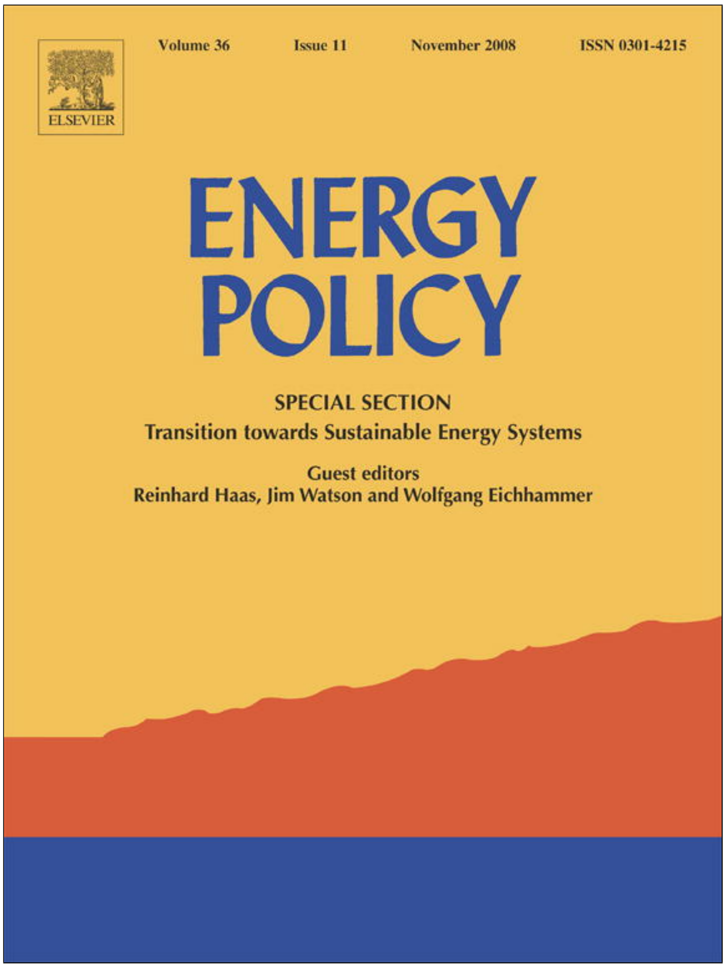

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Key policy considerations for facilitating low carbon technology transfer to developing countries

David G. Ockwell [a,b,*], Jim Watson [a,b], Gordon MacKerron [a], Prosanto Pal [c], Farhana Yamin [d]

[a] Sussex Energy Group, SPRU, Freeman Centre, University of Sussex, Brighton BN1 9RH, UK
[b] Tyndall Centre for Climate Change Research, SPRU, Freeman Centre, University of Sussex, Brighton BN1 9RH, UK
[c] The Energy Resources Institute (TERI), Darbari Seth Block, IHC Complex, Lodhi Road, New Delhi 110 003, India
[d] Institute of Development Studies (IDS), University of Sussex, Brighton BN1 9RE, UK

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ABSTRACT

Based on Phase I of a UK–India collaborative study, this paper analyses two case studies of low carbon technologies—hybrid vehicles and coal-fired power generation via integrated gasification combined cycle (IGCC). The analysis highlights the following six key considerations for the development of policy aimed at facilitating low carbon technology transfer to developing countries: (1) technology transfer needs to be seen as part of a broader process of sustained, low carbon technological capacity development in recipient countries; (2) the fact that low carbon technologies are at different stages of development means that low carbon technology transfer involves both vertical transfer (the transfer of technologies from the R&D stage through to commercialisation) and horizontal transfer (the transfer from one geographical location to another). Barriers to transfer and appropriate policy responses often vary according to the stage of technology development as well as the specific source and recipient country contexts; (3) less integrated technology transfer arrangements, involving, for example, acquisition of different items of plant from a range of host country equipment manufacturers, are more likely to involve knowledge exchange and diffusion through recipient country economies; (4) recipient firms that, as part of the transfer process, strategically aim to obtain technological know-how and knowledge necessary for innovation during the transfer process are more likely to be able to develop their capacity as a result; (5) whilst access to Intellectual Property Rights (IPRs) may sometimes be a necessary part of facilitating technology transfer, it is not likely to be sufficient in itself. Other factors such as absorptive capacity and risks associated with new technologies must also be addressed; (6) there is a central role for both national and international policy interventions in achieving low carbon technology transfer. The lack of available empirical analysis on low carbon technology transfer, coupled with the prominence of the issue within international climate negotiations, suggests an urgent need for further research effort in this area.

1. Introduction

Many developing countries, and China and India in particular, are in the early stages of unprecedented levels of economic growth. Between 1990 and 2001 India's carbon emissions increased by 61%, an increase second only to China's 111% increase in the same period (EIA, 2004; Ghosh, 2005). These levels of growth are set to continue well into the future. It is now widely recognised that one of the key ways in which future emissions can be avoided is through the development and use of low carbon technologies (IPCC, 2007). Many low carbon technologies are, however, owned by firms in developed countries. Understanding how these technologies might be transferred to developing countries is therefore an urgent priority.

This urgency is reflected in the prominence of technology transfer within contemporary international climate negotiations. How to achieve low carbon technology transfer, however, continues to represent a contentious issue, which came close to derailing a major part of the negotiations at the 13th Convention of the Parties (COP) to the UN Framework Convention on Climate Change (UNFCCC) in Bali 2007. The value of creating a multilateral acquisition fund to buy up Intellectual Property Rights (IPRs) for low carbon technologies, for example, continues to represent a sticking point in negotiations between developed and developing nations on this issue.

A key contributor to such disagreements within international negotiations is the current lack of empirical evidence on how low carbon technology transfer might effectively be achieved. Much of

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[*] Corresponding author at: Sussex Energy Group, SPRU, Freeman Centre, University of Sussex, Brighton BN1 9RH, UK. Tel.: +44 1273 873541; fax: +44 1273 685865.
E-mail address: d.g.ockwell@sussex.ac.uk (D.G. Ockwell).

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the work on technology transfer to date, such as the Intergovernmental Panel on Climate Change (IPCC) special report on technology transfer (IPCC, 2000), has focussed more at the theoretical level. In light of this, in 2006 the UK and Indian governments commissioned a collaborative study of barriers to technology transfer as part of the G8 Gleneagles dialogue on climate change (Ockwell et al., 2006). This paper presents some of the findings of the first phase of this study.

The study was approached in three stages around which this paper is structured. Firstly, a literature review was undertaken. Uniquely, this drew on a combination of the literature on technology transfer and technology change more broadly in recognition of the need for low carbon technology to play a more long-term role in the economies of developing countries. The study then examined five case studies of low carbon technologies. 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. Finally, the findings of the case studies were analysed within the context of the conceptual framework developed through the literature review. This yielded some tentative conclusions, which will be built on in the second phase of the UK–India study. The conclusions have been framed as a series of key considerations to guide the development of policies for low carbon technology transfer. These considerations have since been presented and feedback elicited at a series of international climate change meetings.

The case studies in phase I of the UK–India study spanned three different stages of technology development from *pre-commercial* (at the time of selection) through to *commercial with slow diffusion* (see Fig. 1). This recognises the fact that many low carbon technologies are still at early stages of development. Whilst many low carbon technologies are available now (though often at a higher cost than carbon-intensive alternatives), many are still under development (Stern, 2006). As explained in more detail below, this has important implications for technology transfer.

The case studies also cover a range of different energy technology sectors including power generation, energy use in buildings and transport. The evidence is that the most cost-effective global reductions in greenhouse gas emissions are likely to be found across these and other sectors. For example, the most recent assessment report of the IPCC includes a summary of modelling studies, which conclude that cost-effective mitigation includes substantial reductions in energy supply, transport, buildings and industry. It is also expected to include actions to mitigate emissions from forestry and agriculture (IPCC, 2007).

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

Fig. 1. Low carbon technology case studies.

In this paper, due to space considerations, we focus our attention on just two of the case studies analysed in the study, namely hybrid vehicles and integrated gasification combined cycle (IGCC) as these two case studies are illustrative of the majority of the key policy considerations raised by the study.

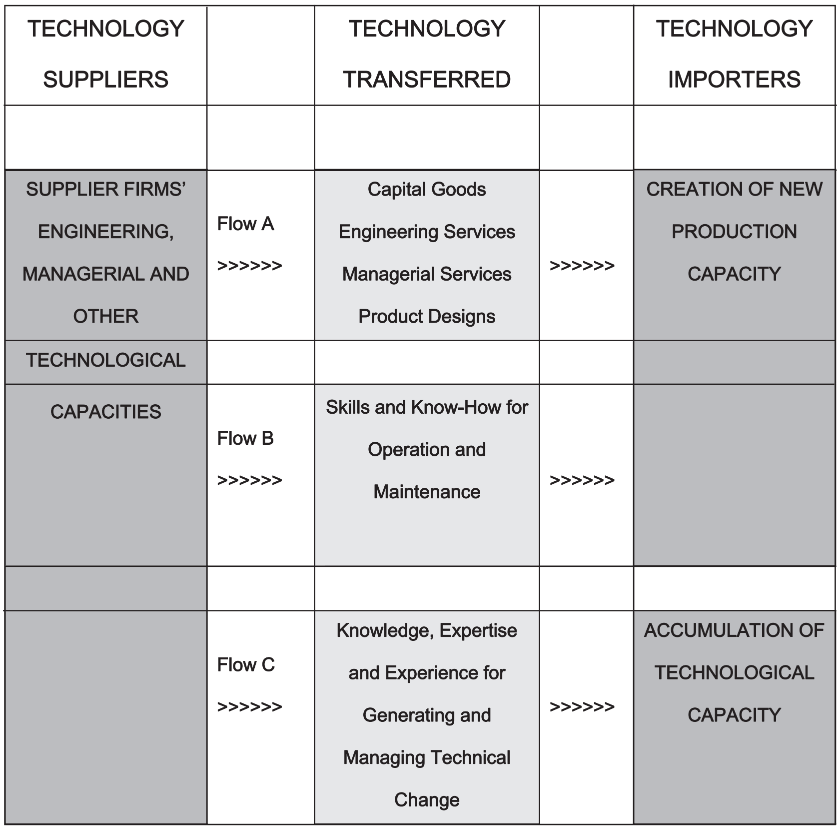
2. Technology transfer and technological change

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." In the case of the transfer of low carbon technology, the economic benefits that Schnepp et al. highlight include the mitigation of the future costs associated with climate change (see Ockwell and Lovett, 2005) as well as any financial benefits to the companies involved in the transfer process.

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 (above) refers to horizontal technology transfer. In the case of low carbon technology transfer between developed and developing countries, there is likely to be elements of both horizontal and vertical transfer as many low carbon technologies are currently pre-commercial or supported technologies and undergo development towards commercialisation within the new country context. The case studies this study focused on were therefore chosen to span all stages of technology development (see Fig. 1).

If technology transfer is to be effective in reducing carbon emissions in developing countries in the long term, technology transfer needs to form part of a broader process of technological change. As Freeman (1992) highlights, technological change occurs through either incremental or radical innovations or combinations thereof. 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 and 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).

At the aggregate level, technological change may culminate in changes in technological systems and changes in the overall 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. 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 and communications technology over the last two decades (Gallagher, 2006) and innovations such as steam power and electricity. The fact that these aggregate level changes can result from both incremental and radical innovations, or a combination of both highlights the fact that the transfer of technologies that contribute to incremental improvements in the



TECHNOLOGY SUPPLIERS		TECHNOLOGY TRANSFERRED		TECHNOLOGY IMPORTERS
SUPPLIER FIRMS' ENGINEERING, MANAGERIAL AND OTHER	Flow A >>>>>>	Capital Goods Engineering Services Managerial Services Product Designs	>>>>>>	CREATION OF NEW PRODUCTION CAPACITY
TECHNOLOGICAL				
CAPACITIES	Flow B >>>>>>	Skills and Know-How for Operation and Maintenance	>>>>>>	
	Flow C >>>>>>	Knowledge, Expertise and Experience for Generating and Managing Technical Change	>>>>>>	ACCUMULATION OF TECHNOLOGICAL CAPACITY

Fig. 2. The technological content of international technology transfer (*Source*: Bell, 1990).

energy efficiency of technologies deployed in developing countries are equally as important as radical changes and can have significant cumulative impacts on aggregate emissions.****

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 but 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 is in the three flows of technology (A, B and C) illustrated in Fig. 2.

Flows A and B contribute to new production capacity in the recipient country, whereas flow C contributes to new technological capacity. It is the generation of new technological capacity that is most likely to ensure the long-term uptake of, and further advances in the development of low carbon technologies in recipient countries (Worrell and van Berkel 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 and van Berkel 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 Fig. 2, assimilation theories highlight the essential role of flows B and C.

Having briefly reviewed some of the relevant literature on technological change and technology transfer, we now turn to the analysis of the two case studies that form the focus of this paper, namely hybrid vehicles and IGCC.

3. Case study 1: hybrid vehicles

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, 2006, p. 2). This includes a large increase in private car ownership due to increasing levels of personal wealth. As a component of broader, integrated transport infrastructure, hybrid vehicles[1] are widely viewed as having a role to play in reducing transport-related carbon emissions, especially from buses and

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[1] Reference to the term 'hybrid vehicle', 'hybrid car' or 'hybrid' in this paper 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.

private passenger vehicles. Hybrid vehicles combine a conventional internal combustion engine with battery-driven electric motors to achieve a significant reduction in fuel consumption and carbon emissions. These reductions are estimated to be anywhere between 20% and 50% relative to conventional vehicles (Weiss and Heywood et al., 2003, p. 11; Hekkert and Hendriks et al., 2005).

For example, Hekkert et al. (2005) report CO_2 emissions of 153 g/km for conventional diesel vehicles relative to 120 g/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 and Heywood et al. (2003, p. 11) report reductions of around 37–47% 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.

Hybrid vehicle technology also has a high potential to contribute to reducing emissions from public transport. Buses play a key role in India accounting for between 60% and 80% of travel demand (CSE, 2006). 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, NO*x* and PM_{10}.[2] 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).

Hybrid vehicles can utilise up to four steps to achieve increased energy efficiency meaning there are different degrees of hybridisation ranging from mild- to full-hybridisation (Fig. 3).

Beyond the basic underlying technology that defines the degree of hybridisation, a further distinction can be made between three different hybrid drivetrain set-ups: series; parallel; and series/parallel. The series/parallel drivetrain is the most efficient and effectively merges the advantages of both other 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.

3.1. Technology status

Hybrid technology is generally considered to be at the supported commercial stage of development (Fig. 1). Sales of hybrid cars are, however, rapidly increasing. In the US, for example, sales have roughly doubled every year since 2000 and this exponential growth is predicted to continue into the future.

Technology utilised	**Vehicle classification**		
	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

Fig. 3. Difference between conventional vehicles, mild hybrids and full hybrids.

Several companies have begun to invest in hybrid technology with large variation in the degree of hybridisation and drivetrains that they have developed. These include engineering and electrical companies rather than just automotive companies implying that, whilst there are a limited number of vehicle manufacturers in India, there is still scope for Indian companies in other sectors to become involved in developing and manufacturing hybrid technology.

Mild hybrids utilising parallel drivetrains are currently available from Honda. There are also a number of mild hybrid technologies being utilised in buses based on diesel-fuelled internal combustion engines. These include: BAE Systems (series hybrid system named 'HybriDrive'); General Motors' (GM) Allison Transmission (parallel hybrid system called 'E^P System'); and, ISE Corporation with Siemens (series hybrid system called 'ThunderVolt').

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'. The Toyota Prius is perhaps the best known, and certainly the most widely sold, full hybrid car available on the market. As of mid-2007, cumulative global sales of the Toyota Prius had reached 700,000 (Smith, 2007). This, however, represents a very small market share (0.1%) of the 700 million vehicles sold annually across all manufactures. 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.

A key risk associated with hybrid vehicles are high R&D costs. This has led Ford and Nissan to choose to licence Toyota's Hybrid Synergy Drive rather than develop their own drivetrains. High costs have also led to R&D cooperation between companies. In autumn 2005, GM, DaimlerChrysler and BMW announced a cooperative research effort they call the Global Hybrid Cooperation (GCC, 2006). It aimed to develop GM Allison Transmission's E^P System into a full hybrid system that can be used in cars rather than buses and that they hope will compete with Toyota by capitalising on the increased fuel efficiencies possible through the two-mode nature of the E^P System compared with Toyota's

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[2] 'PM' stands for 'particulate matter' and refers to small particles of matter emitted during the combustion of fossil fuels. 'PM_{10}' are particles smaller than 10 μm 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.

one-mode system (ENN, 2006). Commercial SUV applications have now been released by GM with DaimlerChrysler reportedly planning the release of its own two-mode SUV in 2008.

A second key risk associated with hybrid vehicles is higher production costs, mainly due to costs of additional components, including 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. Higher production costs are reflected in higher retail prices for hybrid vehicles resulting in concern regarding levels of consumer demand. At present, this higher cost is passed on to consumers. On average, hybrid vehicles command a price premium, based on sales figures, of around 10–15% above conventional vehicles (Hekkert and van den Hoed, 2006, p. 56).

Fuel savings may well offset the increased initial cost to the consumer during the lifetime of a hybrid vehicle. Marketing these fuel savings to consumers, however, represents a key challenge to automotive manufacturers. It is probably too late—but the appetite for hybrids in the US now (at least here in Boston) is very strong indeed. Even car hire firms have started to offer them. Ford and GM are in deep trouble partly because their fleets are too inefficient (and they don't offer hybrids). 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. This has resulted in some companies hesitating to bring hybrids to market. For example, in collaboration with battery and fuel cell experts at Qinetiq, PSA Peugeot Citroen has developed a diesel hybrid, which they call the 'Efficient-C'. Whilst the Efficient-C is reportedly ready for production, the company claims to be waiting until 2010 before starting commercial production. It hopes that by then the costs of the technology will have reduced to a level that enables competitive pricing relative to conventional vehicles. Other than new technological breakthroughs in component manufacturing, especially for batteries, the key driver that is likely to reduce production costs is the economies of scale that might be realised through increased demand for hybrid vehicles.

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 and react by providing the appropriate product range (Nieuwenhuis and Wells, 2003, pp. 3 and 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, particularly due to the higher prices currently necessary to cover the higher production costs. Commenting on the potential for manufacturing hybrid vehicles in India, Tapan Basu of Bajaj Auto is cited as emphasising that, if market returns remain uncertain, no industry would push a product into the volumes required to sustain economical pricing (DTE, 2006). 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, however, the average price premium for diesel engine vehicles was around US$250 (SAM and WRI, 2003), which is significantly less than the thousands of additional dollars that hybrids currently cost.

This study only identified 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.

Despite uncertainties regarding future demand for hybrid vehicles, manufacturers also face huge potential risks if they fail to position themselves to cope with future limitations imposed on carbon emissions. The carbon intensity of vehicle manufacturers' profits is viewed by many observers to be 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.

The anticipation of future carbon constraints is widely viewed as the main driving factor behind the reactive automotive industry's activities in developing hybrid technology. This is a view that was confirmed in interviews undertaken during this study. 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.

This implies that the early transfer of hybrid technologies to developing countries could be essential in determining the development of technological capacity in this technology.

The problem in both developed and developing countries is, however, that manufacturers remain uncertain as to the extent and nature of the carbon constraints that government policy at the national and international level is likely to impose, or what incentives governments are likely to put in place to encourage the adoption of low carbon 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.

3.2. Incentives and policy interventions

The discussion above clearly highlights the fact that the development of technological capacity in hybrid vehicles in India is both a horizontal and a vertical technology transfer issue. Most of the cost and risk issues that policy can focus on overcoming are as much a concern for developed countries as they are for developing countries. Importantly, the international nature of the automotive industry, with component manufacturers and suppliers often separate from automobile firms, implies that any increase in international demand for hybrid vehicles could be beneficial in driving economies of scale in component production, including batteries, which underlie the relative expense of hybrid vehicles. We therefore begin by examining the options for national policy initiatives to encourage demand for hybrid vehicles that are generic for developed and developing countries before discussing options for international policy intervention.

As highlighted above, 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. One 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, although it is questionable to what extent this overrides other considerations such as manufacturing and labour costs and access to export markets. India has introduced emissions limits via its 2003 Auto Fuel Policy, which sets limits for new vehicles as well as standards for existing vehicles. As Fig. 4 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.

Such regulatory action provides a strong indication to manufacturers of the future policy environment and encourages firms to work to develop their strategic positioning in the face of future limits. Many automotive companies are, however, 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, automotive manufacturers in Brazil responded by adjusting technology to enable most vehicles to run on ethanol (IPCC, 2000, p. 209).

Governments can also opt for market-based incentives for low carbon vehicles. Subsidies can be offered to consumers for purchasing low carbon vehicles. In the UK, for example, the government previously offered a £1000 (US$2000) 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, whereas the thousands of pounds of additional upfront costs associated with buying a hybrid vehicle are obviously significant.

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

Fig. 4. Target year for meeting Euro light vehicle emissions standard equivalents in India, China and Europe.

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. This enables manufacturers to respond to incentives to reduce emissions in the most cost-effective way possible. Similar goals might also be achieved by putting an economy-wide price on carbon emissions such as, for example, the introduction of emissions trading schemes at national or international levels. It should be noted, however, that a technology-neutral approach to taxation or pricing carbon 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 NO*x* and PMs have important environmental and health implications. This is particularly the case in some developing country cities, including Delhi. Diesel engines, for example, might be a cost-effective way of reducing carbon emissions but they are higher emitters of NO*x* 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.

A 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 requiring 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 on both environmental and financial grounds.

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-a collaboration between the US government's National Renewable Energy Laboratory (NREL) and industry. This highlights the importance of India's national system of innovation and 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 and to develop the 'absorptive capacity' necessary to absorb, work with and learn from the transfer of new low carbon technologies from developing countries.

There is also an important role here for knowledge sharing and technological capacity development via international initiatives 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 fellow participants on work arising from the implementing agreement on hybrid and electrical vehicles. 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 therefore 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.

There are also certain characteristics of arrangements between firms in developed and developing countries that may have important implications for the level and nature of technology transfer that might result from such arrangements. If, for example, foreign firms supplying hybrid technology maintain a high level of integration in their transfer activities this could make it more difficult for related knowledge to diffuse through the recipient country. The level of integration refers to the extent to which technology suppliers integrate the different flows involved in the transfer process (flows A–C in Fig. 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 and are therefore central to developing technological capacity within recipient countries.

It has, for example, 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, 2004; Xinhua, 2004). The joint venture relationship between the two companies has, however, led to talk of FAW-branded hybrid vehicles being produced in future (Xinhua, 2004). Without a move to this kind of less integrated approach, the relationship is less likely to enable China to develop 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.

In the long term, however, more integrated approaches are not necessarily a barrier to knowledge transfer. For example, BAE System's supply of ready manufactured hybrid drivetrains to Orion buses in the US could limit the short-term 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. But this may not be satisfactory in the case of low carbon technologies as the very reason for government intervention to encourage their transfer to developing countries is rooted in the need for urgent action to rapidly reduce carbon emissions and avoid dangerous climate change.

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. For example, Kim (1998) demonstrates how managers within Hyundai 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.

Even if companies were able to rapidly develop their understanding of and ability to work with hybrid technologies, they may still face barriers related to legal protection of IPRs for 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 licence 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. It is also 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.

4. Case study 2: integrated gasification combined cycle (IGCC)

India is the world's third largest coal producer after China and the USA, accounting for 8% of global production and it has 10% of the worlds proven reserves of coal, the fourth largest after the USA, Russian Federation and China (BP, 2006). The majority, around two thirds, of India's domestically produced and imported coal is used in power generation (TERI, 1998). Indian coal is of poor quality due to its high ash content (around 50%). This adds additional energy requirements in terms of cleaning and transporting coal for power generation and can cause problems for its use with advanced clean coal technologies such as IGCC. India has also experienced problems related to inefficiencies in the coal supply chain including bottle necks in railway transportation over long distances (Shackley, 2007). Nevertheless, the share of power generated using coal is set to rise steadily over the next few decades with significant aggregate increases in coal-fired power generation resulting from the rapid increase in economic activity in India, volatile gas prices and targeted policies that aim to rapidly speed growth in the power sector (Ghosh, 2005; Shackley, 2007). In light of this, clean coal technologies clearly have an integral part to play in reducing future CO_2 emissions in India

4.1. Status of technology

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 fertilisers.

Gasification as an industrial process is an established technology with many applications, including steam, chemicals, fertilisers, clean fuels and hydrogen. Most basic products produced from refineries or from oil or natural gas conversion can also be produced by gasification.

The three main types of gasification technologies currently available 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.

The 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 syngas produced from coal or other fuels instead of using natural gas.

IGCC 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. IGCC can also offer low emissions of other pollutants such as SO_2 and NO*x* (see Table 1). Some analysts believe that first-generation IGCC without carbon capture in India has the potential to reduce CO_2 emissions by a tenth compared with emissions from supercritical pulverised coal (PC) and by a fifth compared with 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, 2005), a situation that is exacerbated by the low quality of Indian coal.

For more radical cuts in carbon emissions, gasification needs to be combined with carbon capture technology to facilitate a pre-combustion carbon capture process involving separating the syngas 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 syngas.

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). Capabilities also exist in specific component technologies. For example, British Gas and Lurgi have developed their own gasifier technology. In addition, some capabilities exist in other countries including India 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). In India, BHEL, the largest power plant equipment manufacturer, has built a small-scale fluidised bed gasifier for testing purposes (6.2 MW) using Indian coal. Some independent observers consulted during this study, who have studied BHEL's gasifier were quite positive about its potential viability.

BHEL has also developed a hot gas cleanup system (HGCS) using a granular bed filter system coupled to a 6 tonne/day 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 has been talking to National Thermal Power Corporation (NTPC)—the national utility—and the Indian Planning Commission about taking this work forward. Their ultimate aim is to build a 125 MW IGCC demonstration at the Auraiya power plant (BHEL, 2006).

NTPC, the Indian national power company, have also been thinking independently about gasification. Whilst, as noted above,

Table 1
Capital costs of coal-fired IGCC plants

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

Source: Various manufacturer and government publications.

[a] First full operation on coal gas.

[b] Gasifiers are either oxygen-blown (OB) or air-blown (AB).

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

[d] Puertollano's capital cost rose to \$2900 kW due to interest charges during a prolonged construction period.

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$10 m, as well as a more multilateral approach via the Asia–Pacific Partnership, which the US is viewed to be coordinating. The US has been fairly active in lobbying developing countries such as China and India to consider IGCC for many years, with little tangible success so far. This could be perceived as an effort to recover some of the funds the US government has invested in IGCC demonstration.

The two key risks associated with IGCC are high capital costs and the lack of reliable operational history and new nature of this particular application of gasification, which in turn amplify the risks associated with high capital costs. Although the first coal-fired IGCC plant went into operation 20 years ago, this technology is still in its demonstration phase. Coal-fired IGCC plants have been constructed at several sites in the USA and Europe. Table 1 below gives details of the five main 'utility-scale' demonstration plants. All have been supported by public funding from EU Framework Programmes or the US Clean Coal Programme.

Table 1 highlights the substantial capital costs of IGCC plants. In general, financial performance has been slightly better in the USA than in Europe. Recent experience with gas-fired CCGT suggests that competition between gas turbine and gasifier suppliers could deliver lower costs for fully commercial plant. Some estimates for UK-based IGCC have been fairly optimistic (McMullan and Williams et al., 2001), but the accuracy of such estimates cannot be confirmed as no commercial coal-fired IGCC plants have been built anywhere in the world, let alone in the UK.

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. 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.

In terms of reliability, availability figures show some evidence of improvement during demonstration programmes. For example, Tampa Electric's overall availability improved from 33% in 1996 to around 80% in its final 3 years of operation from 1999 to 2001 (TEC, 2002). 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 h. 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%.

Since the construction of the five demonstration plants listed in Table 1, 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 250 MW 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 275 MW 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 (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.

A final possible barrier, related to information sharing, is the enforcement of IPRs in relation to advanced industrial gas turbines for IGCC. Previous experience shows that, whilst suppliers from industrialised countries tend to form alliances with developing country equipment companies such as BHEL, in order to maintain competitive advantages 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).

4.2. *Incentives and policy interventions*

As with hybrid vehicles, IGCC is a clear example of a low carbon technology that requires policy aimed at facilitating both vertical and horizontal transfer. From a vertical transfer perspective, incentives need to be targeted towards reducing risks associated with high capital costs and limited operational experience. 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 US Department of Energy for the Clean Coal Technology 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 with industry retaining intellectual property rights. The Government's share in the cost of the project is then repaid by 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 does not, however, 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.

In both developed and developing countries, 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 clean coal technologies, including IGCC. Taking this further to place a value on carbon emissions from power generation through taxes or emissions trading could further 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 relatively high penalty level of $200/tonne 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/tonne 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, 2005). 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.

A central consideration in the context of India is also 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 in India. 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. There is also a strong role here for international initiatives to share information on technology, such as the UNFCCC's TT: CLEAR. 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. Perhaps with this in mind, the Indian government decided in 2006 to contribute to the US government's share of the costs of the FutureGen zero emissions coal project that is planning to build a zero emission IGCC-based plant in the USA. Careful thought, however, needs to be given to the potential usefulness of this given the particular characteristics of Indian coal.

5. Key policy considerations

Analysis of the literature on technology transfer and the case studies examined during this paper highlight a number of key considerations for policies for low carbon technology transfer to developing countries. These considerations can be summarised around six themes.

1. *Technological change and capacity building.*
   In order for the transfer of low carbon technologies to have a sustained impact on the carbon intensity of economic activity in developing countries, it needs to facilitate a broader process of technological change with an overall aim of increasing low carbon technological capacity. It is this capacity that will enable future innovation and ensure long-term adoption of low carbon technologies. Central to the development of this capacity is the flow of knowledge and expertise as part of the transfer process. It also relies on developing the absorptive capacity of recipient firms to ensure they are able to take advantage of collaborations with international suppliers of low carbon technologies. National systems of innovation and international collaborative RDD&D and information sharing initiatives therefore have a central role to play in facilitating low carbon technology transfer. As most technology transfer takes place within the private sector, these activities must ensure private sector participation. Building on international experiences to date, further empirical research could usefully be directed at understanding the structural and organisational elements that are most likely to contribute to the effectiveness of internationally collaborative RDD&D initiatives in facilitating low carbon technology transfer.
2. *Stage of technology development*
   Due to the fact that many low carbon technologies are at early, pre-commercial stages of development, barriers related to both horizontal and vertical transfer need to be overcome. This implies a need for national policy initiatives to facilitate the commercialisation of low carbon technologies in both developed and developing countries. Where technologies are owned by companies based in developed countries, generic barriers to technology transfer between developed and developing countries also need to be addressed.
   The stage of technology development also impacts on the nature of the barriers to technology transfer. For example, risks related to capital costs and reliability are less acute for hybrid vehicles than they are for IGCC, which is still at an earlier stage of development. Pre- and supported-commercial technologies such as IGCC and hybrid vehicles are also likely to require more effort to encourage market development than technologies, such as established power generation technologies, that are already in widespread commercial use.
3. *Levels of integration in the transfer process*
   Less integrated technology transfer arrangements, involving, for example acquisition of different items of plant from a range of host country equipment manufacturers, are more likely to involve knowledge exchange and diffusion through recipient country economies. The lower the level of integration, therefore, the greater the chance that technology transfer will contribute to developing technological capacity within recipient countries. In the long term, knowledge related to more integrated technology transfer activities may eventually diffuse through recipient country firms, but this may not be commensurate with the urgency of the need to encourage the uptake of low carbon technologies in developing countries. This further emphasises the case for government intervention to speed up low carbon technology transfer.

4. *Supplier/recipient firm strategies*
   The level of integration in the transfer process discussed above, whilst heavily influenced by the strategies adopted by supplier firms who may wish to preserve competitive advantages, may also be influenced by strategies adopted by recipient firms. 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. This implies that private companies in developing countries can play a role alongside government in efforts to develop low carbon technological capacity, especially as private companies are not subject to the same level of restrictions under international trade regulations.
5. *IPRs and commercial interests*
   The issue of IPRs has become very prominent within international negotiations around low carbon technology transfer. Firms tend to invest large amounts of money in the development of new low carbon technologies and often attempt to maintain their competitive advantage via legally enforceable IPRs. This could act to prevent recipient firms from gaining access to the knowledge necessary to develop new technological capacity. Access to IPRs is not, however, likely to be sufficient in itself to facilitate technology transfer. Other factors such as absorptive capacity and risks associated with new technologies must also be addressed. For example, the key barrier to transfer of IGCC to India 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. Furthermore, the work of Barton on IPRs and renewable energy technologies concludes that IPR issues are sometimes important. However, they are not likely to present insurmountable barriers for firms in larger developing countries (Barton, 2007). Given the importance attached to the IPR issue within international climate negotiations, further research effort in this area would be beneficial. Empirical analysis should focus on issues such as: the extent to which IPRs as a barrier to technology transfer vary according to the stage of technology development or the specific nature of the technology; the relationship between the strength of the IPR regime in a developing country and the extent to which this fosters technology transfer; the potential for overcoming IPR issues via international collaborative R&D initiatives on technologies at a very early stages of development with the aim of making the IPR available as a free, or low cost, public good (see, for example, UK Commission on Intellectual Property Rights, 2002); the role for international initiatives and international funds, such as those established under the UNFCCC, 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; and, lessons to be learnt from other sectors, such as public health.
6. *Need for domestic and international policy intervention*
   Both case studies highlighted a central role for both national and international policy interventions in achieving low carbon technology transfer. At the national level, domestic policies that provide incentives for the use of low carbon as opposed to conventional technologies can play a strong role in overcoming cost barriers and developing markets for new low carbon technologies. These include, for example, taxes, subsidies and emissions trading schemes as well as setting and enforcing ambitious emissions limits. National level efforts are also required in developing national systems of innovation, actively engaging with international collaborative R&D initiatives and ensuring appropriate infrastructure is in place to foster technological development. It is also important that enabling environments are created to foster international business transactions. 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. The role of national policy highlights the country-specific nature of barriers to low carbon technology transfer.
   At the international level, there is a clear role for fostering activities, such as collaborative RDD&D and information-sharing initiatives that aim to develop low carbon technological capacity within developing countries. Importantly, the success of such initiatives relies on engaging with private companies. The failure to do so has been a key issue in hampering the long-term success of government-led initiatives such as the Japanese Green Aid Plan (Evans, 1999). International efforts can also be targeted at overcoming barriers related to the high costs of low carbon technologies either via direct financing or initiatives that aim to put a price on carbon. International financing initiatives to date have included the Global Environment Facility (GEF) and initiatives, such as the Clean Development Mechanism (CDM), that aim to create prices for carbon. The success of the CDM in facilitating technology transfer is, however, far from certain, not least because it was not specifically designed with this aim in mind. Multilateral institutions such as the World Bank also have a particularly important role to play. The Bank has recently outlined some additional multilateral finance mechanisms that could be implemented, including 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. The likely success of such financing initiatives should be assessed with reference to their attention to all of the key considerations outlined above.

6. Conclusion

The transfer of low carbon technologies to developing countries has a key role to play in reducing carbon emissions associated with future economic development. Achieving this requires both vertical and horizontal technology transfer and must facilitate a broader process of technological change and capacity building within developing countries. As the analysis in this paper has demonstrated, there is no ‘one policy fits all’ approach for achieving this. Rather, a range of carefully structured national and international policy initiatives will be required, each of which should be assessed with reference to the full range of key considerations outlined in this paper.

The lack of available empirical analysis on low carbon technology transfer, coupled with the prominence of the issue within international climate negotiations, suggests an urgent need for research effort in this area. Two areas where future empirical analysis could usefully be directed include the nature of IPR-related barriers to technology transfer and the structure of internationally collaborative R&D mechanisms that are most likely to be effective in facilitating low carbon technology transfer. Importantly, empirical analysis must account for country- and technology-specific contexts. These two areas will be investigated further in the second phase of the UK–India study.

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