their survival (SAM and WRI 2003). This means that governments are now key actors in terms of the potential development and uptake of hybrid technology. This is because vehicle manufacturers are now looking to governments for an indication of what policy will be put in place with regard to vehicle-related carbon emissions. In developing countries in particular, government policy on transport-related carbon emissions is central to creating the right market conditions for encouraging the manufacture of energy efficient vehicles to meet future increases in transport demand. For this reason, this study has paid particular attention to the policy environment and the enforcement thereof in India and in countries where hybrid vehicles are being produced.

3.4.7 Current commercial status of technology

Hybrid technology is generally considered to be at the supported commercial stage. Sales of hybrid cars are, however, rapidly increasing. In the US, for example, sales of hybrid cars have roughly doubled every year since 2000 and this exponential growth is predicted to continue into the future. Dr. Michael Tamor, manager of Ford's Sustainable Mobility Technologies, is quoted as saying (HybridCars.com 2006):

> "If you think about the 15- to 20-year timeframe, you could argue that all vehicles are going to be hybrids. It's just a matter of which powerplant is used in the hybrid system. To freeze time and pretend that hybrids are not going to happen doesn't make sense."

Commercial availability

As outlined in section 4 above, several companies currently have commercially available mild hybrids, including both cars and buses. Toyota and Ford are, however, the only two companies currently offering full hybrid cars for sale, with Ford licensing Toyota's Hybrid Synergy Drive. Toyota has also licensed their technology to Nissan. Nissan is yet to bring a hybrid to market although is expected to do so sometime during 2006.

Toyota is currently viewed as the most commercially successful company in manufacturing and marketing hybrid vehicles. The Toyota Prius is perhaps the best known, and certainly the most widely sold, full hybrid car available on the market. The Prius achieves fuel efficiency of 56.5mpg in urban driving conditions and 67.3mpg on the open road (Toyota 2006a). This makes the Toyota Prius the most energy efficient four-seater hybrid car currently on the market (UCS 2005). Since its launch in 1997, cumulative sales of the Toyota Prius recently exceeded the half-million mark, with 504,700 units having been sold by the end of April 2006 (Toyota 2006b). Toyota is reported as envisaging sales of around 1 million hybrid vehicles per year by 2010 (ENN 2006).

Using Toyota's Hybrid Synergy Drive, Ford has successfully marketed a hybrid version of its Escape Sports Utility Vehicle (SUV). The hybrid Ford Escape is able to achieve 40 mpg relative to the regular, non-hybrid model of the Escape which achieves only 23 mpg in urban driving conditions and 28 mpg in open road conditions (CEC 2005).

Future market growth

As mentioned in section 3 above, GM, DaimlerChrysler and BMW are working together to develop GM's Allison Transmission's E^P System into a full hybrid system that can be used in cars rather than buses in order to be able to compete with Toyota. GM have now announced the launch of two hybrid SUVs to be available in the US in 2007-8 (TheAutoChannel 2006).

PSA Peugeot Citroen's Efficient-C diesel hybrid, also mentioned above, is reportedly ready for production. PSA Peugeot Citroen is, however, waiting until 2010 before starting commercial production. It hopes that by then the costs of the technology will have reduced to a level that makes hybrids competitively priced next to conventional vehicles. The cost structure of hybrid technology is discussed in more detail further below.

Developed/developing country technology gap

It is important to note that, to a large extent, hybrid technology is still largely a vertical technology transfer issue as much as a horizontal technology transfer issue. Whilst the manufacture of the Toyota Prius in China is the only example encountered during this study of the manufacture of hybrid vehicles in developing countries, this should not distract from the fact that they also only account for a marginal amount of vehicles manufactured in developed countries. Sales of hybrid vehicles in the US and Europe are rapidly increasing, but they by no means compare to the sale of conventional vehicles. For this reason it is as much a concern for governments in developed countries to encourage the development and uptake of this low carbon technology as it is for governments in developing countries. At present, however, all of the companies owning commercially viable hybrid technologies are based in developed countries.

3.4.8 Cost structure of the technology

The cost structure of hybrid technology is dominated by research and development (R&D) costs. Hybrid vehicles utilise two well established technologies, internal combustion engines and electric motors. The principal costs involved are therefore in the design and testing of a viable transmission that can effectively combine these two existing technologies to work together to improve fuel efficiency. The high cost of R&D is reflected in the decision of GM, DaimlerChrysler and BMW to cooperate in the development of a full hybrid system. It has also lead to Ford and Nissan choosing to license Toyota's hybrid system rather than develop their own.

There are also additional component costs involved in manufacturing hybrid vehicles relative to conventional vehicles. This includes the additional costs of electric motors, battery packs and other electrical components. The cost of battery packs is widely cited as one of the key contributors to the additional cost of hybrid vehicles. On average, hybrid vehicles command a premium, based on sales figures, of around 10-15% above conventional vehicles (Hekkert and van den Hoed 2006, p.56). At present, this higher cost is passed on to consumers. For example, Ford's hybrid version of the Escape costs US$3,000, or 17% more than the conventional model of the Escape. Despite these price premiums, industry observers suspected that, during the first few years of marketing the Prius (1997-2000), Toyota was actually selling it at a loss. In 2002, however, Toyota announced that it was making a profit from Prius sales (Hekkert and van den Hoed 2006, p.56). Despite the higher price of hybrid vehicles, their increased fuel efficiency does mean that cost savings are made during operation due to reduced fuel consumption.

3.4.9 Perceptions among actors of main risks attached to technology

The commercial and operational success of hybrid vehicles, such as the Toyota Prius and several hybrid buses, is widely perceived to have reduced the technological risks that might previously have been associated with hybrid technology. Perceived risks currently stem from three principal sources. The first perceived risk is uncertain current and future demand for hybrid vehicles. The second perceived risk, conversely, is the risk to companies of failing to position themselves to take advantage of future increases in demand for low carbon vehicles and therefore loosing market share. The third perceived risk, which influences both other sources of risk, is the uncertainty surrounding future government policy on transport related carbon emissions.

The automotive industry is essentially a reactive industry. In other words, its activities are determined on the basis of reacting to meet changing consumer demands. The industry is therefore defined by a consistent need to predict future social and political trends in order to provide the right product range to meet current and future consumer demand (Nieuwenhuis and Wells 2003, pp.3 & 28). Whilst many observers see hybrid vehicles as central to low carbon transport in the medium term (Nieuwenhuis and Wells 2003, p.239, SAM and WRI 2003), demand for hybrid vehicles is by no means certain. One important aspect impacting on demand for hybrids is their higher costs, which were discussed above. PSA Peugeot Citroen, for example, despite having their Efficient-C diesel hybrid ready for production, see the higher cost of hybrid vehicles as prohibitive enough to have delayed production until 2010 when they hope costs will have decreased.

Fuel savings may well offset the increased initial cost to the consumer during the lifetime of the vehicle. Marketing these fuel savings to consumers, however, represents a key challenge to automotive manufacturers. Furthermore, in countries with cheaper fuel prices, such as the US, it is possible that the additional upfront cost of buying a hybrid vehicle might not be recouped in fuel savings over the life of the vehicle. Professor Severin Borenstein, director of the University of California's Energy Institute, for example, is cited as saying (BBC 2004a):

> "It still costs two or three thousand dollars more to buy a Hybrid and if you do the calculations of how much you would save on gasoline over the life of a car it's unlikely you would ever actually cover your costs."

Nevertheless, manufacturers have been successful in generating demand for diesel engine vehicles in Europe, which continue to command a price premium over petrol engine vehicles. In 2000 the average price premium for diesel engine vehicles was around US$250 (SAM and WRI 2003). Other factors such as enhanced safety features that could be possible for hybrid vehicles could also play a role in enhancing their marketability.

Whilst it might be possible for automotive manufacturers to successfully market hybrid vehicles at a higher price, the demand for hybrid vehicles is by no means certain. The increased costs of production and huge R&D investments involved in developing manufacturing capacity therefore still present manufacturers with a risk. Commenting on the potential for manufacturing hybrid vehicles in India, Tapan Basu of Bajaj Auto is cited as emphasising that, if the market returns remain uncertain, no industry would push a product into the volumes required to sustain economical pricing (DTE 2006). At the same time, however, manufacturers face huge potential risks if they fail to position themselves to cope with future limitations imposed on carbon emissions.

The carbon intensity of vehicle manufacturer's profits is seen as the determining factor of their future profitability (SAM and WRI 2003). The carbon intensity of manufacturers' profits refers to the relative amount of profit earned from the sale of higher carbon emitting vehicles. It is used to give an indication of how well manufacturers are placed in terms of technological development and managerial capacity to respond to future carbon constraints. For this reason, most vehicle manufacturers are competing hard to move ahead in the market for hybrid vehicles. John German, manager of Environmental and Energy Analysis for American Honda is quoted as saying (HybridCars.com 2006):

> "Hybrids are different than most technologies. If an OEM [original equipment manufacturer] is sitting back on developing diesel engines, he won't be in too much trouble. But with hybrids, it's becoming more and more sophisticated. You just can't turn it on. If you don't make the system now, as Toyota continues to make hybrids much cheaper and in greater numbers, the others won't be able to catch up."

A study carried out in 2003 examined the relative positioning of car manufacturers in terms of their future ability to cope with future constraints imposed by the need to reduce carbon emissions (SAM and WRI 2003, WRI 2004). This analysed manufacturers' management and technical capabilities in hybrid, clean diesel and hydrogen fuel cell cars. Due to its investment in all three technologies, but particularly its leading position in commercial hybrid technology, Toyota emerged as the clear leader with a better future competitive outlook than all other main car manufacturers. The study supported the predictions of many commentators who cite the carbon intensity of automotive manufacturers' profits as being the key determinant of their likely future success under future carbon constraints imposed through government policy.

The problem is, however, that manufacturers remain uncertain as to what policy approaches governments are likely to take. It is this that represents the defining risk to the automotive industry in the development of low carbon vehicles, including hybrid vehicles. The interviews and correspondence undertaken as part of this study have highlighted that, against a background of uncertain demand and a need to position themselves to take advantage of future carbon constraints, automotive manufacturers' central concern is with the likely direction of government policy on carbon emissions. The incentives and policy interventions most likely to reduce the risks to automotive manufacturers in investing in hybrid vehicles are explored in the next section.

3.4.10 Analysis of incentives and policy interventions

The establishment of manufacturing capabilities in hybrid vehicles can primarily be regarded as a vertical technology transfer issue. It is as much an issue for developed countries as it is for developing countries. At present there is a very limited number of hybrid vehicles on the market. Although the number of hybrids on the market is predicted to increase quite rapidly in future, this is primarily a result of efforts on behalf of automotive manufacturers to stay ahead of predicted trends in future government policy on carbon emissions. It is this policy that will define the level of demand for low carbon vehicles.

Interviews undertaken as part of this study indicate that automotive manufacturers are looking to governments to provide a clear roadmap of their intended measures to reduce carbon emissions. This needs to provide a clear outline of future transport policy strategy and give a clear indication of the taxes and incentives that are likely to be directed towards promoting low carbon transport. In the UK, for example, industry commentators cited the government's Powering Future Vehicles Strategy as an important guide to manufacturers' own market strategies. Their central concern was the need for clear guidance from government in terms of how this strategy will be implemented and concrete commitments to specific incentives for promoting low carbon vehicles. The extent to which such incentives are enforced in practice is also critical to whether or not automotive manufacturers are likely to respond to them.

A key concern for manufacturers was the relative price difference between low carbon and conventional vehicles. Policy can address this in two ways. Firstly, subsidies can be offered to consumers for purchasing low carbon vehicles. In the UK, for example, the government previously offered a £1,000 (US$1,900) subsidy to consumers for certain low carbon vehicles, including hybrids. Industry commentators in the UK highlighted the loss of this subsidy as having a negative impact on hybrid sales, although it was difficult to differentiate the effect of this from other factors such as increased advertising efforts. It is worth noting, however, that this level of public expenditure is likely to be difficult to justify if sales of hybrid vehicles continue to increase.

An alternative policy approach that is widely promoted by many industry observers is to tax vehicles based on their relative carbon emissions. A market study in Switzerland, for example, found that tax incentives on purchasing new cars had lead to a 20% increase in Prius purchases relative to other Toyota models (IEA 2005). Taxation is potentially a more attractive approach than subsidising hybrid purchases as taxation can be engineered to be revenue neutral. In the UK, annual vehicle taxation has recently been modified to differentiate between vehicles on the basis of their associated carbon emissions. Whilst industry commentators tended to welcome this gesture, it was thought that the difference in tax brackets is insufficient to overcome the much higher initial purchase price of hybrid vehicles. For example, the difference in tax payable on a Toyota Prius that emits only 104 g/km CO_2 and a popular four wheel drive (often used as a family car) that emits 389 g/km CO_2 is only £180 (US$340) per year (based on VCA data). A tank of fuel for the same vehicle would cost a third of this amount of money implying that the tax premium is unlikely to impact significantly on the overall running costs of the vehicle. The price premium that consumers have to meet up front when buying a Prius instead of an equivalent non-hybrid vehicle, on the other hand, is in the region of thousands of pounds.

A key concern of several people contacted during this study was that any carbon related taxes should be technology neutral. This involves setting taxes based on vehicles' carbon emissions without any differentiation between different technologies that manufacturers might choose to achieve emissions reductions. This enables manufacturers to respond to incentives to reduce emissions in the most cost effective way possible. It should be noted, however, that a technology neutral approach to taxation would no longer necessarily constitute an incentive specific to hybrid vehicles, rather it would encourage the uptake of any low carbon technology letting the market decide which technology is most viable. For example, it may currently be cheaper for manufacturers to produce low emissions vehicles by utilising small diesel engines rather than hybrid vehicles. This does, however, raise another concern.

The environmental and human health impacts of automobiles are not limited to the impacts of carbon emissions. Other emissions, particularly NOx and PMs have important environmental and health implications. This is particularly the case in some developing country cities, including Delhi. Environmental policies aimed at reducing vehicle related carbon emissions can therefore not afford to ignore these other emissions. Diesel engines, for example, might be a cost effective way of reducing carbon emissions but they are higher emitters of NOx and PMs than most petrol driven vehicles. This implies that petrol driven hybrid vehicles might warrant specific tax incentives over and above diesel engine vehicles. Alternatively, regulations may need to be put in place to encourage the introduction of clean diesel engines. This includes the use of diesel engines in hybrid vehicles.

It is also important to avoid inconsistencies within the taxation system. In the UK, for example, higher emissions-based taxes are currently levelled on company cars than on domestic cars. A key concern for company fleet managers is the resale value of their vehicles. Because the tax advantages of buying low carbon vehicles as company cars are not passed on to consumers, fleet managers have tended to opt for conventional diesel cars rather than experimenting with hybrid vehicles. This is because they can be sure of a domestic resale market for diesel vehicles but demand for hybrid vehicles is not yet established. If consumers were faced with similar tax advantages for buying hybrid vehicles, domestic demand might increase leading to widespread adoption of hybrids as company fleet cars.

One direct action that governments can take to help increase demand for hybrid cars is via their own procurement policies. This would involve introducing a policy that requires all new government vehicles to be hybrids. Hybrid cars impose less cost on society than conventional vehicles in terms of their environmental impacts. They also save money during operation through decreased fuel consumption. The additional cost of purchasing low carbon vehicles, such as hybrid cars, can therefore arguably be justified by governments.

Another key policy area is the setting and enforcement of emissions standards for new vehicles. In China, for example, new emissions limits for new vehicles have been introduced that are stricter than current US emissions regulations. This has been cited by Toyota as a key motivation for its decision to manufacture hybrid vehicles in China. India has introduced emissions limits via its 2003 Auto Fuel Policy. This sets out emissions limits for new vehicles as well as standards for existing vehicles. Figure 3.4.1 shows the date by which China, India and Europe are aiming to meet the various Euro equivalent emissions standards for new vehicles. Euro I is the least stringent standard and Euro V is most stringent. As Figure 3.4.1 illustrates, India is not moving as fast as China in enforcing emissions standards for new vehicles and both China and India have some way to go before they will mirror current European standards.

Figure 3.4.1 Target year for meeting Euro light vehicle emissions standard equivalents in India, China and Europe

	Euro standard				
	I	**II**	**III**	**IV**	**V**
India		2005	2010		
China			2007	2010	
Europe	1992	1996	2000	2005	mid-2008?

Such regulatory action provides a strong indication to manufacturers of the future policy environment and encourages firms to work to develop their strategic positioning with regard to future low carbon market conditions. It is, however, essential that emissions limits are properly enforced. Many automotive companies are likely to be keeping close tabs on whether or not emissions regulations in emerging markets such as China and India are enforced in order to inform their strategies in marketing low carbon vehicles. Consistent review and active enforcement of India's 2003 Auto Fuel Policy is therefore critical to creating the right conditions for uptake of hybrid vehicles in India. Consultation undertaken during this study has suggested that there may be a need to upgrade and increase resources for some of the testing facilities for in use vehicles in order to ensure adequate enforcement of emissions limits.

The example of China's emissions limits highlights the possibility of unilateral emissions policy action within an economy where the market for personal mobility is set to boom in the near future. The move by the Brazilian government in the 1970s to promote the use of carbon neutral ethanol distilled from sugar cane in response to concerns over oil security is another example of how effective unilateral government action in the transport sector can be. Following this move by the Brazilian government, automotive manufacturers responded by adjusting technology to enable most vehicles to run on the ethanol (IPCC 2000, p.209).

The vertical transfer nature of hybrid technology also raises the possibility of government assistance with R&D initiatives. GM Allison Transmission's E^P System, for example, was developed as part of the US Department of Energy's Advanced Heavy Hybrid Propulsion System, AH^2PS, Programme. This involved collaboration between the US government's National Renewable Energy Laboratory (NREL) and industry. This highlights the potential for R&D institutes in developing countries, such as India's Indian Renewable Energy Development Agency (IREDA), to work collaboratively with industry on developing capabilities in hybrid technology. This could be important in helping Indian vehicle manufacturers to develop the technological capabilities necessary to maintain and develop their market share under future carbon constraints.

3.4.11 Interventions with more medium/long term implications

The policy initiatives discussed in section 10 above are likely to have a positive effect in providing incentives to the automotive industry to develop and market hybrid and other low carbon vehicles. Providing a clear indication of long term carbon policy intentions will also be important in reducing the risks to manufacturers of investing in R&D to develop increasingly lower or zero emissions vehicles. From a horizontal technology transfer perspective, however, there are several other important issues that require consideration in order to encourage technology transfer to developing countries. As highlighted in the literature review to this study, the key issue here is how to ensure that technology transfer to developing countries' results in the long term development of their capacity for innovation in relation to hybrid vehicle technologies. The issues of most importance in terms of hybrid vehicles include:

- **Degree of integration of transfer activities**
  If foreign firms supplying hybrid technology maintain a high level of integration in their approach to transferring the technology this could make it more difficult for knowledge

regarding the technology to diffuse within the recipient country. For example, it has been reported that, due to the difficulty of transferring hybrid technology in the short term, Toyota's joint venture with FAW in China to manufacture the Prius is currently relying on importing parts from Japan (BBC 2004b, Xinhua 2004). The joint venture relationship between the two companies has, however, lead to talk of FAW-branded hybrid vehicles being produced in future (Xinhua 2004). Without this kind of less integrated approach, the relationship would be less likely to enable China to develop its technological capacity in hybrid drivetrains. The Chinese government has introduced legislation requiring all foreign investors engaging in non-export oriented automotive manufacturing in China to do so through a joint venture with a majority Chinese company. This may have been beneficial in achieving the Toyota FAW joint venture. It is, however, questionable as to whether this legislative requirement violates WTO trade rules.

Linked to the issue of integration is the use of host country manufacturers to supply parts to foreign hybrid vehicle manufacturers. At present, Toyota is importing many components from Japan for manufacturing the Prius in China. BAE System's supply of hybrid drivetrains to Orion buses in the US could also be highlighted as potentially limiting the potential for US manufacturers to develop technological capacity in this area. However, BAE have had to supply detailed technical know-how to Orion to enable it to fit the hybrid drivetrain. They are also supplying even more in depth know-how to the network of companies that they are licensing to maintain buses fitted with their hybrid drivetrain. This implies that, in the long-term, the knowledge necessary to imitate and/or innovate around this technology will slowly diffuse through US based companies. Importantly, some studies of technology transfer in vehicle manufacturing have suggested that it is not necessarily the quantity of local suppliers that are used that matters. What is more important is the quality of the linkages and their long-term effects on learning among local component suppliers (Ivarsson and Alvstam 2005).

- **IPRs**
  Host country companies may be able to develop technological capacity through involvement in supplying parts for, or maintenance services for vehicles fitted with imported hybrid technology. Even so, there may be IPR issues associated with imitating patented hybrid drivetrains. Companies such as Toyota, GM and BAE have strict patents relating to their hybrid drivetrains. It is this that enables Toyota to license their drivetrain to other companies such as Ford and Nissan. A better understanding of the extent to which IPRs might limit the development of new hybrid drivetrains by developing country based manufacturers is an important issue that warrants further investigation.
- **Absorptive capacity**
  An analysis of the absorptive capacity of potential recipient developing country automotive manufacturers could provide valuable information on their ability to take advantage of collaborations with foreign firms on producing hybrid vehicles. This could be assessed in India as part of a technology needs assessment to feed into the UNFCCC TT:CLEAR initiative.
- **National systems of innovation**
  The production of a technology needs assessment on India's automotive industry would also benefit from related analysis of how well placed India's national system of innovation is to support development of domestic manufacturers' absorptive capacity. This should include analysis of the current capacity and future needs of organisations such as the Indian Renewable Energy Development Agency (IREDA) and other national R&D facilities to support development of low carbon vehicle technology. It is also important to take advantage of other relevant international initiatives here such as relevant outputs from the Carbon Sequestration

Leadership Forums' (CSLF) Technology Group and the outputs of discussions from the Energy Research and Innovation Workshop (WIRE) that was held under the UK's G8 Presidency. The International Energy Agency (IEA) implementing agreement on hybrid and electrical vehicles could also provide a useful forum for India to share information with other countries on hybrid development. The IEA's G8 initiative 'Networks of Expertise in Energy Technology' (NEET) will also be an important opportunity to engage with follow participants on work arising from the implementing agreement on hybrid and electrical vehicles.

- **Micro-level management of transfer projects**
  One issue that has been highlighted as particularly important in developing the knowledge and expertise necessary for innovation is the micro-level management of technology transfer projects by recipient firms. This implies a requirement for automotive manufacturers to take a proactive approach to acquiring knowledge during the technology transfer process. As discussed in the literature review for this study, such a strategic approach to acquiring knowledge was instrumental in the development of Hyundai's capacity for innovation.

- **Information barriers**
  It is important that automotive manufacturers both in recipient and potential supplier countries have access to sufficient information on market opportunities and policy incentives in the field of hybrid vehicles. Active participation in the TT:CLEAR initiative may provide an important opportunity for India to disseminate such information.

- **Need for private sector involvement**
  The automotive industry is a global industry that is driven by the research and marketing activities of a number of major private companies. It is important that any government intervention that seeks to develop technological capacity in hybrid vehicles does not discount the critical need to retain the central role of private investors in the transfer process.

- **Markets for carbon**
  Finally, as with all low carbon technologies, the introduction of a market for carbon could play a key role in encouraging the future development and transfer of hybrid vehicle technology.

3.5 Improving combustion efficiency (TERI)

3.5.1 Introduction

The total installed power generation capacity of India as on March 2006 was 118,558 MW. Thermal power generation accounts for 70 % of total generation. Out of this, 58 percent predominantly comes through coal based power plants, and 12 percent through natural gas (NG), naphtha and diesel. Ratings of thermal power plants have improved gradually from 60 – 100 MW to 250 – 500 MW. The ratings of new power plants are generally 250 MW, 500 MW and 660 MW. In order to meet the peaking shortage (12.2 percent) and energy deficit (8.8 percent) of the country, the Government of India has set a target to increase the installed power generation capacity to 215,804 MW by March 2012 (see table 3.5.1). This would require a capacity addition of 97,246 MW during this period. The share of thermal (coal /NG/ naptha/diesel) power will increase to 68 percent of total capacity.

Table 3.5.1: India's perspective plan for electric power

Power generation	Thermal – Coal and lignite (MW)	NG/naptha/ diesel (MW)	Nuclear (MW)	Hydro (MW)	Total (MW)
Installed capacity (as on March 2006)	69,004	13,985	3,645	31,924	118,558
Addition of capacity planned (till March 2012)	45,486	17,440	8,455	25,865	97,246
Total expected capacity (as on March 2012)	114,490	31,425	12,100	57,789	215,804

Source: Central Electricity Authority, Ministry of Power, Government of India (www.cea.nic.in)

Improvements in combustion efficiency of coal based thermal power plants would result in overall efficiency improvements due to reductions in various energy losses, such as, dry flue gas losses, unburnt carbon monoxide formation, unburnt in bottom ash, and unburnt in fly ash. These improvements would lead to reduction in heat rate of power plants (kCal/ kWh) and hence the GHG (greenhouse gas) emissions.

3.5.2 Contribution to reducing carbon emissions

GHG emissions from thermal power stations have been drawing attention in recent times. The improvement of efficiencies of turbine and boiler will lead to reduction of GHG emissions. For a typical 500 MW coal based thermal power plant, there is a potential to reduce carbon dioxide emissions by about 40,000 tonne per year due to improvements in heat rates. The estimate is based on the following data from an operating thermal power plant in India.

Plant capacity	:	500 MW
PLF (Plant load factor)	:	85 percent
GCV (gross calorific value) of the coal used	:	3622 kCal/kg
Carbon content of the coal	:	44.7 percent
Heat rate before improvements	:	2400 kCal/kWh
Heat rate after improvements	:	2376 kCal/kWh
GHG (CO_2) emission reduction/year	:	40,460 t/year

3.5.3 Description of technology

Thermal power cycles
The thermal power cycles adopted by Indian power plants are outlined below.

Sub-critical power cycle
Coal based thermal power generation uses conventional steam cycle technology with sub-critical steam parameters. Gas turbine combined cycles employing contemporary gas turbines technologies are used in NG/ naphtha based power plants. Gradual increase in the capacities (from 30 MW to 500 MW), improvements in coal firing and improvements in turbine designs led to improvements in heat rates of thermal power plants (see table 3.5.2). The plant efficiencies of power plants in India using sub-critical steam parameters have already reached their peak. Further significant improvements will be possible only by adopting super-critical steam parameters and other advanced cycles based on pressurized fluidized bed combustion or gasification.

Table 3.5.2: Power generation steam cycles with different unit ratings

Unit rating	Steam cycle parameters	Design turbine heat rate (kCal/kWh)	*Design gross plant heat rate (kCal/kWh)
70 MW	90 ata, 537°C, Non-Reheat	2200	2588
120/130 MW	130 ata, 537°C/537°C, Reheat	1980	2330
210 MW	150 ata, 537°C/537°C, Reheat (with motor driven BFP)	1970	2318
250 MW	150 ata, 537°C/537°C, Reheat (with motor driven BFP)	1970	2314
500 MW	170 ata, 537°C/537°C, Reheat (with steam driven BFP)	1945	2288

*Considering boiler efficiency as 85 percent. For net heat rate, auxiliary power consumption also to be considered
Source: Abbi. 2003.

Super-critical steam cycle
A steam cycle operating at steam pressure above 225.36 ata is called supercritical. At this pressure, densities of water and steam are the same, requiring no need for a boiler drum that separates steam from water. Figure 3.5.1 shows possible improvements in heat rates with super-critical systems. Compared to the base case of steam parameters (170 ata/ 537°C /537°C), improvement in heat rate will be 2.1 percent if steam parameters of 246 ata/537°C/565°C are adopted and 5.0 percent when ultra-supercritical (USC) parameters (306 ata/ 598°C/ 598°C) are adopted. The first super-critical thermal power plant (3x 660 MW capacity) is being set up in India by NTPC (National Thermal Power Corporation) at Sipat in Orissa state.

Figure 3.5.1: Improvements in heat rate with super-critical parameters

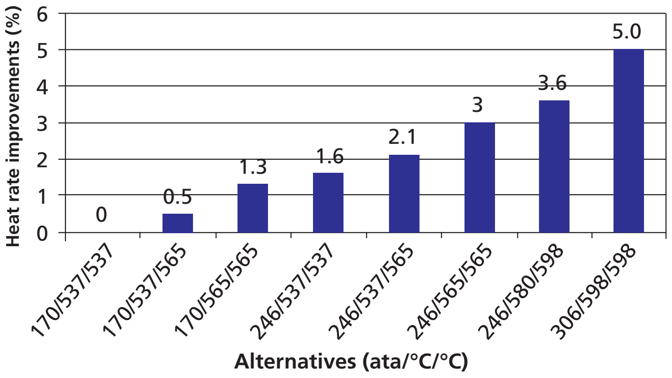


Figure 3.5.1 Improvements in heat rate with super-critical paramaters (Abbi. 2003)

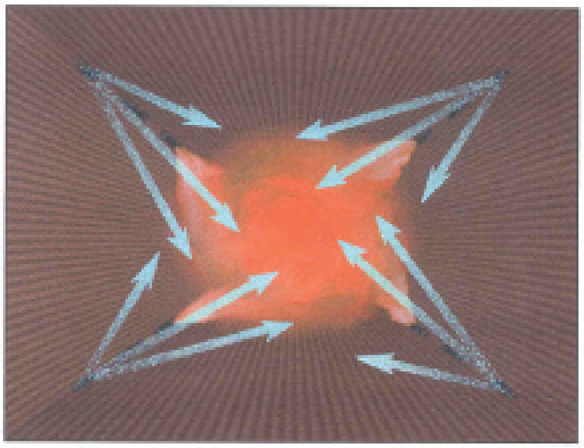
Coal usage in boilers
The majority of the utility boilers use sub-bituminous coal with high ash content (35 percent to 45 percent). The gross calorific value (GCV) of coal is generally in the range of 2500 to 3500 kCal/kg. The ash also contains a significant share of silica (as alpha quartz) which makes it highly erosive. The melting point of ash is in the range of 1200 – 1250°C. Coal from open cast mines is supplied to power plants as run-of-mine product without any processing resulting in inconsistencies in coal quality. Beneficiated coal has been introduced in a few plants recently. Some power plants also blend high ash coal with good quality coals imported from Australia, Indonesia and South Africa.

Technologies used for combustion of coal
Steam generators are designed for combustion of pulverized coal with tangential firing with the burners located at different levels – two pass or single pass (tower type). In the last few years, a few plants of 120 MW with Circulating Fluidized Bed combustion (CFBC) technology for firing high sulphur lignite have been constructed. A few more 250 MW CFBC units are under construction.

- **Pulverized fuel combustion (PFC)**

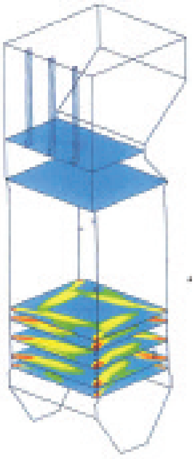
In pulverized coal firing, coal is crushed to a fineness such that 70 – 80 percent passes through a 200 mesh sieve, and carried forward directly to the burners with hot air. Coal and air mixture gets ignited upon entering a combustion chamber. Combustion of coal takes place partly in the burner flame and partly in suspension in the boiler furnace.

Figure 3.5.2: Tangential firing in PFC boiler



The different types of mills used for pulverizing coal are (1) Bowl mill, (2) Tube mill, and (3) E-type mill. Selection of mill type is usually based on the experience of the utility of each type. All types of mills mentioned here are used successfully in India. The coal-air mixture from each mill is distributed to four corners at a particular level of firing. This is called tangential firing or corner firing (refer figure 3.5.2). The number of mills used in a boiler is dependant on capacity rating for steam generation and coal crushing capacity of the mills. The levels of firing in the furnace are equal to the number of mills. A schematic of multi-level firing is given in figure 3.5.3.

Figure 3.5.3: Tangential firing in PFC boiler



Boiler sub-systems affecting combustion efficiency
The combustion efficiency of a PFC boiler is dependant on quality of coal and performance of various sub-systems, which include:

- Coal pulverizing mills
- Distribution of coal dust to four corners of boiler
- Coal burners
- Control of combustion air supply
- Performance of air pre-heaters and level of air infiltration

The combined performance of all the sub-systems governs the ability of the boiler, for a given fuel, to regulate furnace heat absorption for steam temperature control by tilting the fuel and air nozzle assemblies of the burners, up and down automatically. Incorporating all the parameters has not been possible in design of Indian utility boilers as the overall combustion phenomenon is very complex and involves a number of variables and a number of sub-systems. Only recently, analytical techniques and softwares are being developed in advanced countries. These will definitely help in evolving precise designs of boilers. However, the boiler designs in India are presently being done based on field experiences, and from the design standards evolved by different organizations over years of experience.

The performance of the sub-systems, excess air supply and velocity in the furnace also influence the NOx emissions in flue gases. In advanced countries, NOx emissions from coal fired power plants are controlled to a level of 250 mg/Nm3 and below. There are no NOx emission standards enforced in India. However, both the major boiler suppliers in India – BHEL & Alstom, supply "low NOx burners" whenever demanded by the utility companies. Treatment of flue gases for reducing the NOx emissions is not practiced in India.

- **Circulating fluidised bed combustion (CFBC)**

CFBC boilers are suitable for taking care of frequent fluctuations in coal quality. Different types of CFBC boilers used are (1) Hot cycle CFBCs (>400oC) and (2) Cold cycle CFBCs (<400oC). Present day CFBCs use air velocities above 6 m/sec. The design features of CFBCs include water wall separator of U-beam separator for trapping unburnts. Salient features of CFBC boilers include the following:

- Wide fuel flexibility (Oil to washery rejects).
- Simple fuel feeding systems (Only two feed points for a 125 MW unit)
- High carbon burn-up (>99 percent)
- Effective in-situ pollution control for low SOx/NOx emissions

3.5.4 Firms owning relevant technologies in industrialised countries

There are a number of firms worldwide that are involved in design and manufacture of boilers for thermal power plants. Collaborations between manufacturers in different countries either existed or, in some cases, still exist.

International firms supplying PFC and CFBC boilers include the following:

- Alstom Power, France
- Babcock & Wilcox, USA
- Combustion Engineering, USA (Pulverized fuel fired boilers)
- Lurgis Lentjes Energietechnik Gmbh (LLB), Germany (CFBC boilers)
- Mitsui Babcock Energy Ltd, UK
- Pyro Power, USA (CFBC boilers)

3.5.5 Firms owning relevant technologies in India

A limited number of Indian firms are engaged in the design and supply of boilers for thermal power plants. Bharat Heavy Electricals Limited (BHEL), a public sector company, has been a pioneer in providing designs and supplying boilers since the 1960s. BHEL used to supply small capacity boilers with technical know-how from Czechoslovakia. It had a technology transfer agreement with Combustion Engineering for about 30 years. Based on its vast experiences in the field, BHEL at present supply sub-critical boiler (pulverized fuel) units up to 500 MW, without any technology transfer agreements. For super-critical units, they have very recently entered into a collaboration agreement with Alstom.

Alstom was initially owned by Babcock & Wilcox and then by Combustion Engineering during the 1990s. Each takeover has brought in technology from its principles abroad. The Indian manufacturers of utility boilers are shown in table 3.5.3.

Table 3.5.3: Indian manufacturers

S No	Manufacturer	Type	Supplier of PFC	Supplier of CFBC
1	Bharat Heavy Electricals Ltd (BHEL), Tiruchirapalli	Public sector	Yes	Yes
2	Alstom, Durgapur	Private sector	Yes	

3.5.6 Current commercial status of technology

PFC boiler technology is a mature technology in India and the majority of the power plants use this. However, interaction with end-users (thermal power plants) and boiler manufactures has indicated that there are certain gaps which still exist affecting the overall efficiency and the performance of power plants. Major technology gaps identified relevant for PF firing are outlined below.

PF fired boilers

- **Improvements in designing boilers based on coal properties**

Frequent variation in coal quality from mines is one of the major problems faced by Indian power plants, which directly affects the operating parameters and optimization of coal mills and control of excess air. Present boiler designs in India are generally based on volumetric heat loading and furnace area heat loading. These factors are fixed based on past experiences with similar coals, and lead to sub-optimal performance. There is a need to design boilers based on parameters such as properties of coal, combustion characteristics of the flame and the furnace, and radiative and convective heat transfer characteristics of heat transfer surfaces (e.g. water wall, superheaters and reheaters). Petrographic characteristics for coal must also be taken into account while designing boilers, to take care of slagging problems.

- **Coal mills**

Though different types of coal mills are operating successfully in Indian thermal power plants, “fast wear out” of rolls in bowl mills is an important issue to be addressed. Better quality rolls give a higher service life. There is a need for longer life of bowl mills so that the availability of rolls is about 8,000 hours which would require change only during annual shutdown.

- **Coal burners**

There are significant emissions of NOx from Indian power plants. However, norms for NOx emissions are presently not enforced in the country. Though Indian manufacturers claim development of low NOx burners, their performance is yet to be proved on a commercial scale. European firms have rich experience in low NOx combustion systems (DTI, 2000).

- **On-line monitoring of coal feeding**

Combustion efficiency may be improved with availability of on-line monitoring systems for pulverized coal distribution (in all four corners) in tangential firing systems. Proven systems are not available in India. Availability of such systems would help in optimizing combustion air supply to the boiler and hence energy losses.

- **Low temperature heat recovery from air pre-heaters & air-seal to avoid infiltration**

Air pre-heaters for large capacity utility boilers are designed for a flue gas outlet temperature of 137°C to 140°C. There is a know-how gap on economic low temperature heat recovery from flue gases below “dew point temperatures”, especially in extreme summer weather. There is also air leakage in air pre-heaters from the high pressure cold air side to the low pressure hot flue gas side, which is a perennial issue and requires development of air seals with zero leakage for air-preheaters.

- **Beneficiation of coal**

Beneficiation of coal is relevant in the Indian context where there is a large percentage of ash in Indian coals. Beneficiated coal has yielded better control of combustion and the availability of the plant. Additional investments are required for this purpose. There is a need to develop low cost coal beneficiation technology to produce low ash and uniform quality of coal.

- **Intelligent soot blowers**

The thickness of ash deposits or fouling of tubes greatly affects the heat transfer efficiencies in boilers. Soot blowers are used for removal of scaling. The frequency of operation of soot blowers, however, is based on experiences rather than the thickness of ash deposits. This is a complete know-how gap.

- **Service providers for specialized works**

There is lack of capacity available for all R&D services related to measurements in the field on operating units, data analysis, and recommendations for improvements.

CFBC boilers

Circulating fluidized bed combustion (CFBC) boilers are being introduced in Indian thermal power plants by BHEL, Thermax Limited and Cethar Vessels Limited. CFBC offers a better option for using high ash content Indian coals and their frequently varying quality. There are a number of barriers for large-scale adoption of CFBC in India such as high wear of refractories in the cyclones, control of circulation of hot solids and also high overall costs.

- **Optimization of fluidization velocities**

Fluidization velocities in CFBC systems are in the range of 6 to 10 m/sec. For optimum combustion efficiencies, there is a need to optimize the fluidization velocities in CFBC boilers with respect to fuel properties and particle size. This is currently not being done by Indian boiler designers. The fluidization velocities are fixed based on experience.

- **Cost optimization**

Investment requirements of CFBC boilers are higher than PF fired boilers. There exists a lot of scope for optimizing the costs of CFBC boilers.

3.5.7 Stakeholders involved in technology transfer activities

A number of technology sources have been identified with whom Indian firms may collaborate to bridge the existing gaps in boilers and sub-systems (table 3.5.4).

Table 3.5.4 Technology gaps and sources in improving combustion efficiency in boilers (Source: DTI, 2000 and DTI, 2001.)

S.No.	Technology gap	Technology source(s)
1	PF mass & velocity measurements in pipes • Electrostatic system (PF Master) • Microwave system (PfFLO, AirFLO, AshFLO)	• ABB Automation, Ltd (UK) • Promecom (Germany)
2	PF distribution control devices	• Foster Wheeler (USA) • GE-EER (USA) • M&W (Denmark)
3	Combustion optimization and control system	Softwares • GNOCIS, ULTRAMAX – to be merged with power station's DCS (www.eon_uk.com)
4	Zero leakage Ljunstrom air pre-heaters	James Howden & Co (UK)
5	Low NOx burners with over-fire air	• Mitsui Babcock Energy Ltd (UK) • ABB Alstom Power Combustion Services (UK)
6	New Technologies • Grinding rolls to combat high silica high ash erosion • Low-cost coal beneficiation • Materials for low temperature heat recovery from air pre-heaters • Intelligent soot blowers based on soot thickness measurement	Availability of commercial technologies, if any, to be explored
7	Optimization of CFBC boiler performance	Lurgis Lentjes Energietechnik Gmbh (LLB), Germany

3.5.8 Perception among actors of major risks

The following were the major risks attached to introduction of newer technologies to improve combustion efficiency of thermal power plants.

Technology risks

There are know-how gaps which exist for optimization of the performance of Indian thermal power plants. Feedback from end-users (thermal power plants) and boiler manufacturers clearly indicates possibilities for collaborative efforts in sharing information and collaborative R&D, which would benefit the industry.

Financial risks

The estimated R&M (renovation and modernization) business of old power plants in India is Rs 50 billion (US$ 1,100 million). There is a risk of uncertainty associated with investments in R&M by old thermal power plants, as the present focus of R&M is more towards "restoration" of original capacity of the plant (with high ash coal) and not for possible thermal efficiency improvements.

3.5.9 Interventions with medium/long-term implications

Some of the key interventions that would help promote adoption of new technologies for combustion efficiency improvements are outlined below.

Collaboration & R&D efforts on technology improvements

The project has identified a number of areas for improvements for different boiler technologies in consultation with various stakeholders such as thermal power plants and boiler manufacturers (table 3.5.3). These collaborative projects would help bridge the existing gaps in pulverized fuel boiler technology and CFBC boiler technology. The improved performance would enhance the overall efficiency of thermal power plants in India.

Evolving policies on R&M

A shift in R&M focus to "cost effective technology upgradation" would help in improving plant output, availability and enhance efficiency of power generation. This would require developing suitable and clear cut policy addressing uncertainty regarding recovery of investments made in R&M. While the return on investments in R&M should be on par with "new builds", there is a need to devise a common "win-win" strategy for R&M activities between various stakeholders to put Indian plants on par with developed countries.

Power Sector Reforms in India

From this study, it is clear that there is considerable potential for improving the technology for the coal fired thermal power sector through combustion efficiency improvements in pulverized fuel firing as well as the introduction of advanced technologies like IGCC. It is not happening because Independent Power Producers (IPPs) from developed countries, who are likely to bring with them new technologies, are not setting up plants in India. The prime reason for this is the poor financial health of State Electricity Boards (SEBs) who are responsible for distribution of electricity in different states of India. The IPPs will necessarily have to supply power produced to these SEBs. The IPPs are not sure whether SEBs will pay them for the power supplied. Though the Government of India has modified the Electricity Act in 2003, the reforms in the states have not happened fully, and many SEBs are not financially sound. Thus, there is a need for implementation of the reforms of this sector throughout the country. This will help with the introduction of advanced technologies in the country, and hence with reducing GHG emissions.

CDM in the Power Sector

This study highlights the fact that combustion efficiency improvements will reduce the heat rate of power plants and hence reduce CO_2 emissions. These emission reductions can also attract CDM benefits through the sale of Certified Emission Reductions (CERs) under the UNFCCC, thus partially offsetting the additional costs for advanced technologies. At present, however, no methodology for CDM projects in the power sector has been approved by the Executive Board of the CDM, and the project developers don't want to take the financial risk involved in getting the methodology approved. Thus there is a need to develop new methodologies and present them to the Executive Board of the CDM for their consideration. An international bilateral funding agency could consider this. This could help with introducing energy efficiency improvements for thermal power plants in developing countries.

4. Recommendations for future action

Based on combined analysis of the findings of the literature review and the case studies, this section presents a summary of key areas for future action in order to facilitate the transfer of low carbon technology to developing countries. It begins by outlining six key issues that this study has highlighted as important when addressing technology transfer. After highlighting several areas that require further research, it then moves on to make recommendations for national and international policy initiatives.

4.1 Key considerations when addressing technology transfer

The analysis of the literature on technology transfer and the case studies examined during this study has highlighted a number of key issues that require consideration when addressing technology transfer. These can be summarised around six themes, namely:

1. Technological change and capacity building
2. Levels of integration in the transfer process
3. Supplier/recipient firm strategies
4. Absorptive capacity
5. Stage of technology development
6. Intellectual property rights (IPRs)

These themes are explored below.

4.1.1 Technological change and capacity building

An essential insight highlighted by the literature review is that technology transfer takes place within a broader context of technological change. A useful image is a drop of water (the transferred technology) hitting the surface of a pond. The pond represents the technological capacity of the country receiving the transferred technology. In the long term, it is the ripples that spread across the pond as a result of the transferred technology that are the most important consideration. These ripples represent the impact of the transfer of low carbon technologies on the overall technological capacity of recipient countries. It is this capacity that enables future innovation to take place and that is most likely to ensure long term adoption and development of low carbon technology in recipient countries. Building technological capacity is especially important in developing countries where long term economic development and poverty reduction are central concerns.

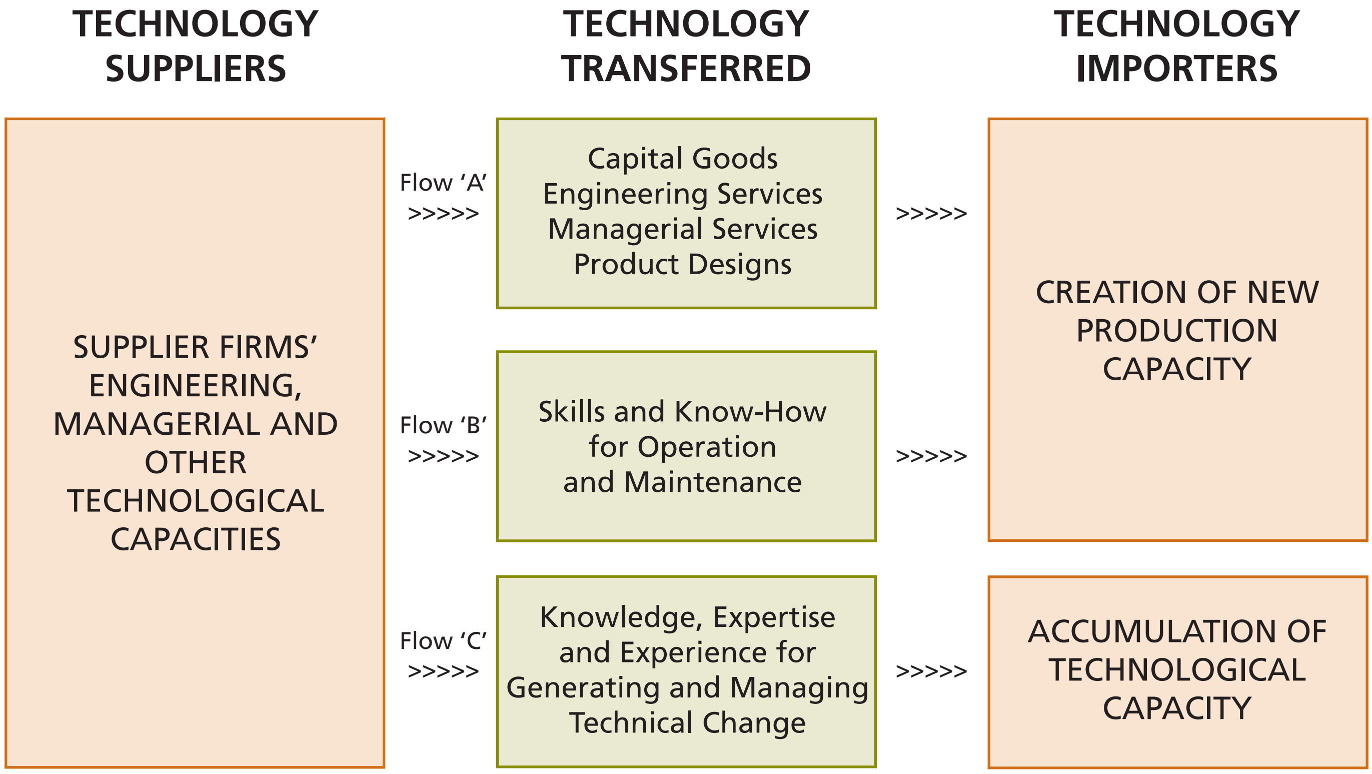
Importantly, the literature review also highlighted the fact that technological change mostly occurs as a series of incremental changes. For example, through a line of continuous incremental innovations over forty years, the Korean steel industry eventually overtook the technological capabilities of more developed economies in this industry.

Another central insight that the literature review highlighted is that there are essentially three different flows that make up the technology transfer process. These are:

A. Capital goods and equipment
B. Skills and know-how for operating and maintaining equipment
C. Knowledge and expertise for generating and managing technological change

As Figure 4.1.1 illustrates, Flow C, the flow of knowledge and expertise, determines whether or not technology transfer results in the development of technological capacity within recipient countries. The transfer of knowledge and expertise is therefore an essential part of technology transfer.

Figure 4.1.1: The three flows of international technology transfer



4.1.2 Levels of integration in the transfer process

The literature review also highlighted that an important determinant of the impact of technology transfer on the technological capacity of recipient countries is the degree of integration involved. This is the extent to which technology suppliers integrate the different flows involved in the transfer process (flows A-C in Figure 4.1.1). For example, the transfer of technology might be highly integrated (e.g. involving some form of turnkey project), or highly disaggregated (e.g. via the acquisition of different items of plant from a wide range of host country equipment manufacturers). These links with host country companies are integral to knowledge generation among local suppliers. They are therefore central to developing technological capacity within recipient countries**.**

In the case study of hybrid vehicles, for example, it was found that Toyota is manufacturing its Prius hybrid in China. However, even though Toyota has established a joint venture with Sichuan FAW to manufacture the Prius in China, they are taking a fairly integrated approach. It seems that they are importing most of the parts directly from Japan and then assembling the vehicles in China as opposed to manufacturing the individual parts (including, presumably, the hybrid drivetrains) in China. This implies that there might be limited technological capacity building amongst Chinese firms as a result of this arrangement in the short term. In the long term, however, FAW's involvement with hybrid technology could result in the gradual development of technological understanding of hybrid drivetrains so Toyota's decision to enter into a joint venture should still be viewed as a positive step.

The LED case study also highlighted the importance of technological capacity. Indian firms dealing with LEDs currently act only as packaging vendors for international firms that actually manufacture LEDs. This means that Indian firms have not been able to develop any technological capacity in this area. In China, on the other hand, a number of international firms have set up LED manufacturing plants leading to the development of considerable capacity building in this technology amongst Chinese firms.

4.1.3 Supplier/recipient firm strategies

The level of integration in the transfer process discussed above is often a direct result of strategies adopted by supplier firms. The strategies adopted by recipient firms may be equally important to the outcome of the transfer process. Recipient firms that, as part of the transfer process, strategically aim to obtain technological know-how and knowledge necessary for innovation are more likely to be able to develop their capacity as a result. Examination of hybrid vehicles within this study highlighted the example of Hyundai's approach to gaining knowledge and expertise in conventional vehicle manufacture. Managers within Hyundai have proactively taken a strategic approach to acquiring knowledge during the acquisition of foreign technology in order to expand the firm's knowledge base and shift its learning orientation from imitation to innovation.

4.1.4 Absorptive capacity

Absorptive capacity is a firm's ability to absorb new technology. If absorptive capacity is weak amongst recipient firms, they are less able to take advantage of collaborations with international technology suppliers. For example, in the case of LEDs, this study has identified that, whilst individual skills exist in India that are of relevance to manufacturing LEDs (e.g. engineering, material sciences, control electronics), the capacity does not exist to harness these skills to actually manufacture LEDs. This lack of absorptive capacity is a key barrier to LED manufacture in India. The biomass case study also highlighted a lack of capacity in rural areas of India for carrying out maintenance on briquetting machines as a key barrier to the expansion of briquette production in India.

A two-way relationship exists with regard to the absorptive capacity of recipient firms. Absorptive capacity *impacts on* the outcome of technology transfer (higher absorptive capacity implies a higher propensity to develop capacity as a result of transfer). It is also *influenced by* technology transfer, in that transfer activities have the potential to increase recipient firms' absorptive capacity depending on what flows are included in the transfer process (flows of hardware, know-how and knowledge– Figure 4.1.1 above).

Developing national systems of innovation in developing countries has an important role to play in developing firms' absorptive capacity. National systems of innovation refer to a country's infrastructure and capacity for undertaking innovation related activities such as R&D. This includes universities as well as networks of R&D facilities and expertise in the public and private sectors. The findings of all five case studies highlighted the fact that, in order to contribute to developing absorptive capacity, R&D activities must include collaboration across public and private sectors – it is within the private sector that most technology transfer activities take place. R&D activities must also include bilateral or multilateral collaboration in order to share lessons learned from experience with new low carbon technologies.

4.1.5 Stage of technology development

The five case studies of low carbon technologies within the study covered technologies at different stages of commercialization (Table 1.1, p. 19). This is because the barriers to successful technology transfer are likely to vary according to the stage of technology development. For example, the case studies suggest that absorptive capacity is a more significant barrier to technology transfer for technologies at early stages of development than for technologies at later stages of commercialization. There may also be a need to encourage market development for these early stage technologies, as was the case for the LED, biomass and hybrid vehicles cases studies examined in this study.

The stage of technology development highlights an important issue in low carbon technology transfer, namely that transfer may be both vertical (from the R&D stage through to commercialisation) and horizontal (from one geographical location to another). The early stage of development (pre-commercial and supported commercial) of many low carbon technologies implies a need to focus on barriers to both vertical and horizontal transfer. In some cases, such as hybrid vehicles and IGCC examined within this study, this may mean that similar barriers exist to the adoption of low carbon technologies at early stages of development in developed countries as in developing countries. However, where these technologies are owned by companies based in developed countries, generic barriers to technology transfer between developed and developing countries will also need to be addressed.

4.1.6 Intellectual property rights (IPRs) and commercial interests

Technology transfer can impact on the relative commercial standing of technology owners as well as owners of alternative technologies. It may also impact on the relative economic wealth of supplier and recipient countries. The interests and political and economic power of the different actors involved in the technology transfer process are therefore likely to have significant bearing on the barriers to, and outcomes of, technology transfer processes. This may be of particular relevance in the case of low carbon technologies where a wide range of powerful interests stand to be affected. One example is the supply of advanced industrial gas turbines for IGCC. Previous experience shows that suppliers from industrialised countries tend to form alliances with developing country equipment companies such as BHEL. However, in order to maintain competitive advantage, they often retain control over the design and manufacture of the most advanced, high tech parts and/or products (e.g. the first row of turbine blades, incorporating advanced materials, cooling technologies and manufacturing techniques.)

The clearest specific way in which these commercially driven interests appear in technology transfer is in relation to IPR. Protection of IPRs by supplier firms can prevent recipient firms from gaining access to the knowledge necessary to imitate and then innovate on the basis of new technologies. This can act to prevent or inhibit the development of technological capacity within recipient countries. For low carbon technologies, gaining ownership or access to IPRs may therefore be a necessary, but not sufficient requirement for successful low carbon technology transfer. IPR issues are not framed narrowly in terms of access but also address other factors and barriers, such as tacit knowledge and absorptive capacity. As these factors differ by country, technology and sectors, a case by case approach may yield more useful insight in how to address IPR related barriers. For example, in case of LEDs , industry commentators felt that without improved technological capacity in India in this industry, ownership of relevant IPRs would make little difference to India's ability to manufacture white LEDs. Another example comes from the IGCC case study, where the key barrier to transfer is not ownership of IPRs but rather a lack of knowledge of whether IGCC will work with low quality Indian coal and the overall lack of worldwide successful commercial demonstration of this technology.

In some cases, in the long term, protection of IPRs for some technologies may not be a barrier to developing technological capacity in recipient countries. One possible example arose from the hybrid vehicles case study . Hybrid drivetrains are subject to strict IPRs. But, where they have been supplied to other countries, the firms owning the IPRs have had to train engineers and mechanics in the recipient country in fitting and maintaining the drivetrains. This implies the potential for companies in recipient countries to develop their own technological capabilities in hybrid drivetrains which may also filter through to the wider economy in the longer term.

An important issue that needs to be understood in relation to low carbon technologies is whether IPRs as a barrier to technology transfer might vary in importance according to the stage of technology development or the nature of the technology itself. For example, the stage of development of a particular technology may have implications in terms of the level of private investment already made in a technology and the level of returns that IPR owners need to derive before they are happy to release the IPR.

Furthermore, there is a complex relationship between the strength of the IPR regime in a developing country and the extent to which this fosters technology transfer. There may also be implications of country specific IPR regimes for different types of technologies at different stages of development.

One possible route forward in addressing IPR issues in the context of technology transfer is international collaboration on low carbon technology development. This could be on the basis of international collaborative R&D initiatives on technologies that are at a very early stage of development. As these technologies would be collaboratively developed, the IPRs could be structured to benefit the various partners involved, including with the aim of making the IPR available as a free or low cost public good. This kind of international collaborative R&D based approach has the added benefit of enabling knowledge sharing between collaborators which could aid long term capacity building in developing countries. The idea of a Global Research Alliance was put forward by the UK Commission on Intellectual Property Rights as a way of linking developmental objectives (capacity strengthening and sustainable development) with the more commercially driven IPR framework (UK CIPR, 2005).

In cases of technologies covered by existing IPRs, international initiatives and international funds, such as those established under the Convention, could potentially play a role in facilitating role in negotiating licences or buying down the costs of specific technologies to make them more widely accessible – as has happened in the case of the Montreal Protocol dealing with ozone depletion. Insights from how global private/public partnerships have addressed issues of access to proprietary technologies in other sectors, such as public health, might also provide a fresh approach to the issue of technology transfer.

4.2 Knowledge gaps and future research

As well as yielding a number of important findings, this study has highlighted several areas that require additional research. These include[11]:

1. There is a clear need for internationally comparative analysis of technology transfer to developing countries to understand what barriers to technology transfer are country-specific as opposed to generic. For example, this might explain why only 7.3% of CDM projects in India mention technology transfer in their initial project documentation compared to 55.1% in China or 83.3% in Malaysia. Understanding the different issues faced by countries at different stages of development would also be of value. One output would be to propose changes to national approval processes and the CDM project cycle that could advance the transfer of low carbon technologies.

2. Analysis of the technology needs assessment (TNA) studies submitted by countries to the UNFCCC secretariat to compare the perceived needs for technology transfer by project type, and the perceived barriers to technology transfer by country. This would distinguish between projects that include significant technology transfer, those that favour local technology and those that are "indifferent". Similarly host countries could be grouped into those whose policies favour or discourage technology transfer to see if there is a difference in the barriers they identify, and their proposals to address those barriers.

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[11] The authors would like to thank Erik Haites, Margaree Consultants Inc, Toronto, for his helpful comments and suggestions.

3. Much technology transfer literature focuses on the challenges faced by developing countries in accessing technologies. Additional work may be required to build on the smaller body of work (e.g. Watson, 1999) that analyses perceptions of barriers to technology transfer within firms, governments and other actors in developed countries. The US, for example, believes that barriers to the transfer of low carbon technologies could result from the actions of developing countries and not just the actions by American firms. Further work is planned in the US to analyse this issue. When the results become available in 2006/7, it could be useful to compare any technology-specific barriers with the lessons from this study and the TNAs from developing countries.

4. Valuable work could be done towards the development of specific assessment criteria for international financing, information sharing and R&D mechanisms based on the ability of these mechanisms to contribute to long term low carbon technological development. This should include criteria to assist in the identification of suitable institutional structures within which these mechanisms would be most effective. As part of this, there is a need for ongoing evaluation of various mechanisms designed to deliver R&D collaboration and other technology transfer objectives. This could include, for example, analysis of the Asia Pacific Partnership, FutureGen, and the Carbon Sequestration Leadership Forum.

5. A review of the mandate of the UNFCCC Expert Group on Technology Transfer (EGTT) is envisaged at the Conference of Parties meeting in Nairobi in November 2006. Since the EGTT was established, several international bodies and initiatives, such as the World Bank, IEA and Asia-Pacific Partnership, have increased their work on low carbon technology and innovative financing of these. This presents an opportunity to study how the EGTT can work with these other initiatives in its future work.

6. Further analysis needs to be done of IPR issues within the context of specific technologies and problems with the aim of developing an approach that brings together relevant stakeholders to address specific problems on a case by case basis. An area with considerable potential highlighted by this study is the scope for bilateral and multilateral collaboration on R&D for new low carbon technologies to help overcome IPR barriers.

7. Examining lessons learnt from successful examples of technology transfer (such as wind turbines in India) would be complementary to the analysis carried out in this report of technologies that have not yet been successfully transferred.

8. More detailed analysis of the specific technologies examined in this study over a longer time period than was possible during this study would be valuable. This would enable consultation with a wider number of actors and stakeholders and the development of more concrete actions that could be taken to facilitate transfer. The potential for developing underground coal gasification in India also warrants future detailed investigation.

9. The potential for integrating PV with LED lighting in rural areas that was highlighted in this study points towards an important area that requires focussed research. This would involve the analysis of specific development oriented technology transfer such as that facilitated by NGOs. This could be linked with a focus on matching the needs of developing countries with technology transfer activities.

4.3 Government influence on technology transfer

Governments in both recipient and supplier countries have a key role to play in facilitating low carbon technology transfer. There are three main motivations for government involvement:

1. Reducing carbon emissions contributes to reducing the economic, social and environmental costs of climate change.

2. Many low carbon technologies are currently at pre-commercial or supported commercial stages of development and may therefore require some form of government support to facilitate their wider adoption.

3. Early investment in technologies that are likely to be of more domestic importance in future may be worthwhile. Governments might also wish to gain competitive advantages in new technologies with a view to developing future export markets.

Government involvement is usually designed to overcome barriers to low carbon technology transfer. However, unless it is undertaken with proper awareness of the full range of issues highlighted in this summary, government involvement can also introduce new barriers to technology transfer. Government involvement requires initiatives at both the national and international level.

4.3.1 National level government initiatives

Domestic policy environment: Clearly defined and enforced domestic carbon emissions policies are integral to encouraging low carbon technology transfer. For example, the hybrid case study highlighted the fact that China's recent introduction of a strict policy limiting carbon emissions from new vehicles, together with processes for enforcing this policy, has led to Toyota to enter into a joint venture with a Chinese company to manufacture hybrid vehicles in China.

National systems of innovation: As mentioned above, national systems of innovation are integral to developing absorptive capacity among national firms. Governments have a clear role to play here in supporting and encouraging R&D initiatives, facilities and networks across both the public and private sectors. This will also benefit from governments' engagement with bilateral and multilateral information sharing activities such as the UNFCCC's TT:CLEAR initiative.

Intellectual property rights (IPRs): Insufficient protection of IPRs can be a deterrent to international firms transferring technologies. A well defined and enforced national IPR legal structure is therefore important to encourage transfer of some low carbon technologies.

Political stability: Political instability in some countries might act as a deterrent to foreign investors, particularly where new commercial technologies are concerned.

Enabling business environment: As well as political stability, there is also a linked need to focus on creating an enabling economic, social and business environment to encourage technology transfer. For example, certain large power station equipment manufacturers interviewed during this study highlighted a number of problems with doing business in India that made them reticent to engage in technology transfer activities.

Infrastructure: National governments have an important role to play in ensuring that the appropriate infrastructure is in place to foster technological development. For example, the intermittent or non-existent supply of electricity in many rural areas of India was cited as a key problem in rolling out biomass technologies in India.

Creating markets: Three of the four pre-commercial and supported commercial technology case studies (LEDs, biomass and hybrid vehicles) highlighted a need for national policy intervention to help create domestic markets for these technologies. As well as a clearly defined domestic policy environment as outlined above, this could also include government procurement initiatives and targeted information campaigns (aimed at, for example, the construction industry) that promote the use of these technologies.

Access to finance: For some smaller scale financing issues, there may be a role for national government intervention. For example, the biomass case study highlighted how investors in the technology often had problems with cash flow due to the seasonal nature of biomass availability. They were unable to overcome this by borrowing as biomass is traditionally viewed as waste and banks are unwilling to lend against it, even though banks are willing to lend against briquetting machinery which is viewed as a capital asset. Governments may therefore wish to intervene to try to address such misunderstandings in relation to novel new low carbon technologies.

4.3.2 International government initiatives

In the case of climate change, extensive institutional arrangements and funding provisions exist pursuant to the Convention to provide a framework for further action with the Expert Group on Technology Transfer (EGTT) play a focal role in this process. Since the Gleneagles Summit the role of other multilateral institutions such as the World Bank and IEA has also come to the fore. Although outside of the UNFCCC/Kyoto process, a number of supportive initiatives have also been established to further international technology development and transfer, such as the Asia-Pacific Partnership (Hoehne et. al.2006).

Collaborative R&D and technology demonstration and diffusion: One of the most important issues that this study has highlighted is the need for bilateral and multilateral collaboration between developed and developing countries on R&D, demonstration and diffusion (RDD&D) of low carbon technologies. This is central to developing technological capacity in developing countries through sharing knowledge and experiences in relation to specific low carbon technologies. For example, industry respondents to this study cited a lack of transparent information on international experience with coal based Integrated Gasification Combined Cycle (IGCC) power generation technologies as one key barrier to the use of this technology in India. This type of concern was also shared by briquetting companies who saw a lack of communication and information sharing as a key barrier to technological development. The biomass case study also demonstrated how collaborative R&D between an Indian briquette manufacturer and a Dutch University led to specific technological improvements. The LED case study also highlighted collaborative R&D as the central requirement for developing technological capacity in this industry in India.

The International Energy Agency's (IEA) implementing agreements provide one potential vehicle for achieving collaborative RDD&D, either bilaterally or multilaterally. There is, however, a need to revise the focus of the implementing agreements so that as well as fostering information sharing they are also able to deliver more output oriented projects as well as demonstration projects. They also need to focus on engaging developing countries. Energy R&D carried out under the European Union's Framework Programme could also provide a potential funding vehicle for collaborative R&D that includes developing countries such as India.

Intellectual property rights (IPRs): As noted above, lack of access to IPRs may act to prevent recipient countries from gaining access to the knowledge necessary to improve their technological capacity. There may therefore be a role for bilateral and multilateral government collaboration in R&D for low carbon technologies that are at very early stages of development with public ownership of IPRs and in fostering targeted initiatives that aim to bring together relevant stakeholders to address specific IPR problems. The potential for new kinds of global public/private partnerships, drawing on the experiences of global arrangements that have been agreed internationally to support access to anti-retroviral drugs for low income countries, have not been fully explored in the climate context. More detailed work analyzing the potential application of these approaches to the climate context, bearing in mind the unique features of climate change, might create a fresh approach to discussions.

High costs of new technologies: Many low carbon technologies are new or still being developed and therefore entail higher costs for acquiring and/or using/operating them. National governments as well as international governmental bodies may therefore play a role in financing initial uptake of these technologies. International financing initiatives to date have included the Global Environment Facility (GEF) and the Clean Development Mechanism (CDM).

Need for private sector involvement: Government intervention in technology transfer must recognise the central role that private investors play in the transfer process. Failure to engage with private companies has been a key issue in hampering the long term success of government led initiatives such as the Japanese Green Aid Plan.

Information barriers: Poor knowledge of available technologies and financing opportunities reduces demand for new technologies. Bilateral and multilateral information sharing initiatives such as TT:CLEAR have an important role to play in overcoming these barriers. The success of such initiatives does, however, rely on national governments to properly engage with them, for example through the submission of technology needs assessments which are a central part of the TT:CLEAR initiative. As mentioned above, information sharing was seen as a central barrier to the transfer of LED and IGCC technologies. It was also seen as important for helping thermal power plants and boiler manufacturers to optimise the performance of thermal power plants in India.

Markets for carbon: Creating prices for carbon through economic instruments has the potential to enable the carbon reduction benefits of low carbon technologies to be reflected in the market. Although the EU ETS and CDM are playing an important role in providing a price signal, globally the incorporation of the social costs of carbon is still at an early stage. The inclusion of the social cost of carbon emissions within market prices will support the financing of some low carbon technologies by helping to make these more competitive relative to less environmentally sound technologies. However, there are many institutional and regulatory barriers that also need to be examined if the full suite of low carbon technologies is to be taken up in developing countries.

Under the Kyoto Protocol to the UNFCC, the Clean Development Mechanism (CDM) is provides a market price for carbon in the context of developing countries. It allows investors from industrialised countries listed in Annex I of the Convention to generate Certified Emissions Reductions (CERs) by investing in projects that reduce greenhouse gases in developing countries. Current analysis of technology transfer aspects of CDM projects show that some technology transfer is happening in developing countries but perhaps less than might be expected. Countries can try to rectify this by focusing on the kinds of technology they wish to promote and through policy towards CDM projects and programmes. The low number of registered CDM projects that intend to transfer technology in India as compared to other developing countries such as China suggests, however, that there may be some India-specific barriers to technology transfer via the CDM. Examination of India's CDM national approval processes in comparison with those of other countries, and the extent to which these might address this problem requires further study.

Multilateral institutions such as the World Bank have a particularly important role to play. The Bank has recently outlined some additional multilateral finance mechanisms that could be implemented. Following Gleneagles, the World Bank and Regional Development Banks are working on an energy investment framework that aims to address cost, risk, institutional and information barriers to scaling up public and private investment in low carbon technology. Options that have been put forward include a Clean Energy Financing Vehicle that would blend carbon finance and capital grants for highly efficient technologies. They also include proposals to help upgrade the efficiency of existing capital equipment, to provide venture capital, and to develop candidate projects for financing via other mechanisms. As outlined above, the success of such mechanisms will depend on a range of domestic factors such as absorptive capacity, supportive institutional and regulatory frameworks as well on the availability of the technologies in question. There is also an inherent need to ensure that any technology transfer activities that are financed under such mechanisms are aimed at moving beyond just the demonstration of low carbon technologies. Rather they need to be carefully structured to respond to the issues outlined in this report with the explicit aim of contributing to long-term low carbon technological capacity building in developing countries.

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Published by the Department for Environment, Food and Rural Affairs.

Printed on material that contains a minimum of 100% recycled fibre
for uncoated paper and 75% recycled fibre for coated paper.

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