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Barriers to the diffusion of climate-friendly technologies

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Abstract: Based on an extensive literature review and research interviews of energy experts, this article asks: what are the remaining impediments to clean energy systems and how can a Post-Kyoto Protocol climate framework be designed to overcome them? The article begins by exploring commercially available ‘clean’ energy systems and practices relating to energy end-use and infrastructure, energy supply, carbon capture and storage, and non-CO_2-related greenhouse gas emissions. The article then examines a selection of persistent financial, market, information and intellectual property barriers. Lastly, it articulates the implication of these barriers for the design of future national and international climate change policies.

Keywords: energy policy; technology transfer; renewable energy; energy efficiency; carbon capture and sequestration.

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1 Introduction

Tackling climate change promises to be one of the most significant technological challenges of the 21st century. It will require scientific and engineering genius to produce entirely new energy systems that avoid emitting greenhouse gases (GHGs) while simultaneously powering global economic growth. Success will also necessitate institutional, economic, social and policy innovations to foster the widespread and rapid deployment of technology solutions. A thorough understanding of the impediments currently hampering GHG-reducing technologies provides a basis for developing effective strategies to accelerate technology commercialisation and deployment.

Many believe that it is not possible to stabilise GHG concentrations without deploying new and improved technologies (Montgomery, 2006). Further, if many technologies are successfully developed in parallel with early action to promote deployment, the cost of stabilisation could be significantly reduced. Assumptions about the availability and deployment of future technologies is therefore a strong driver of stabilisation costs in most climate change models (Nakicenovic and Riahi, 2003; Weyant, 2004). Edmonds et al. (2004) studied stabilisation at 550 parts per million by volume (ppmv) carbon dioxide (CO_2) and showed that the accelerated pace of technology improvements and deployment could produce a reduction in costs of a factor of 2.5 in 2100 relative to a baseline incorporating the 'business as usual' rate of technical change.

A litany of recent studies, however, has documented barriers to innovation for cleaner energy systems at every stage of the commercialisation and deployment process. The Interlaboratory Working Group (2000) identified scores of barriers relating to misplaced incentives, inconsistent regulations, and information and market failures. Painuly (2001) provides an extensive table of barriers/failures to renewable energy penetration, highlighting in particular the problem of missing market infrastructure that may increase costs. Beck and Martinot (2004) identify the following types of barriers to renewable energy: subsidies for conventional forms of energy, high initial capital costs, imperfect capital markets, lack of skills or information, poor market acceptance, technology prejudice, financing risks and uncertainties, high transaction costs, and a variety of regulatory and institutional factors. The Carbon Trust (2005) suggests that clean energy technologies tend to be impeded by financial and market challenges on the 'supply side' and behavioural and organisational 'non-optimalities' on the 'demand side'. Sovacool (2008b) interviewed more than 180 experts working for utilities, in government agencies, and the national laboratories and identified 38 non-technical barriers to the deployment of distributed generation, renewable energy and energy efficiency technologies.

Based on an extensive literature review and research interviews of energy experts, this article asks: what are the remaining impediments to clean energy systems and how can a Post-Kyoto Protocol climate framework be designed to overcome them? The article begins by exploring commercially available 'clean' energy systems and practices relating to energy end-use and infrastructure, energy supply, carbon capture and storage, and non-CO_2-related GHG emissions. The article then examines a selection of persistent financial, market, information and intellectual property barriers. Lastly, it articulates the implication of these barriers for the design of future national and international climate change policies.

2 Defining GHG-reducing systems and practices

GHG-intensity reducing technologies refer to technologies that decrease GHG emissions per unit of economic output. This article limits its scope to technologies that have been found to be 'suitable for deployment' based on technical maturity. Technologies that are still in basic research and development (R&D) stages are excluded from this assessment – even though their use may eventually offer GHG reductions. Commercially available GHG-reducing technologies are separated into four categories by goal: reducing emissions from energy end-use and infrastructure, reducing emissions from energy supply, capturing and sequestering CO_2, and reducing emissions of non-CO_2 GHGs (Table 1).

Table 1 Fifteen types of GHG-reducing technologies

End-use efficiency and infrastructure		*Energy Supply*	
1	Transportation	5	Low-emission, fossil-based fuels and power
2	Buildings	6	Hydrogen
3	Industry	7	Renewable energy and fuels
4	Electric grid and infrastructure	8	Nuclear fission
Carbon capture and sequestration		*Non-CO_2 GHGs*	
9	Capture	12	Methane from energy and waste
10	Geologic storage	13	Methane and nitrous oxide emissions from agriculture
11	Terrestrial sequestration	14	Emissions of high global warming potential gases
		15	N_2O emissions from combustion and industrial sources

Source: CCCSTI (2009)

2.1 Energy end-use and infrastructure

End-use energy efficiency offers some of the greatest near-term opportunities for large-scale GHG mitigation. Energy-efficient technologies can be loosely divided into four subcategories: transportation, buildings, industry, and electricity transmission and distribution (U.S. CCTP, 2006, 2005).

Transportation of people and goods accounts for approximately one-quarter of the world's energy consumption and slightly more of the energy budget in the USA (28% in 2007). Transportation also accounts for a significant share of energy-related CO_2 emissions: 20% globally and 34% in the USA [IEA, (2008), p.506; IPCC, (2007), p.325; EIA, (2009), Tables A2 and A18]. Growth in this sector is expected to continue, both in the developed and developing world. Broader application of advanced technologies can significantly reduce fuel consumed and emissions produced by transportation. For example, 'hybrid-electric' vehicles and 'plug-in hybrids' use a combination of electric and mechanical power to reduce GHG emissions by one-half or more compared to conventional gasoline vehicles. Regardless of the powertrain or vehicle, lightweight technologies can also profoundly affect fuel efficiency. In aviation, GHG emissions could be lowered through improved technologies including improved engine designs, fuel blends and air traffic management systems.

The built environment, consisting of residential, commercial and institutional buildings, accounts for about one-third of primary global energy demand [IEA, (2008), p.506] and is the source of 35% of global energy-related CO_2 emissions [IPCC, (2007), p.389]. In the USA, the energy services required by residential and commercial buildings demand a greater proportion of the nation's energy budget (40%) and contribute approximately 39% of energy-related CO_2 emissions [EIA, (2009), Tables A2 and A18]. Over the long-term, buildings are expected to continue to be a significant component of increasing CO_2 emissions, driven in large part by the continuing trends of urbanisation, population and GDP growth, and the longevity of building stocks. Energy-efficient building technologies currently suitable for deployment include a number of ENERGY STAR appliances that have not yet fully penetrated markets. This is illustrated by compact fluorescent lamps for homes and T-5 fluorescent systems for offices that are cost-effective today and can use 75% less energy than incandescent bulbs. Suitable heating and cooling technologies include air and ground source electric heat pumps, gas-fired absorption heat pumps, desiccant air preconditioners, and combined cooling, heating and power systems. Numerous building envelope technologies and integrated designs are also ready for use.

Heavy industry is generally more energy-intense than light manufacturing, but both parts of this sector combine to be the largest consumer of energy worldwide, accounting for approximately 36% of energy consumed globally and producing an even larger share of CO_2 emissions – 40% [IEA, (2008), p.506; IPCC, (2007), p.449]. In the USA, the industry accounted for only 32% of the national energy budget in 2007 and 27% of US energy-related CO_2 emissions, reflecting the movement away from energy-intensive manufacturing and toward service and information-based activities [EIA, (2009), Tables A2 and A18]. The industrial sector can reduce emissions through technologies that increase the efficiency of process heating or process and design enhancements that can improve quality, reduce waste, reduce the intensity of material use and increase in-process material recycling. Improvements are possible in steam boilers, direct-fired process heaters and motor-driven systems, such as pumping and compressed air systems.

The sector can also make greater use of coordinated systems such as combined heat and power and cascaded heat.

Electricity demand is projected to increase by 19% from 2003 to 2012. To accommodate growing demand and greater reliance on regionally concentrated renewable sources, the future electricity transmission infrastructure needs to evolve into an intelligent and flexible system that enables the use of a varied set of baseload, peaking, and intermittent generation technologies. High temperature superconducting cables can transmit electricity with half the energy loss of conventional cables, and distributed generation and combined heat and power offer the ability to productively reuse waste heat.

2.2 *Energy supply*

Reducing GHG emissions of energy supply requires transitioning from high emissions fossil fuels to those with low or net-zero CO_2 emissions. Many options have been developed for making such a transition including: non-emitting sources for electricity generation such as nuclear fission and renewable technologies, carbon-free sources for hydrogen generation and replacing fossil fuels with bio-based fuels (U.S. CCTP, 2006, 2005).

Because fossil fuels are so plentiful and easily converted into usable mechanical energy, they are expected to maintain hold on a large share, about 80%, of the global energy market. Efforts to improve fossil fuel use have focused on clean and efficient coal technologies, such as gasification and combined-cycle plants, co-production efforts and high efficiency improvements. A specific example is oxygen-enhanced combustion, which is a type of advanced combustion system, can reduce NO_x emissions and facilitate carbon sequestration.

Hydrogen has the potential to be an attractive non-carbon energy carrier for both the transportation sector and stationary applications through the use of fuel cells. Advancing hydrogen to a point where it displaces conventional fuels will depend not only on successfully overcoming technology barriers related to hydrogen production, storage and fuel cells, but also on developing a substantial hydrogen delivery infrastructure. Today, more than 90% of the hydrogen produced in the USA for industrial purposes is derived from steam reforming of natural gas; however, there are other options for future production, such as partial oxidation or thermal reforming. Once the hydrogen is produced, advanced technologies can convert it to mechanical energy; for example, proton exchange membrane fuel cells are being demonstrated in bus and taxi fleets around the world as well as indoor-operating forklifts.

Considerable flexibility in uses for renewable fuels, thermal energy and power offers opportunities for combining GHG reductions with other needs in the long-term; these technologies can be modular and used in combination with others. Renewable technologies include wind, solar thermal and photovoltaics, geothermal power and heat pumps, small hydroelectric; for a particular example, significant untapped wind resources remain with advanced turbine and blade designs for offshore and low-speed wind energy. In the area of renewable fuels, ethanol from corn has increased in market share, while cellulosic ethanol promises to expand the source base to include woody biomass and newspaper waste.

Nuclear fission is already a significant source of non-GHG emitting electricity production worldwide; in 2005, 443 operating nuclear fission power plants produced over one-quarter of the world's electricity. Nearly a quarter of these is operated in the USA and provides about 20% of the nation's electricity. Nuclear power plant licenses are being extended to 60 years and several consortia have submitted early site permit applications for new plants using Generation III or III+ technologies. Examples of Generation III+ technologies include the General Electric Advanced Boiling Water Reactor and the Westinghouse AP600 and AP1000 plants, which offer shorter construction times and improvements in safety, reliability, operation and maintenance.

2.3 Carbon capture and storage

Due to the widespread use of hydrocarbon fuels, capturing the emissions rather than releasing them may be a near-term option. For example, CO_2 could be directed into deep-geologic storage or sequestered by soils, trees and oceans (U.S. CCTP, 2006, 2005).

Carbon capture could be used at coal-fired power plants and large industrial facilities to remove carbon from the plant's emissions. Capture from coal gasification is already being demonstrated on a commercial level in the US; a coal gasification (for synfuel) plant captures more than 200 million standard cubic feet (scf) per day of CO_2, using pre-combustion capture, in a 96% pure stream. Another suitable technology is post-combustion capture, which involves separation of CO_2 from flue gases, accomplished by using amine-based chemical absorbents.

Long-term geologic storage of CO_2 is one possible way to avoid GHG emissions even with continued production of GHGs. Geologic storage would include some form of injection into suitable geologic sites, such as saline formations, deep seam coal beds, or depleted oil and gas wells. Such geologic formations, located deep underground, could store injected CO_2 much like natural gas and oil have been stored naturally for millennia. For example, CO_2 injection has been used to boost oil production since 1972 and accounts for 50% of enhanced oil recovery projects in the USA. Similarly, CO_2 can be injected into deep seam coal beds to release methane from the surface of the coal, while the CO_2 is left stored in the coal seam.

Terrestrial sequestration is the storage of CO_2 in vegetation and soils through photosynthesis. These processes are already at work: terrestrial sequestration currently offsets about 12.5% of all GHG emissions in the USA [U.S. EPA, (2008), Table ES–2]. At the same time, deforestation and other land use changes currently account for about 30% of global GHG emissions (U.S. EPA, 2006). For forestlands, forest management practices such as afforestation, reforestation and the mitigation of deforestation all preserve stand-level forest carbon stocks minimise carbon loss. Terrestrial sequestration technologies and practices suitable for commercialisation and deployment include conservation tillage, cover crops, active forest management and low-impact harvesting.

2.4 Other GHGs

Other gases besides CO_2 must be considered in any plan to reduce GHG emissions. These include methane (CH_4), nitrous oxide (N_2O), and high global warming potential (GWP) gases such as sulphur hexafluoride (SF_6), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6), which have been identified as causing increased radiative forcing.

These other gases afford significant near-term opportunities for addressing the underlying causes of climate change (U.S. CCTP, 2006, 2005).

Methane emissions from the energy and waste sectors (i.e., coal mining, oil and natural gas systems, landfills and wastewater treatment) accounted for 31% of global non-CO_2 GHG emissions and nearly 50% of global methane emissions in 2000. Landfill methane emissions are expected to increase in developing nations and countries with economies in transition as solid waste is increasingly diverted to managed landfills (U.S. EPA, 2006). Bioreactor systems could significantly decrease these emissions by accelerating the decomposition of organic matter in the waste stream via enhanced microbiological processes. Advanced methane measurement and detection technologies are available for the cost-effective visualisation of methane leaks.

Globally, agricultural sources of methane and nitrous oxide (i.e., crop and livestock production, fermentation of livestock manure and rice production) account for nearly 60% of global non-CO_2 emissions. Methane produced from manure can be reduced through processing by digester technologies similar to those used in domestic wastewater treatment plants. The biologic processes used in the digesters allow for controlled collection of methane which can be used to generate electricity.

Emissions of high GWP gases can also be curbed. These synthetic gases represent about 4% of global and 14% of US non-CO_2 emissions, but are expected to increase significantly worldwide due to growing demand for refrigeration and air conditioning and the industrialisation of developing economies (U.S. EPA, 2006, 2008). Hydrofluorocarbons (HFCs) and other high-GWP gases are being used as replacements for chemicals (like CFCs) that deplete the stratospheric ozone layer, while others are used in industrial applications for processes such as etching and cleaning and as cover gases. Many technologies have been developed recently that could reduce or eliminate the use of high-GWP gases for melt protection. These include alternative refrigerants, newly developed catalysts and climate-friendly alternative cover gas technologies.

Globally, stationary and mobile source combustion of fossil fuels and industrial production of acids accounted for about 4% of global non-CO_2 emissions and 10% of US non-CO_2 emissions (U.S. EPA, 2006). In production of nitric acid (for applications like fertiliser) the suitable technology of non-selective catalytic reduction is very effective at controlling nitrous oxide emissions, but is installed in only about 20% of today's nitric acid plants.

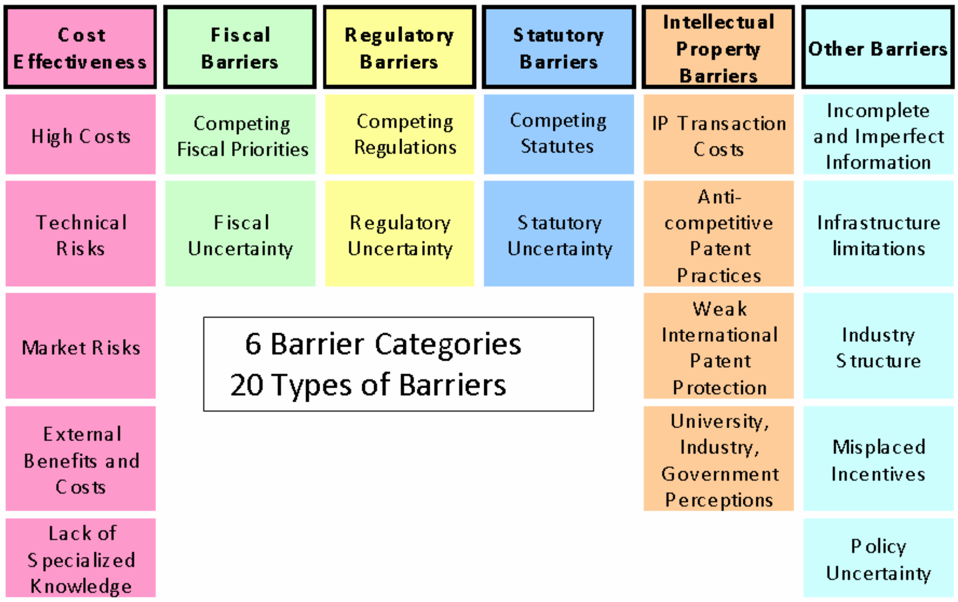
3 Barriers to the diffusion of clean energy systems

Our assessment of barriers to the low carbon technologies mentioned in the section above began with a review of the literature, which is plentiful and diverse. The review spanned the published literature on commercialisation and technology transfer, barriers to the deployment of new technologies, market penetration of climate change mitigation technologies, and intellectual property and law.

The literature review was followed by interviews with 27 experts from the government, national laboratories, industry, universities and consulting firms. These interviews provided a more current overview of market and technology conditions and associated barriers, along with an ability to probe more deeply into the nature of market imperfections and to uncover illustrative deployment failures and successes. The interview protocol involved asking the experts: 'what barriers impede the commercialisation and deployment of GHG-reducing technologies in your area of expertise?' Statements were followed with questions to elucidate greater detail on the particular barrier and how it is seen by the expert to impede the technology's success. In addition, input from the multi-agency CCTP Working Group provided assistance with the cross-walk between deployment barriers and technology sectors.

The literature sampled and participants interviewed listed six categories of barriers – cost effectiveness, fiscal, regulatory, statutory, intellectual property and 'other' – and more than 20 barrier types and 50 detailed barriers (not shown) that are more specific in their scope (see Figure 1). For example, under the heading of cost effectiveness, the deployment barrier 'high costs' is divided into two detailed barriers: high upfront costs and the high cost of financing. Similarly, 'market risks' are divided into four detailed barriers: low demand typical of emerging technologies, uncertain cost of production, the possibility of new competing products and liability risks.

Figure 1 Typology of barriers to the diffusion of GHG-reducing technologies (see online version for colours)



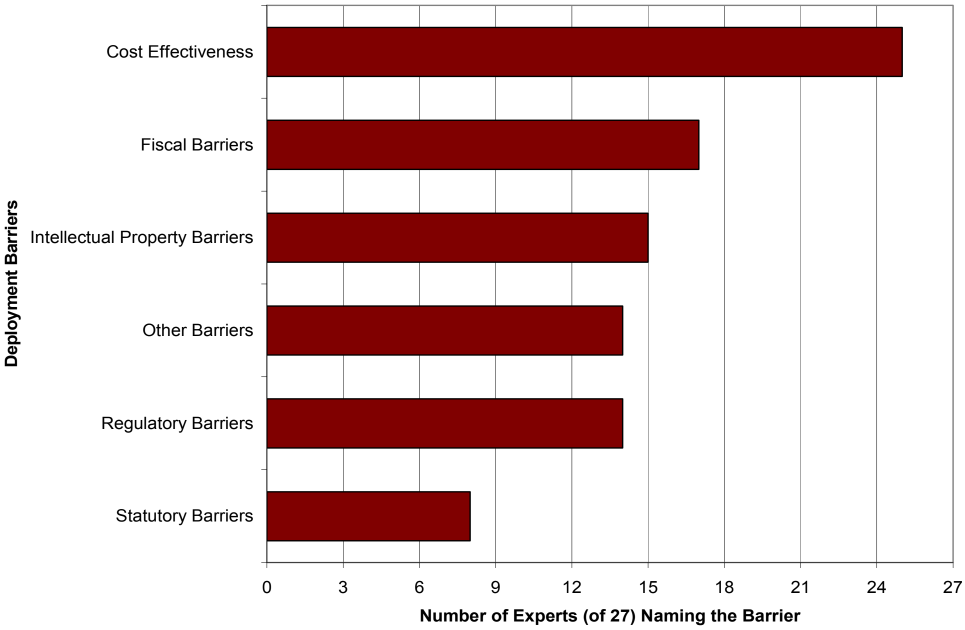
Cost Effectiveness	Fiscal Barriers	Regulatory Barriers	Statutory Barriers	Intellectual Property Barriers	Other Barriers
High Costs	Competing Fiscal Priorities	Competing Regulations	Competing Statutes	IP Transaction Costs	Incomplete and Imperfect Information
Technical Risks	Fiscal Uncertainty	Regulatory Uncertainty	Statutory Uncertainty	Anti-competitive Patent Practices	Infrastructure limitations
Market Risks				Weak International Patent Protection	Industry Structure
External Benefits and Costs				University, Industry, Government Perceptions	Misplaced Incentives
Lack of Specialized Knowledge					Policy Uncertainty

6 Barrier Categories
20 Types of Barriers

Source: Brown et al. (2008, p.x)

One way to assess the relative impact of these impediments is to consider how many experts mentioned barriers of a particular type during the interview process. The results of this assessment are shown in Figure 2. Many experts emphasised the role of cost-effectiveness, particularly problems associated with high costs, market risks and the external benefits of GHG reduction. Fiscal barriers were also noted frequently, including distortionary and fluctuating tax subsidies, fiscal policies that slow the pace of capital stock turnover, and unfavourable electric utility pricing and cost-recovery mechanisms. Intellectual property barriers, 'other' barriers and regulatory barriers were also mentioned by at least half of the 27 experts. Key impediments included among the 'other' barriers are information failures, infrastructure limitations, and policy uncertainty regarding long-term emissions reduction goals and the future legal treatment of GHGs. Statutory barriers, on the other hand, were only mentioned by eight experts; they tended to focus on outdated and unenforced building codes and unclear property rights associated with CO_2 sequestration.

Figure 2 Number of experts citing each barrier category (see online version for colours)



Source: Brown et al. (2008, p.xi)

Because exploring all 50 detailed barriers and 20 barrier types would be exhaustive – and since many of the fiscal, regulatory and statutory barriers identified were specific to the USA – we have chosen to focus this section on only four specific barriers: high costs, market risks, information failures and intellectual property issues. These barriers, unlike some of the others, are applicable beyond the USA and are also some of the most frequently identified challenges by participants.

As this section will explain, *high costs* are impacted by market and technical risks associated with commercialisation or commercial deployment of a technology. To purchasers of the technology, high cost means that some combination of the capital cost of the technology, its cost of operations or other ancillary requirements yield a product that costs too much relative to alternatives. The high cost barrier is a function of endogenous costs (e.g., the nature of the fabrication process and its materials requirements), but it also reflects fiscal and regulatory uncertainties – the intermittent nature of renewable production tax credits and the lack of approved permitting procedures for offshore wind development being two examples. Infrastructure limitations can also contribute to high costs, as with wind generation in the Upper Midwest, which requires investment in transmission lines to reach urban markets.

Market risks refer to uncertainties associated with the cost of a new product vis-à-vis its competitors and the new product's likely acceptance in the marketplace. It includes the risk of long-term demand that falls short of expectations, possibly as a result of misplaced incentives or unfavourable fiscal policy, statutes or regulations. Market risks may be particularly high under certain industry structures: fragmented industries are generally slow to adopt innovation and industries characterised by monopolies aggressively defend incumbent technologies.

Information failure results from a lack of trusted information about technology performance. This information barrier is particularly a characteristic of the new and unproven technology, which creates an environment of uncertainty and technical risk that the innovation will be able to perform to specifications. Financial markets respond by increasing the cost of financing, resulting in high costs. Trusted information is limited because stakeholders, constituents, supply chain providers and user communities have not yet emerged in the early stages of a technology's deployment.

Intellectual property barriers relate to high transaction costs for patent filing and enforcement, conflicting views of a patent's value, and anti-competitive techniques such as patent warehousing, suppression and blocking.

3.1 High costs and externalities

GHG-reducing technologies often have inherently higher upfront costs due to the need for additional features and subsystems required to achieve GHG reductions. Additional features or systems can increase the capital to operating expense ratio. For example, SF_6 is a high GWP gas used in the magnesium industry as a cover gas. SO2 is being considered as an alternative, but it is more toxic and therefore requires additional monitoring (and cost) to deal with the health and safety issues. There are no simple drop-in substitutes. Similarly, high upfront costs make capital intensive solar-electric projects 'not appear as attractive to investors as expense intensive conventional technologies when compared using discounted cash-flow analysis' (DeLaquil, 1996).

The efficient operation of markets may be compromised by the existence of unpriced benefits and costs. These 'externalities' are benefits or costs resulting from a market transaction that are received or borne by parties not directly involved in the transaction. Externalities can be either positive, when an external benefit is generated, or negative, when an external cost is imposed upon others.

In the marketplace for GHG-reducing technologies, both positive and negative externalities operate as barriers to deployment. On one hand, external environmental benefits exist because GHG-reducing technologies mitigate climate change and therefore reduce societal costs of warmer and more extreme weather. However, producers and consumers of these technologies are not rewarded for their climate mitigation benefits. On the other hand, external environmental costs impact the market for GHG-reducing technologies because GHGs result from the consumption of fossil fuels. However, polluters do not pay for the resulting societal damages. This 'free ride' makes it difficult for the higher-priced GHG-reducing technologies to compete. In general, goods generating positive externalities are underproduced and goods generating negative externalities are overproduced. The free market fails to encourage enough CO_2 abatement because firms are not rewarded for the GHG emissions they displace and the market fails to discourage climate-damaging emissions because polluters do not pay for the damage they cause.

Externalities in the energy sectors are quite large. Current energy systems impose multiple negative externalities that damage and degrade the environment, stifle economic productivity, and contribute to human injury, illness and even death. Some of the more severe examples include nuclear meltdowns, oil spills, coal mine collapses, natural gas wellhead explosions and dam breaches. The full social cost of these externalities, while difficult to quantify, can be quite large. Looking at just the electric utility sector in the USA, anticipated negative externalities for 2006 amounted to \$420 billion, \$143 billion *more* than the entire industry's revenues for the same year (Sovacool, 2008b). If looked at globally for the electricity industry, and using Sovacool's methodology, these numbers amount to roughly 13.46 ¢/kWh for every unit of electricity generated worldwide or \$2.55 trillion in external damages every year.

3.2 Market risks

The commercialisation and deployment of technologies is largely a private sector activity to gain market advantage ultimately leading to increased profits. Consumers are not likely to adopt otherwise costly GHG-reducing technologies and practices in the absence of policies or incentives. Market risks include: low demand typical of emerging technologies; uncertain feedstock and product prices; the possibility that a superior technology will emerge making the newly commercialised technology obsolete; and lack of indemnification.

Usually, when new technologies are first launched, niche markets – early adopters – will begin to consume the technology. As awareness of the technology increases and uncertainty decreases, adoption begins to pick up until it reaches a plateau; this model is generally referred to as simply 'the S-curve'. However, technology adoption along this curve is certainly not uniform and this curve can also indicate that the technology is undergoing incremental improvements as adoption increases.

Uncertainties associated with the production costs of new products and the possibility that a superior product might emerge are two of the reasons why firms generally focus on their existing competencies and away from alternatives that could make their present products obsolete. Capital investments in firms go preferentially toward perfecting the performance and reducing the production costs of existing products. This technology 'lock-in' phenomenon helps to explain the fact that new enterprises and not incumbent firms are typically the source of radical innovations that displace existing dominant designs. Lock-in is also reinforced by financial institutions, which prefer to make loans to companies with collateral and the ability to repay debts – characteristics of successful firms within the existing network (Unruh, 2000).

Finally, liability is always an issue; however, new technologies and ideas face barriers with unknown liabilities. Parties involved may not know who is liable in case of a casualty or they may not have estimates for financial loss associated with being the liable party. When failure of a technology may cause harm, liability must be established and the expected magnitude of costs should be known. Investors may be unwilling to become involved in a technology where there is unlimited liability. This barrier has been overcome for nuclear fission power with the Price-Anderson Act, which limits the liability of any one utility in the event of an incident. This sort of instrument is known as indemnification, when a party's total liability is limited by some other mechanism.

3.3 Information and education failures

Lack of technical knowledge to produce skilled workers to install, operate, maintain and evaluate technology is generally considered to be a product of inadequate or unavailable training programmes. Worker training programme quality and availability are very technology and location specific. Some of the variability in these programmes is described below with technology specific examples; technologies not described here may face similar knowledge barriers.

In the buildings industry, few small enterprises have access to sufficient training in new technologies, new standards, new regulations and best practices. Local government authorities tend to face this difficulty as well with building officers working without skills necessary for maintenance and installation of technologies which increase efficiency. The auto and truck repair and service labour force lacks knowledge required to support advanced powertrain designs and alternative fuels; similarly, transition to a large-scale hydrogen economy would require that training and certification systems are developed to address the technical, safety and environmental challenges.

The PV industry lacks not only trained workers, but adequate purchasing channels – consumers cannot find complete systems or get them installed or maintained. In the USA, the Interstate Renewable Energy Council is working with related organisations to identify where standards and certification are necessary and provide assessment of existing training programmes. Only eight states had providers in 2006, however, that included a basic training programme in photovoltaics.

The nuclear industry is concerned about not only trained nuclear engineers and operators, but also the availability of qualified construction and fabrication talent. Many of these craftsmen, like welders, boiler makers and heavy equipment operators go through multiyear apprenticeships to do quality work and there are doubts that the current supply of craftsman would be sufficient to meet expected fission plant demand. The craftsmen shortage is related to possible supply chain issues as the USA lacks some heavy machining capacity necessary for production of certain fission reactor parts. Trained engineers, in nuclear and other fields, are in high demand for reviewing nuclear licensing applications as well as fulfilling applied engineering roles in nuclear power plants and auxiliary industries.

Economic sectors that are diverse and fragmented, like agriculture and forestry, face unique challenges, which impact technologies related to terrestrial sequestration, methane recovery from livestock and poultry operations, and nitrous oxide emissions. Industry fragmentation slows information dissemination and technological change, complicates coordination efforts and limits investment capital. Many thousands of actors operate in agriculture and forestry, largely autonomously, and they may not have land resources as their primary occupation – such as hobby farmers, hunting landowners or simply owners of land that has been in the family for generations. Besides the difficulties of motivating individual land owners, complexity is added because of the need for joint action of many owners to sequester large amounts of carbon. Of course, there are other barriers, as well, including the lack of a formal carbon market that captures the full social value of sequestering CO_2.

Finally, the knowledge barriers that business managers face are exacerbated by the absence of motivation to obtain the knowledge and absence of trust of those who may be able to impart knowledge. As one respondent put it, ‘the number one issue with increasing end-use efficiency is the shortage of qualified energy managers and analysts’.

Business managers in commercial and industrial sectors are facing knowledge barriers, but commercial managers are more likely to adopt new technologies because the main efficiency improvements are related to common technologies, like lighting and air conditioning. Industrial managers, however, have very specific energy consuming (and GHG emitting) technologies that do not have off-the-shelf improvements. Additionally, industrial sectors may not trust companies like energy services companies, which specialise in energy efficiency technologies, because these companies do not have industry specific knowledge to provide accurate estimates to the manager; these same managers may lack resources to hire in-house energy experts. This is partially due to the small (line-item) cost of energy consumption that industry managers face.

3.4 Intellectual property barriers

Generally, lawmakers have designed intellectual property law (IPR) to stimulate innovation, entrepreneurship and technology commercialisation. However, its application can also impede innovation and technological development. High patent filing costs can serve as a financial impediment for inventors and firms with scarce capital including many small businesses. Other impediments include patent manipulation through techniques such as warehousing (owning the patent to a novel technology, but never developing that technology) and suppression (refusing to file for a patent so that a novel process or product never reaches the market). Weak international patent protection among developing countries prevents some companies from investing in international energy projects (Sovacool, 2008a).

Patent blocking – when firms use patents not to promote innovation or technological development, but instead to prevent another firm from innovating – has occurred at least twice in the past five years relating to GHG-reducing technologies. First, while Ford has used Toyota technology (in the Ford Escape), Ford has resisted purchasing Toyota's technology for hybrid vehicles because of hefty licensing fees and Honda has not been able to successfully negotiate a license to use nickel metal hydride batteries in their hybrid vehicles. Second, General Electric has used its 1992 patent on variable speed technology for wind turbines to block Mitsubishi (a Japanese manufacturer) and Enercon (a German manufacturer) from entering the US market for wind energy.

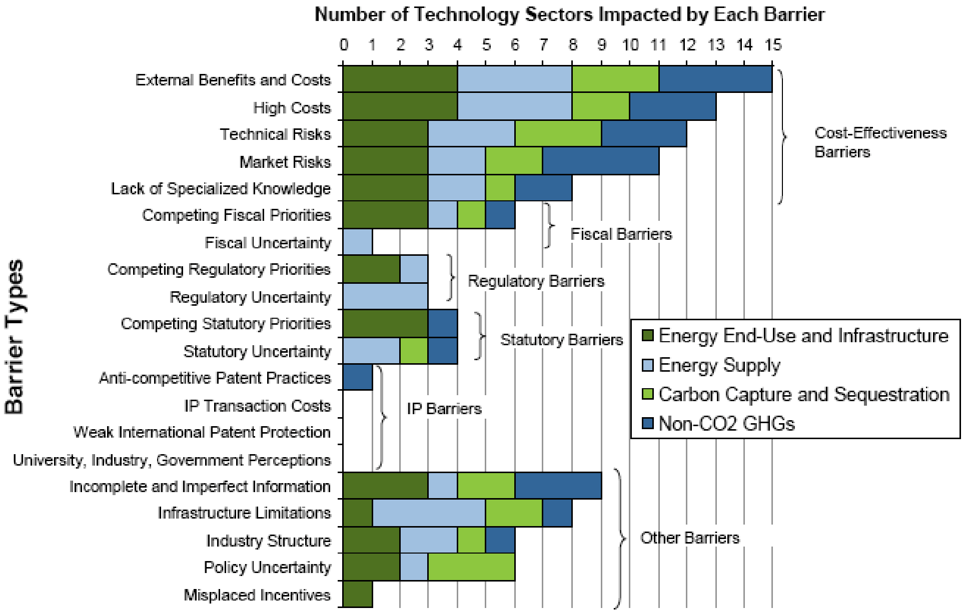
Finally, concerns about weak IPR protection in international countries can deter innovation, as firms believe they would be at a competitive disadvantage to distribute their technology. Also, many companies do not want to collaborate with overseas partners because participation may attract those that have the most to gain and the least to contribute, risking an asymmetrical relationship where sharing is uneven between firms. Moreover, host companies in developing countries may be reluctant to purchase or acquire technology that they believe competitors could freely copy in their own markets.

Thus, weak international IPR protection affects both the supply and demand components of technological diffusion. Such barriers are especially true for efficient industrial boilers, fluidised bed combustion, coal gasification, and various end-of-pipe pollution abatement technologies such as carbon capture and storage. For example, weak IPR protection has prevented US and European companies from developing more advanced clean coal technologies (such as more efficient coal washing processes, advanced combustion turbines, and carbon capture and storage systems). IPR concerns connected with clean coal systems are cited as one of the most significant impediments towards diffusing such technologies to China, Indonesia and other developing countries – especially where new technologies could be reverse engineered or copied.

3.5 Linking barriers to technology sectors

Some barriers to deployment affect relatively limited numbers of technologies or limited portions of the market, while others are economy-wide and broad in influence. This range of impacts is illustrated in Figure 3, which provides a cross-walk between the 20 deployment barriers shown in Figure 1 and the 15 technology sectors shown in Table 1. These linkages were refined and confirmed by the Committee on Climate Change Science and Technology Integration (CCCSTI, 2009) following a lengthy multi-agency review process.

Figure 3 Breadth of impact of different barriers (see online version for colours)



Source: CCCSTI (2009, p.111)

On one hand, many of the barriers are judged to be critical impediments to deployment in only a narrow range of technology sectors. On the other hand, ten barriers are found to have particularly broad impacts, affecting five or more of the 15 technology sectors and spanning three or four of the CCTP goal areas. The most notable among these are the existence of external benefits and costs, the high costs associated with the production, purchase and use of low carbon technologies, and technical and market risks. The principal external benefits are the GHG emission reductions (e.g., from substitutes for high GWP gases and carbon sequestration) that the owners of the technologies are unable to appropriate. The principal external costs are the unpriced GHG emissions from fossil fuel consumption, which make it difficult for higher priced, GHG-reducing technologies such as wind energy and power generated from recycled heat to compete. High costs refer not only to intrinsic features of a technology such as extra components or unusually high levels of precision manufacturing that raise the costs required to produce or use it, but also to price penalties deriving from related barriers such as market and technical risks that raise the cost of financing. Technical and market risks are also critical deterrents to deployment in many technology sectors. Most novel technologies are handicapped by uncertain performance that can forestall adoption and use. Market risks hinder the innovation process generally and pervade the highly competitive electric and liquid fuels markets where numerous alternatives are being promoted.

Also widespread in their applicability are incomplete and imperfect information, lack of specialised knowledge and infrastructure limitations. The shortage of technology performance information coupled with decision-making complexities and bundled benefits present key deployment barriers for nearly half of the CCTP sectors. Similarly, inadequate workforce competence, compounded by the high cost of developing specialised knowledge throughout the supply chain, poses barriers to the deployment of many CCTP technology sectors. Supply chain issues and other infrastructure limitations are also characteristic of new technologies, which often require new methods of delivering parts, services and supplies. The underdeveloped infrastructure for delivering alternative transportation fuels to users is a case in point.

The uniqueness of the barriers faced by different types of technologies highlights the fact that specific deployment policies and programmes may be required. At the same time, economy-wide actions may be more efficient in addressing common barriers in a broad, systematic fashion in ways that could significantly accelerate and expand the uptake of GHG-reducing technologies. This tension between highly specific versus general policy interventions requires careful consideration.

4 Policy lessons for a Post-Kyoto world

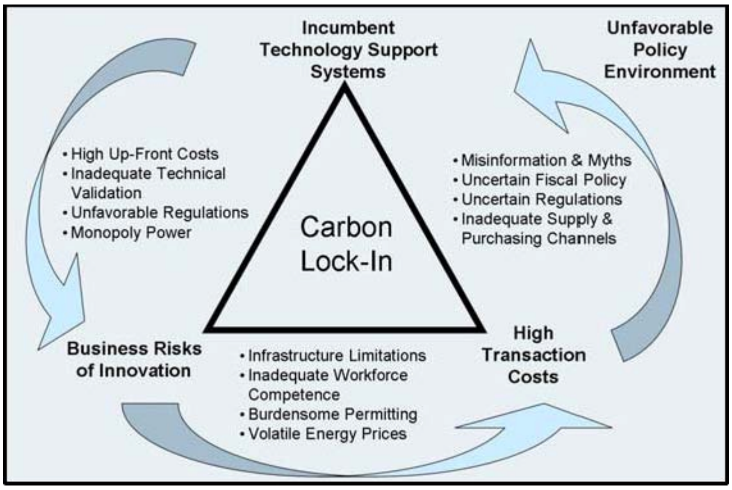
What lessons do the four impediments identified above (high costs, market risks, information failures and intellectual property concerns), as well as the dozens of other barriers not explored in detail, offer those crafting new national and international climate and energy policies after the expiration of the Kyoto Protocol? This section expands on three central insights:

1. the barriers to GHG-reducing technologies are persistent and interconnected
2. adoption of GHG-reducing technologies will not occur without government intervention
3. government R&D programmes need to change.

4.1 The barriers to GHG-reducing technologies are interconnected

Barriers hinder GHG-reducing technology commercialisation and deployment in different ways: by locking in incumbent technologies, by escalating the business risks of innovation and by increasing transaction costs associated with change. These powerful and restraining influences reinforce one another. Systems of positive feedback between government, financial institutions, suppliers, and existing infrastructure support and sustain status quo technologies even in the face of superior substitutes. Inventions and innovations face an array of obstacles in the marketplace, and since many GHG-reducing technologies are relatively new, these obstacles can strongly impact them. Costs associated with gathering and processing information, developing patent portfolios, obtaining permits, and designing and enforcing contracts can all be prohibitive during the early stages of a technology's deployment. Further reinforcement of incumbent technologies is provided by the policy environment that tends to support the status quo. GHG-reducing technologies are often subjected to unfavourable treatment by fiscal, regulatory and statutory policies, and they are impacted by policy uncertainty that causes marketplace inefficiencies and a reluctance to innovate. Taken together, these barriers create 'carbon lock-in'; that is, they 'lock' societies into carbon-intensive modes of energy production and use (see Figure 4).

Figure 4 Incumbent technologies, business risks, high transaction costs and unfavourable policies create 'carbon lock-in' (see online version for colours)



Source: Brown et al. (2008)

Tackling these systematic forces requires comprehensive forms of intervention. For example, overcoming lock-in of incumbent technologies suggests the need to decouple government organisations from the systems that support mainstream technologies, while overcoming business risks of innovation requires reduction of costs and financing hurdles. Some of the options available to address the numerous barriers and forces that impede the progress of GHG-reducing technologies are described in the next subsection.

4.2 Government intervention is needed

Because of these interconnected barriers, if there is one central and overarching lesson for those wanting to promote cleaner forms of energy infrastructure and supply, it is that the market is insufficient to do it alone. Robust government policy is needed to internalise externalities, reduce market risks, provide information and alter intellectual property rights. This government intervention can take a variety of forms, including creating a tax on carbon emissions, financing and procuring cleaner technologies for public use and demonstration, and changing intellectual property law.

For example, one of the simplest actions that countries and international institutions such as the United Nations could take is to provide a market price for GHG emissions and charge emitters for the high cost of climate mitigation technologies. Unlike many of the barriers that are specific to individual technologies or sectors, this single obstacle is economy-wide. A carbon cap and trade system, carbon tax or other policy mechanism for internalising externalities in energy prices could help address cost-effectiveness barriers connected to unpriced costs and benefits related to carbon emissions. Such an approach would increase the competitiveness of low carbon fuels and would place greater value on carbon capture and sequestration projects.

Implementation of such mechanisms would also help to address the policy uncertainty that has become an important barrier to the domestic deployment of low carbon technologies. Energy markets face numerous uncertainties even when operating within a stable policy framework. Today, there are strong ambiguities about possible future GHG regulations. Investors, electric utilities and other key stakeholders who deal with fuel futures must decide what to build as a next generation of power plants and transportation fuels, not knowing if CO_2 and other GHGs will remain unregulated. Similarly, consumers must make ‘rational’ choices about the purchase of energy-consuming products. All of the uncertainties associated with future and current GHG regulations are impediments to positive action. Like high costs, policy uncertainty increases risks for investors and retards progress in the development and deployment of GHG mitigating technologies.

High costs are also a function of technical risks, which suggest policy interventions such as increased support for public-private R&D collaborations and demonstrations as well as greater documentation of technology performance. Given the impact of ‘learning by doing’, stronger government procurement policies that create early markets for GHG-reducing technologies can also be effective. Insufficient investment and lack of capital could be addressed by expanded R&D activities and by more aggressive tax subsidies, loan guarantees and low-interest federal loans for GHG-reducing technologies. In addition, the government funded scholarships for engineers and scientists wishing to pursue careers in fields related to GHG mitigation, such as advanced energy production sciences, agriculture management or forestry could at least partially address the lack of specialised knowledge.

In terms of intellectual property impediments, non-exclusive and compulsory licensing, ‘obligations to use’, cross-licenses, patent pools and trade agreements have been proposed as potential remedies to some of the intellectual property barriers discussed in this article. To respond to anti-competitive patent practices such as warehousing, suppression and patent blocking, governments can force companies to create non-exclusive or compulsory licenses for products that have a significant benefit to the public. As another potential solution to suppression and patent blocking, countries can initiate an ‘obligation to use’ mandate for all new patents. Such obligations could prevent the proprietor from enforcing their trademark rights if they do not use the patent within five years of registration. Further, governments could endow any person with legal standing to seek action for cancellation of a patent that has not been used. Patent pools may help reduce patent blocking. A patent pool is created when two or more companies join together to share or ‘pool’ their patents related to different aspects of the same technology or system. Such pools allow firms to cross-license each other’s patents to create a package where eventual profits can be divided among the participants. One example of a successful patent pool for renewable energy comes from Denmark, where in 1999, separate owners of patents relating to wind turbine blades, environmental monitoring, aeroelastic models, inverters and rotors decided to cross-license each other's intellectual property to develop an advanced prototype (Larsen and Skrumsager, 2000).

4.3 Government R&D strategies need to change

The tendency for the obstacles facing GHG-reducing technologies to be simultaneously technical as well as political and economic means that policy makers continue to design R&D programmes ineffectively. Creating R&D policies to reduce one type of barrier in isolation – say, overcoming lack of funds by awarding research grants – will not overcome barriers at deeper political, cultural and social levels. Instead of creating government incentives and R&D programmes that aim to further increase the efficiency and technical performance of GHG-reducing technologies, policy makers should shift to focus at least partially on increasing public understanding, overcoming market and information failures, and challenging entrenched and incumbent industries.

Put another way, despite the billions of dollars in R&D, procurement, tax incentives, tax credits, subsidies, standards and financial assistance, the impediments to more sustainable forms of energy supply and use are at least partly social and cultural. Until these remaining cultural barriers are targeted in the same way that engineers and scientists tackle technical impediments, the promise of new GHG-reducing systems will remain unfulfilled. Consumer attitudes, values, beliefs and expectations are just as important as improved tyres, better fuel economy, longer lasting batteries, and tougher and lighter wind turbines. These social factors help explain why people embrace some forms of technology, but not others.

Of course, how government policies can best address these cultural and behavioural impediment is not obvious and is the subject of a sizeable body of research by social scientists. Evidence to date does clearly indicate that the strongest influences on behaviour are often contextual (e.g., lack of local availability of a new technology or the inability to retrofit it into one's factory, home or office building). The weaker such contextual constraints, the stronger the influence of personal factors in determining technology choice (Stern, 2008).

5 Conclusions

Many GHG-reducing technologies and practices involve novel and sometimes radical departures from prior practice. As such, they must overcome a wide range of technical and market risks to gain widespread commercial use. Risks must be minimised because success requires displacing the market shares of established and mature incumbent technologies with demonstrated performance records.

A host of technologies relating to energy end-use infrastructure, energy supply, carbon capture and storage, and non-CO_2-related GHG emissions are currently available and technically feasible. However, a collection of barriers impede progress across the complete spectrum of GHG-reducing technologies and operate at every stage of the commercialisation and deployment process. These barriers to the deployment of climate mitigation technologies are wide-ranging. First and foremost is the economy-wide market failure caused by the absence of a price on GHG emissions. In combination with other cost-effectiveness issues, these are the most critical and pervasive deployment barriers. However, additional obstacles play important roles as well, including financial, technical, and market risks, infrastructures and supply chain gaps, misplaced incentives and imperfect information.

Some obstacles are broad in scope, others are more targeted; some appear amenable to policy solutions, while others may not be. Indeed, some barriers are the result of existing regulations, statutes and fiscal policies that unfavourably treat climate change mitigation technologies (Brown and Chandler, 2008). In addition to reforming these existing policies, policy makers should consider the traditional policy instruments as well as the novel climate policies being launched in smaller testbeds across the world. By designing policies to address the numerous and specific deployment barriers impeding GHG-reducing technologies, the immense economic and technical potential of climate mitigation solutions can be more fully realised.

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