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International Collaboration: the Virtuous Cycle of Low Carbon Innovation and Diffusion

An Analysis of Solar Photovoltaic, Concentrating Solar Power and Carbon Capture and Storage

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HIGHLIGHTS

SHIFT TO LOW CARBON TRAJECTORY International collaboration can be leveraged to accelerate the innovation and diffusion of low carbon technologies required to realize the shift to a low carbon trajectory.

COLLABORATION FOR INNOVATION A collaborative approach to innovation has the potential to capture several benefits, including: pooling risks and achieving scale; knowledge sharing that accommodates competition and cooperation; the creation of a global market; facilitation of policy learning and exchange; and the alignment of technology, finance and policy.

COLLABORATION FOR DIFFUSION A range of obstacles to the diffusion of low carbon technologies provides ample opportunity for international collaboration in global market creation and capacity building, expanding beyond conventional modes of technology transfer.

LOW CARBON TECHNOLOGY REVOLUTION Current collaborative efforts for carbon capture and storage, solar photovoltaic and concentrating solar power technologies are active in all stages of innovation and diffusion and involve a wide range of actors. Yet, current efforts are not sufficient to achieve the necessary level of emission mitigation at the pace required to avoid catastrophic levels of atmospheric destabilization. This analysis sets forth recommendation to scale up current endeavors and create new ones.

An Analysis of Solar Photovoltaic, Concentrating Solar Power and Carbon Capture and Storage

International Collaboration: the Virtuous Cycle of Low Carbon Innovation and Diffusion

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Introduction

The challenge of limiting global temperature rise to 2°c will require the stabilization of atmospheric CO_2 concentrations through the reduction of greenhouse gas emissions. There are a variety of positions regarding the level at which CO_2 concentrations must be limited, ranging from estimates of around 350ppm CO_2[1] to 450 - 500 ppm CO_2.[2] Beyond this threshold, scientists predict that it becomes increasingly probable that the earth will experience catastrophic and irreversible effects from changing climate. Furthermore, global emissions would need to peak within the decade in order to stabilize at this level.[3] To accomplish atmospheric stabilization in the time period required demands a massive trajectory shift in emission trends. Achieving the transition from carbon-intense to low-carbon growth will require coordinated efforts in technology, policy and finance at the international and national level and the active participation of both the public and private sectors.

There is broad agreement that technologies capable of realizing the shift to a low carbon trajectory currently exist or are in an advanced stage of development and can be implemented at a non-prohibitive cost.[4] However, there is wide debate regarding precisely which suite of technologies should be the beneficiary of low carbon policies. Moreover, the particular combination of low carbon technologies implemented will depend on the strategy pursued to achieve the low carbon transition; the nature of economic transformation will determine the optimal combination of technologies adopted.

1. Hansen, 2009.

2. Grantham Research Institute on Climate Change and the Environment, 2009.

3. Stern, 2006.

4. Ibid.

In visualizing low-carbon scenarios for India, Shukla, et al (2008) describe two distinct pathways, one assuming a conventional development pattern with a carbon price and a second pathway that incorporates a sustainable development pattern.[5] Each paradigm requires a different combination of low carbon technologies. Table 1 below illustrates three possible combinations of mitigation options.

In order to realize the scale of the transition at the pace required to forestall the consequences of significant temperature increases, the acceleration of the innovation and diffusion of low carbon technologies is imperative. One of the critical mechanisms that can be leveraged to achieve this acceleration is international collaboration.

The focus of this analysis is on understanding how current energy technology collaborations catalyze innovation and diffusion. Empirically, our research is centered on examples from large energy production technologies that are either currently deployed or in advanced stages of development, in particular, solar technologies (photovoltaic and concentrating solar power) and carbon capture and storage. This focus is not meant to obscure the importance of energy efficiency technologies, which have the potential to contribute substantially to mitigation efforts; neither does it intend to neglect the potential contributions of disruptive innovations, yet to emerge.

The analysis begins by describing the fundamental characteristics of innovation and diffusion processes that create opportunities for international collaboration. It then illustrates a broad array of on-going collaborative activities, depicting how these efforts contribute to innovation and diffusion. Finally, highlighting the gap between the current level of collabora-

5. Shukla, PR, et al, 2008.

tive activities and technology targets deemed critical for emission mitigation, the report sets forth several recommendations to build on current efforts and construct new endeavors.

Defining Innovation and Diffusion

The notions of technological innovation and diffusion are vast. Joseph Schumpeter (1939) defined innovation as "new combinations" of existing resources. Typically, a distinction is made between invention, which is the first occurrence of an idea for a new product or process, and an innovation, which is the first attempt to implement it in practice.[6] Schumpeter drew attention to the fact that innovators, individual "entrepreneurs" or large organizations, play a critical role in overcoming inertia, or "resistance to new ways", the prevalence of which often inhibits successful innovation.[7]

Diffusion, writes Hall (2006), is the "process by which innovations become useful by being spread throughout a population."[8] Hall indicates that it is also an intrinsic part of the innovation process, noting that the spread of new technologies creates learning, imitation and feedback effects that improve the original innovation.[9] However, Fagerberg (2006) makes the distinction that while the process of diffusion may require incremental adaption, "...there is a qualitative difference between *(a)* commercialization of something for the first time and *(b)* copying it and introducing it in a different context. The latter arguably includes a larger dose of imitative behavior (imitation), or what is sometimes called 'technology transfer'. This does not exclude the possibility that imitation may lead to new innovation(s)."[10]

Remaining mindful of these finer points regarding the interrelated nature of diffusion and innovation, in order to emphasize an approach based on the function of international collaboration, this report treats innovation and diffusion as two discrete processes.

Innovation

Innovation: an Uncertain, Non-linear and Diverse Process Driven by "Market Pull" and "Technology Push" Dynamics

Several fundamental characteristics of the innovation process render it well disposed to collaborative activities. These characteristics are: a high degree of uncertainty for outcomes, the non-linearity and diversity of activities, and its manifestation at the intersection of market and technological forces. Each of these exigencies expands the scope for collaboration among actors engaged in innovation.

Uncertainty

Scholars characterize the innovation process as one defined by "radical fundamental

6. Fagerberg, 2006, 4-5.
7. Ibid, 6.
8. Hall, 2006, 460.
9. Ibid.
10. Fagerberg, 2006, 8.

Table 1. Mitigation options employing low carbon technologies

Pacala and Socolow (2004): Stabilization Wedges[1]	Shukla, et al (2008): Carbon Tax Scenario[2]	IEA (2008): Energy Technology Perspectives[3]
Efficient vehicles Reduced use of vehicles Efficient buildings Efficient baseload coal plants Gas baseload power for coal baseload power Capture CO_2 at baseload power plants Capture CO_2 at H_2 plants Capture CO_2 at coal-to-synfuels plant Nuclear power for coal power Wind power for coal power PV power for coal power Wind H2 in fuel-cell car for gasoline in hybrid car Biomass fuel for fossil fuel Reduced deforestation, plus reforestation, afforestation, and new plantations Conservation tillage	Electricity (Fuel Switch) CCS Renewable Energy Device Efficiency Others Shukla, et al (2008): Sustainable Society Scenario Electricity (Fuel Switch) Buildings (Material Design) Renewable Energy Device Efficiency Material Substitutions Recycling Reduced Consumption Urban Planning Transport (Modal Shift) CCS Other	CCS fossil fuel power Nuclear power Onshore, offshore wind BIGCC and co-combustion PV CSP Coal IGCC systems Coal USCSC Energy efficiency in buildings and applications Heat pumps Solar space and water heating Energy efficiency in transport Second-generation biofuels Electric and plug-in vehicles Hydrogen fuel cell vehicles CCS industry, H2, fuel transformation Industrial motor systems

Table footnotes are listed in a separate section p. 20.»

uncertainty."[11] This refers to a situation where it is impossible for agents to compare between different alternative lines of action to define in advance all possible outcomes of the decision they make. Such uncertainty may reflect the "complexity of the world and/or the limited analytical capacity of the agents."[12] Pavitt (2006) concurs, "innovations – especially radical innovations – remain unpredictable in their technical and commercial outcomes."[13] As a consequence of this fundamental uncertainty organizations engaged in innovation may seek to share risk through collaboration.

Non-linearity and Diversity

Innovation is a highly complex process irreducible to a linear sequence of discrete steps. It can be described as consisting of several stages including, basic science, research and development, demonstration, deployment and commercialization. However convenient these stages may be for categorizing innovation activities according to the degree of maturity of a technology, these stages should not imply that innovation is a linear process constituted by causal, sequential stages. Decades ago, Kline and Rosenberg[14] emphasized the two main flaws of the so-called "linear model" of innovation. First, the "linear model" implies a chain of causal activity that is the exception, not the rule for most innovations. Often, innovations occur through the novel combination of existing knowledge, in the aim of fulfilling a commercial need, as opposed to originating in basic science. Secondly, the model does not account for the non-linear attributes of the innovation process, including important feedback loops, which have far-reaching impacts on final outcomes. Consequently, activities to develop a particular technology, or suite of technologies, are typically manifold, simultaneous and interrelated. Innovation can include the development of entirely new technologies, novel combinations of existing technologies, novel processes for production, novel applications of existing or new technologies, or consist of several of these elements. Moreover, activities for a particular technology may be ongoing at various stages, simultaneously. Specifically, for any given technology, various innovation activities typically occur concurrently: R&D searches for next generation materials and processes; demonstration activities test new applications of current technologies, deployment activities scale-up pilot efforts and introduce them into new contexts; commercialization efforts build market share of innovations. All of these stages produce results that become critical input for the others. The multifarious and non-linear nature of the innovation process amplifies possibilities for collaboration for a range of different types of actors: firms, research institutions and government entities. The range and diversity of activities required for innovation may often exceed the expertise or capacity of any given organization, which provides powerful incentives for collaboration.

Driven by Market and Technological Forces

There are two distinct, but interrelated, forces animating the process of innovation: market and technological.[15] "Market pull" is used to describe those processes that relate to the creation of the economic conditions that stimulate innovative activity. In order words, these forces generate the conditions and incentives for actors to innovate. "Technology push", is used to refer to the technological and scientific advancement that expands the frontier of knowledge that engenders innovation. Debates over policies favoring the support of one of these dynamics over the other has at times resulted in the appearance of a false dichotomy. Contrary to an approach favoring one aspect over the other, these two realms should be understood as closely intertwined and their interaction is often consequential for the success of a technological innovation.[16] Successful outcomes require innovation policies to support for both technological ("push") and market regulations that encourage economic ("pull") dynamics. Consequently, this characteristic portends an important role for collaboration between policymakers and innovators in the articulate of coherent and coordinated policies.

Several core aspects of innovation, its funda-

11. Lundvall, 2007, 4.

12. Ibid.

13. Pavitt, 2006, 108.

14. Kline and Rosenberg, 1986.

15. Ibid, 275.

16. Ibid, 277.

mental uncertainty, non-linear and diverse activities and its emergence at the juncture of market and technological forces create conditions that may be well addressed through collaborative efforts. Organizations collaborate in order to reduce risk, confront the demands of diverse, simultaneous activities that may exceed the limits of individual organizations, and to contribute to the creation of coherent and credible government policies and regulations on which innovation depends.

Investment in Energy Technology R&D

Generally speaking, R&D in the energy sector has been historically driven by various motives, most prominently energy security and efficiency objectives. The demand for low carbon technologies is a comparatively new exigency for energy technologies. Given the scale of the climate challenge, recent public and private spending trends in energy R&D are discouraging.

According to the IEA, private sector spending on RD&D in energy-related sectors is estimated to be four to six times the amount of government RD&D.[17] The IEA notes that government energy RD&D budgets in most OECD countries shrunk by half in the early 1980's and 1990's.[18] Over the past decade, the decline in spending has stabilized and slightly recovered. However, it is notable that over the 20 years from 1985 to 2005 energy RD&D as a share of total RD&D in OECD countries has declined from 11% to a mere 3%, the majority of which is concentrated in only two countries, Japan and the US.[19] While RD&D spending in several non-OECD countries is increasing, the level of expenditure for science and technology RD&D as a percentage of GDP is well below the level of OECD countries.[20]

Furthermore, the recent World Bank Development Report 2010 illustrates that total public funding on energy R&D worldwide is a mere fraction of the funds allocated to energy subsidizes in the 20 highest-subsidizing non-OECD countries.[21] The report illustrates that the combined energy subsidies in the largest developing economies are thirty times public energy R&D funding worldwide, at over $300 billion. The report also indicates that the level of subsidies afforded to petroleum products is roughly fifteen times total public funding on energy R&D worldwide.[22] This comparison of funding allocation is an important indication that despite scarce public resources, much more can be done to address the lack of funding for R&D for low carbon energy technologies.

While investment in R&D is only one measure of innovation activity, it is a crucial one. The modest level of spending on energy RD&D globally has meant that energy technologies are far from attaining their potential in many dimensions, most notably in the area of low carbon.

Private Investment Models are Inadequate for the Provision of Low Carbon Technologies

Low carbon technologies provision the global public good of atmospheric stabilization and consequently face several market and regulatory failures that result in significant underinvestment. Thus, there is a need to address these failures through effective government policies and regulation in order to assure the level of innovation necessary to achieve climate stabilization goals.

The atmospheric stabilization that low carbon technologies contribute to is a global public good. A public good is defined by its nonrivalry and nonexcludibility.[23] In other words, atmospheric stabilization is non-rivalrous in that one person benefiting from a stable climate does not reduce or infringe on the benefits enjoyed by others. Additionally, it is impossible to exclude people from benefiting from atmospheric stabilization, regardless of who provisions it. Climate is an international commons. Due to these circumstances conventional conditions of private markets will lead to underinvestment, as compared to levels that are considered socially optimal.[24]

In the case of innovation for low carbon tech-

17. IEA, 2008, 177.

18. Ibid, 173. Budgets shrank from USD 18 billion in 1980 to USD 8 billion in 1997.

19. Ibid, 173-75. Japan and the US account for more than 70% of total energy RD&D public spending in IEA countries. In addition, nuclear technology accounts for a significant portion of public RD&D spending.

20. Ibid, 176.

21. World Bank, 2010, 293.

22. World Bank, 2010, 293.

23. Kolstad, 2000, 78-83.

24. Ibid.

nologies, several market failures exist, as noted by the IEA in the 2008 publication "Energy Technology Perspectives" (2008). First is the problem of "spillover", which occurs when society at large benefits from the innovation, but the innovator cannot appropriate enough of the resulting gains to justify his investments. Secondly, innovation in low carbon technologies produces positive externalities, or unvalued public benefits, unless specific policies are enacted to value (price) these benefits, which may then be captured by producers. Finally, innovation in energy technologies typically demands long time horizons with uncertainty and risk levels that exceed risk thresholds and payback periods for private firms.[25]

Policies must address two fundamental problems. First, in certain cases, low carbon technologies are not fully mature. Second, there is an absence of a sufficiently high carbon price to incentivize innovation and diffusion at the level required to meet mitigation targets. Private investment models of innovation are based on the assumption that innovation will be supported by private investment and that private returns can be appropriated from such investments.[26] Due to the market failures of low carbon technologies, achieving a socially optimal level of innovations for these technologies will require intervention by governments: both to create an appropriate regulatory framework to allow private investors to appropriate sufficient returns from investments and to allocate public funds and effort to stimulate innovation processes directly.

Rationale for Collaboration in Innovation: Potential Benefits

Transcend Organizational Constraints: Pool Risks and Achieve Scale

Collaboration allows actors to engage in projects that exceed organizational capacity or tolerance for risk. Organizations face financial, human capital and infrastructure constraints that may be traversed by working in partnership with others. Collaborations also provide opportunities for participants to influence and drive innovation activities in a sector.

Furthermore, the complexity, sophistication and pace of contemporary scientific and technological endeavors account in large part for increasing trend in collaboration between organizations engaged in innovation. For example, Powell and Grodal (2006) cite a National Research Council study on general industrial R&D trends in the US. The study found that, "...inter organizational partnerships are now core components of corporate strategy."[27] Notably, research on innovation networks has revealed the advantages, even necessity, of collaborative partnerships. Research by Powell, et al. (2004) found that in science-driven fields, the central players in industry networks were those organizations that developed ties to different kinds of organizations and carried out multiple types of activities with them.[28] There are several ways in which actors can extend organizational capacity through collaborations. Examples include:

- *Pooling Resources for Capital-Intensive Projects.* For particularly capital-intensive technologies such as carbon capture and storage, which is yet unproven at a scale necessary for widespread deployment, the cost of demonstration projects is prohibitive (estimated cost is between $500 million to $1 billion each[29]).
- *Creating research and development networks.* The Electric Power Research Institute serves as the organizing force to link researchers and infrastructure across organizational and national boundaries to create research networks. These networks allow for the execution of research and development program that no one company or institute could achieve in isolation.
- *Building Strategic Partnerships.* Firms often create strategic partnerships based on complementary core competencies. For example, small research-oriented technology firms often seek a "champion" in a large multinational firm with a large manufacturing capacity or distribution network that can help bring new technologies to market.
- *Avoiding duplication of effort in cases of large scale, indivisible technology projects.* In cir-

25. IEA, 2008, 171.

26. Demsetz, Harold, "Towards a Theory of Property Rights," 1967. Cited by Von Hippel and Von Krogh, 2006, 212.

27. Powell and Grodal, 2006, 57.

28. Ibid, 60.

29. IEA, 2008, 199.

cumstances where technology projects are large-scale and indivisible, and hence confront large constraints in terms of cost and/or time, collaboration is vital in order to reduce duplication of effort. For example, the demonstration of Concentrating Solar Power technology, an international test center was built by an international collaboration, SolarPACES, an IEA Implementing Agreement. However, the elimination of duplication of effort is not ideal in all circumstances. In instances where technologies are small scale the optimal outcomes will emerge from an ecosystem of innovation where actors engage in experimentation of many approaches.

Knowledge Sharing Accommodates Competition and Cooperation

Innovations often emerge from insights derived from a collective pool of accumulated knowledge. Information sharing is a central activity in collaboration. Concurrent to primary activities to advance the development of a particular technology are a range of peripheral, yet essential issues that will be decisive for a particular innovation's uptake into the market. For example, a particular technology may raise industry-wide issues of environmental impact or health and safety of workers, or social acceptance. These broader issues related to technologies are particularly good candidates for collaborative activities as they affect a variety of stakeholders and can create mutual benefit for competing firms.

As noted by the IEA, for technologies in the pre-commercialization stage, "international collaboration can create a common pool of knowledge which can contribute to global industry-level competitiveness and knowledge accumulation. This can eventually be capitalized on by individual industry players to build national- and firm-level competitiveness."[30] Examples include:

- *Facilitating information sharing: explicit, codified knowledge.* Information sharing occurs across all dimensions, research, industry and policymaking. It is the cornerstone of cooperation and is enhanced by trust between parties. It takes many forms: workshops, conferences, databases, publications, among others.

30. Ibid, 193.

- *Producing authoritative, unbiased research repositories.* The Clean Coal Center, an IEA Implementing Agreement, provides a source of technical information on clean coal technologies for policy makers, which provides a counterbalance to information from industry consortia.
- *Assembling and disseminating practical information on current projects.* The Global CCS Institute, with broad international participation, intends to act as a "knowledge broker" for carbon capture and storage projects worldwide.

Creation of a Global Market

Policies to spur innovation at the national level are important to enhance national competitiveness and ensure that technologies address particular national circumstances. However, in order to address the scale of the climate change at the required pace, a global market for low carbon technologies is indispensible. Examples of collaborative market building activities include:

- *Linking geographically separated manufacturers and markets.* In the case of Concentrating Solar Power, industrial know-how for production of CSP technology and systems is concentrated in Europe and the US, whereas suitable sites for installation are those which get a lot of direct sunlight, at least 2,000 kilowatt hours (kWh) per square meter annually.[31] Thus, according to a recent report by Greenpeace International, areas with most potential for CSP include the south-western US, Central and South America, North and Southern Africa, the Mediterranean countries of Europe, the Near and Middle East, Iran and the desert plains of India, Pakistan, the former Soviet Union, China and Australia.[32] SolarPACES, the IEA Implementing Agreement, has launched several "START" (Solar Thermal Analysis, Review and Training) missions to developing countries with a high potential for CSP installation. START teams consist of SolarPACES representatives who promote information exchange, identify and visit potential installation sites, and discuss and review solar thermal power project opportunities.[33]

31. Greenpeace International, 2009, 14.

32. Ibid.

33. SolarPACES website. 2009.

- *Developing international standards and norms.* A study proposing recommendations for a definition of "carbon capture ready" performed by the IEA Implementing Agreement Greenhouse Gas R&D Programme was influential for both EU and UK policymakers, among others.[34] This definition has contributed to the development of best practices for CCS readiness. Developing common international standards is important signal for the deployment and commercialization of technologies. Common standards contribute to the process of harmonization of policies, which in turn contributes to achieving greater economies of scale. Greater production at scale reduces costs of emerging technologies and hence aids their diffusion.
- *Linking technical and industrial know-how to countries with significant mitigation requirements.* The IEA notes that by 2050, less than one-third of "business-as-usual" emissions are expected to come from OECD countries, where technical and industrial expertise is often concentrated.[35] The Clean Coal Center, an IEA Implementing Agreement, has an expanding membership, which currently counts twenty-six members from both the North and South. Participation includes government and industry actors as well as a research organization.[36] The Centre creates and disseminates research on the sustainable and efficient use of coal.

Facilitate Policy Learning and Exchange

Collaboration among policymakers can encourage the sharing of best practices between countries across a range of issues, including design of policy instruments, institutions to address safety, monitoring and regulation.

- *Evaluating policy instruments.* The Renewable Energy Technology Deployment Implementing Agreement funded and published a study evaluating renewable energy policy instruments. The study focused on the elements on policy instrument design that could reduce financing costs for renewable energy technology projects.[37]
- *Creating a platform for dialogue to address common policy issues.* In the case of carbon capture and storage, social acceptance issues and the lack of public awareness of the technology could pose an important obstacle to its broader deployment. The Carbon Sequestration Leadership Forum, a ministerial level collaboration among policymakers facilitates the exchange of approaches to address these common concerns.

Alignment of Technology, Finance and Policy

The alignment of three critical domains: technology, finance and policy, is important in order to create a coherent vision that can foster an environment conducive to technological innovation and diffusion.[38]

- *Creating an interface between policymakers, industry and research institutions.* The Carbon Sequestration Leadership Forum is composed of two distinct bodies: the technical group and the policy group. Each has a different area of specialization, but interface under the same Secretariat, ensuring a degree of coherence and coordination between a multitude of actors.

Potential Drawbacks of International Collaboration

International collaboration has the potential to facilitate innovation, but there are risks to taking a collaborative approach, which should be considered alongside potential benefits. The process of innovation is "cumulative and path-dependent."[39] When many players set a common research agenda and articulate explicit roadmaps for specific technologies, they are essentially concentrating efforts and funds on a narrower range of activities. This may result in the adoption of inferior or more costly technologies. This is a problem that is an inherent risk of the innovation process itself. It is not created by a collaborative approach, but may be confounded by it. Additionally, the process of concentrating resource allocation to technologies perceived as promising can result in more conservative bets in technology investment. In a collaborative context, technologies considered high potential benefit from the resources and attention from researchers, but

34. IEA Greenhouse Gas R&D Programme website, 2009.

35. IEA, 2008, 37.

36. Clean Coal Centre, 2009.

37. Renewable Energy Technology Deployment Implementing Agreement website, 2009.

38. World Resources Institute, 2007, 1.

39. Lundvall, 1992.

more players are concentrated on fewer targets, resulting in a less diverse and narrower portfolio of technologies.

"Group think" can also be a drawback to innovation in a collaborative context. Researchers have noted that just as organizations can show signs of path-dependence, in established networks, participants may, "converge to a common perception of reality."[40]

Collaboration can increase transaction costs as lengthy and detailed legal agreements must be negotiated between parties. This process requires highly specialized legal advice and must address the contribution of each party, the allocation of potential benefits, including any intellectual property rights that might be created as a result of the agreement and a dispute resolution clause. Parties may also face substantial costs in resolving potential disputes.

Finally, participants in collaborations may have strong incentives to engage in strategic game playing that may render collaborations sterile. This may pose a significant obstacle to forming collaborations. A report from the OECD (2004) notes that those participants furthest advanced in a particular field may have the least incentive to share information or findings. Also, participants with the most to gain and least to contribute may have the most incentive to join collaborative efforts.[41]

Overall, the reality is usually much more subtle and nuanced, as indicated by a variety of respondents directly involved in international collaboration who were interviewed for this research. Typically, respondents emphasized that successful collaborations were founded on the identification of areas of mutual interest among parties. Participants engaged with the understanding that the benefits derived are often related to contributions made. Finally, members of collaborations typically exercised discretion regarding accepting new members and hence, had the possibility to exclude potential free riders.

How Current Collaborations Contribute to Innovation

There are many current examples of international collaboration for low carbon technologies. In order to better distinguish the role that collaboration can play as a catalyst for innovation, examples of current efforts are described below, taking examples from carbon capture and storage, solar (photovoltaic and concentrating solar power) and energy efficiency. The emphasis is on understanding the mechanisms by which collaborative efforts

40. Fagerberg, 2006, 12.

41. OECD/IEA, 2004, 12.

Box 1 A Variety of Collaboration Models

Collaborations vary along many dimensions, including the number and types of members, the functional scope, degree of formality and duration. Collaborations can be bilateral or multilateral. Moreover, there exist multilateral collaborations that encourage bilateral partnerships between members for project execution. They also vary by degree of formality from highly formal contract-based collaborations to loosely governed agreements based on good will. Most collaborators interviewed for this research reported benefits from collaboration where sufficient emphasis has been placed on the identification of areas of mutual interest and complementary partnerships, irrespective of the structure and form of the agreement.

The table below identifies several prevalent forms of collaboration.

Form	Description	Principal Actors
Intergovernmental Organizations	Organization formed through voluntary cooperation by sovereign states	Governments, other intergovernmental organizations
Research Consortia	Cooperation between two or more research institutions	Universities, public or private research institutions
Multi-party Collaborations	Organization formed through cooperation between different types of actors, typically across the public and private sectors	Governments, intergovernmental organizations, firms, research institutions, industry consortia, NGOs, universities
Public-Private Partnerships	Cooperation between a governmental authority and a private firm or firms	Government entity, private firms
Joint Ventures	Organization formed by two or more parties in order to share costs, benefits and control over an enterprise	Private and state-owned firms
Strategic Alliances	Formal relationships between two or more parties formed to pursue common objectives while maintaining organizational independence	Private and state-owned firms, government entities, non governmental organizations
Subcontracting	Agreement by which a principle contracts with a another party in order to outsource specific activities	Private and state-owned firms

advance innovation. Box 1 describes a variety of models of collaboration, listing prevalent organizational forms and principal actors. A brief inventory and description of international organizations promoting low carbon innovations can be found in the annex. This list is not intended to be exhaustive.

Examples of Collaborative Activities for Innovation

Basic Science

The realm of basic science is an important contributor to innovation. This stage is characterized by the highest level of technologic risk due to a great degree of uncertainty regarding outcomes. However, at this stage, outcomes while uncertain, also have great potential and may result in radical innovation and the emergence of new and independent technologies.[42] Due to the high level of technologic risk as well as the long time horizon to commercialization, the most important actors engaged in basic research are national and university labs. These efforts are typically supported by public funds, but the contribution from industry is growing.[43]

Key Activities	Examples
Research	Concentrating Solar Power: IEA Implementing Agreement, SolarPACES, has undertaken work that encompasses activities dealing with solar-driven thermochemical and photochemical processes for the production of energy carriers, processing of chemical commodities and detoxification and recycling of waste materials.[4]
	Coal Science: IEA Implementing Agreement, Clean Coal Sciences, is focused on performing basic research on the science of coal combustion. Current research topics include, among others: behavior of coal minerals in combustion and gasification, new kinetic models for the prediction of char reactivity and carbon burnout and mathematical modeling of coal flames.[5]

Research and Development

Research and development activities are concerned with the application of basic science, techniques and knowledge for practical purposes. The interaction between public policies and industry incentives for R&D investments is of clear importance. Industry consortia may also contribute to R&D activities, as firms seek to spread risk, reduce costs and increase project scale.[44]

Key Activities	Examples
Technical and economic evaluations	Carbon Capture and Storage: The Greenhouse Gas R&D Programme performs studies evaluating technology options for mitigating GHG (CO2 and non-CO2) emissions in major sectors, including: power generation, major industrial, transportation and building.
Applied research on components, subsystems and waste materials	Concentrating Solar Power: Task II of the SolarPACES collaboration focuses on solar chemistry including processes for converted solar energy into chemical fuels, which can be stored long-term and transported. The research also has potential for application for treatment of polluted air, water, soil and recycling waste materials.[6]
	Energy Efficiency in Lighting: The Electric Power Research Institute (EPRI) runs the Advanced Light Source research program through a virtual research network aimed at breakthrough basic research in lighting technology.[7]
Creating a research repository	Clean Coal Technologies: The Clean Coal Centre manages a searchable database containing more than 200,000 abstracts of coal literature addressing all aspects of the coal chain.[8]
Prioritization of R&D activities for high potential technologies/ identification of research gaps	For a broad range of energy technologies, the IEA supports a collaborative effort to define roadmaps that help to prioritize R&D activities and investments.

Demonstration

Demonstration activities are crucial to moving technologies out of laboratories and into real world contexts. This stage allows for testing technologies at various scales and in different circumstances. The outcomes of demonstration activities, including reliability and performance data become important inputs for subsequent deployment and scaling-up activities, as well as provide feedback to on-going R&D work, particularly for next generation technologies. Typically, at this stage costs, and technological risks are high and securing finance is pivotal. The goal is to create a workable and reliable product.

Key Activities	Examples
Production and sharing of performance and reliability data	Concentrating Solar Power: Task III of SolarPACES is developing methods and procedures to shed light on questions of lifetime performance of plant components and systems.[9]
Pilot-scale projects/ Proof of concept	Carbon Capture and Storage: A recent collaborative pilot-scale project demonstrated the feasibility of coal bed methane recovery and storage of CO2 in anthracitic coals of Shanxi Province.[10] The Carbon Sequestration Leadership Forum supported this project by providing regular assessments and recommendations.
	Carbon Capture and Storage: EPRI has launched a program aimed at the development and demonstration of second-generation technologies for CO_2 capture. This program includes an EPRI-lead effort targeted at proof-of-concept of key candidate technologies that will be performed at distributed locations worldwide.[11]

42. Renewable Energy Technology Deployment (RETD) Implementing Agreement, 2006, 8.

43. IEA, 2008, 191.

44. IEA, 2008, 192.

Creating a repository of on-going demonstration projects to share "learning by doing" information	Carbon Capture and Storage: The Global Carbon Capture and Storage Institute is performing a comprehensive audit of current CCS projects worldwide. The Institute estimates that there are currently over 300 projects in various stages of planning and execution.[12] Additionally, the CSLF supports a project database for CCS demonstration projects.[13]

Deployment

Once the technology has been successfully demonstrated in practice, it can begin its introduction to the market. At this stage, the risk shifts from technical to financial. Innovation in this phase is characterized as incremental.[45] Typically, a technology is not yet cost competitive, but may gain a foothold in niche markets. Economies of scale may begin to emerge as production expands. As deployment increases, "technology learning" will put downward pressure on costs.[46]

Key Activities	**Examples**
Establishing norms for policy frameworks to enable future deployments	Carbon Capture and Storage: A study proposing recommendations for a definition of "carbon capture ready" performed by the Greenhouse Gas R&D Programme was influential for both EU and UK policymakers, among others.[14] This definition can assist in the development of best practices for CCS readiness.
Linking experts with industrial/technologic know-how to decision-makers in high potential markets	Concentrating Solar Power: SolarPACES, an IEA Implementing Agreement, sent international teams of experts to developing countries in the Sunbelt, considered high potential contexts for deployment due to high solar radiation (direct sunlight). These "START (Solar Thermal Analysis, Review and Training) missions" proposed specific demonstration projects.[15]
Developing new applications of the technology	Photovoltaic: The Photovoltaic Power Systems Programme, an IEA Implementing Agreement, has undertaken various projects in emerging applications of PV. These include, very large scale PV power generation, building integrated PV and hybrid systems within mini-grids.[16]

Commercialization

The process of commercialization is characterized by greater cost competitiveness and deeper market penetration of a technology. At times, the term commercialization is used interchangeably with diffusion. However, as noted earlier, this analysis makes the distinction between activities aimed at commercializing a technology for the first time and its broader diffusion, or introduction into new markets.

Typically during this phase, products become increasingly reliable and standardized. The primary risk is a market risk, characterized by the necessity to achieve sufficient market share.[47] The private sector usually plays a dominant role, however, public policies establishing a fair and competitive playing field are a prerequisite for markets to function.

Key Activities	Examples
Addressing barriers to deeper market penetration: environmental health and safety	Photovoltaic: The Photovoltaic Power Systems Programme, an IEA Implementing Agreement, has undertaken a five-year-long project focused on environmental health and safety. The task aims to quantifying the environmental profile of PV through a life cycle analysis and addressing sustainability issues deemed key for market growth.[17]
Building a global market	Concentrating Solar Power: The ambitious "Global Market Initiative" is a collaboration launched by several governments, the GEF, the American and European solar energy industry associations and IEA SolarPACES. It aims to make CSP cost competitive in the power market by achieving the deployment of 5,000 MWe.[18]
International norms and standard setting/ harmonization of standards	Energy Efficiency: The "4E" Efficient Electrical End-Use Equipment IEA Implementing Agreement focuses on policy, not technical, issues facing efficient electrical appliances. A "mapping and benchmarking" project has been undertaken to encourage voluntary harmonization of minimum standards.[19]

Diffusion

Describing the Process of Diffusion

Innovation scholar, Hall (2006) writes, "for entities which are 'catching up', such as developing economies, backward regions, or technologically laggard firms, diffusion can be the most important part of the innovation process."[48] Analysis of the diffusion of innovations is typically centered on the barriers that impede the process. Underlying this conceptualization of the diffusion process is an implicit faith in the efficiency of markets. Barriers to this process are considered anomalies to be addressed by specific measures. However, inefficiencies are prevalent and diffusion is far from being automatic. As Rosenberg (1972) noted, "in the history of diffusion of many innovations, one cannot help being struck by two characteristics of the diffusion process: its apparent overall slowness on the one hand and the wide vari-

45. Renewable Energy Technology Deployment (RETD) Implementing Agreement, 2006, 8.

46. IEA, 2008, 204.

47. Renewable Energy Technology Deployment (RETD) Implementing Agreement, 2006, 8.

48. Ibid.

ations in the rates of acceptance of different inventions, on the other."[49]

The Diffusion Landscape

Diffusion is a process that is contingent on a particular context. The diffusion landscape, or the context in which an innovation spreads, has various dimensions that directly impact the rate and degree of diffusion. Many studies have identified various economic, institutional and social barriers that stall the diffusion of technological improvements. Factors that tend to increase the pace of diffusion of technologies include: the level of competition in a sector, the transparency and efficiency of markets, the absorptive capacity and know-how of domestic industry, the availability and diversity of capital and financial instruments (including foreign direct investment).

There is wide debate regarding the precise role that IPR plays in the diffusion of low carbon technologies. Furthermore, there is a lack of empirical studies to conclusively demonstrate the role of IPR in the process of diffusion.

Modes of Technology Transfer

Technology transfer, in this context, can be understood to be one aspect of the diffusion process. Barton (2007) outlines three modes of technology transfer.[50] The first is the provision of products incorporating the technology. A second is through licensing, which confers the legal right to produce such products, either directly to the indigenous firm or by way of a joint venture. A final mode is to support the enhancement of national capability to research and produce the products independently.

Depending on particular domestic circumstances and industrial policy, national level policymakers may advocate policies that encourage specific approaches to acquiring, adapting or replicating foreign technology. Domestic scientific and technology capacity alongside industrial know-how as well as the characteristics of a given low carbon technology will also likely influence to a large extent the preferred mode of technology transfer. Where domestic capacity for developing and manufacturing technologies is weak, countries may seek to attain technologies through the direct purchase of products. Where there is a large manufacturing and industrial capacity and potential to exploit economies of scale, countries may seek to a joint venture or licensing approach to acquire technologies and then manufacture products for domestic use and/or export. If technologies are easily replicated, or reverse engineered, technology transfer may be shunned in favor of an import substitution approach. Countries with deep scientific and technology capacity with requisite human capital may seek to be leaders in technology innovation in their own right. Ultimately, modes of technology transfer between countries will depend on domestic circumstances and be shaped by industrial policy.

49. Cited by Hall, 2006, 460.

50. Barton, 2007, xi.

Overcoming Barriers to Diffusion: Market Creation and Capacity Building

A range of obstacles to the diffusion of low carbon technologies has been identified and provides ample opportunities for international collaboration.

Economic Barriers

Economic barriers arise from the lack of cost competitiveness for low carbon technologies in the absence of a clear, credible and long-term carbon price signal. There are two interrelated measures that can address these economic barriers: setting a carbon price and specific policy instruments, such as technology-based nationally appropriate mitigation actions (NAMAs) that would finance the incremental costs of specific technologies and/or reduce risk through the provision of indemnity.

A clear, credible, long-term carbon price signal is key to attracting long-term investment in low carbon technologies. Governments can improve the effectiveness, transparency and credibility of carbon markets by articulating clear rules that govern markets.[51] Government credible commitment, also essential for long-term investors, can be enhanced through delegation of authority to manage carbon markets to an independent agency.

Many investors and policymakers recognize that a carbon price alone will not be sufficient to fully address the climate challenge and should be complemented by other policies focused

51. Institutional Investors Group on Climate Change, 2009, 5.

on specific technologies, such as: financial incentives to address incremental costs, standard setting and other regulatory and/or fiscal measures.[52] Technology-based NAMAs could be measured in terms of technology selections (either specific technologies, production processes, or their performance equivalents) and/or future market penetration goals.[53]

The transparency, coherence and credibility of long-term national policies would be augmented by an international registry system that monitors and oversees national-level climate change policies, ensuring that they are measurable, reportable and verifiable. A transparent and well-governed registry would increase investor confidence and as a result, stimulate capital flow to low carbon investments.[54]

Finally, the elimination of subsidies for carbon intensive sources would increase low carbon cost competitiveness. As stated previously, the IEA estimates that the largest developing countries spend over $300 billion a year on energy subsidies.[55] Leaders at the recent G20 summit in Philadelphia proposed plans aimed at eliminating these subsidies, estimating that emissions could be reduced by 12% as a result.[56]

Non-Economic Barriers

Non-economic barriers also create significant market distortions that inhibit the diffusion of low carbon technologies. Some low carbon technologies, including many in energy efficiency, provide net financial benefits yet have been under-exploited. The McKinsey global GHG abatement cost curve (2009) provides a striking visual depiction of costs and abatement potential of a spectrum of low carbon technologies. Notably, the cost curve estimates sizable cost benefits for a suite of energy efficiency measures.[57] Principal-agent problems are often to blame for the lack of diffusion in these circumstances. For energy efficiency in buildings, actors making decisions about energy efficiency characteristics during the construction and/or retrofitting of a building are typically not the eventual occupants who will incur energy costs.

Other non-economic barriers include: administrative hurdles (planning delays and restrictions, lack of coordination between different authorities, long lead times in obtaining authorization), grid access, electricity market design, lack of information and training, social acceptance and lack of standards and norms.[58]

A range of approaches can be used to address non-economic diffusion barriers for energy efficiency technologies. First, public policies can enhance the dynamic force of "market pull" through standard setting and public procurement programs. Second, Lundvall's notion of "interactive learning"[59] resulting from user-producer collaboration can be aptly applied for energy efficiency technologies, in particular for demand-side management in the consumer market. Finally, research networks, such as Electric Power Research Institute (EPRI), build circuitry that contributes to technological diffusion.

Capacity Building

The question of capacity building is fundamental to the long-term considerations of innovation diffusion. As observed by Powell, et al. (1996), "What can be learned is crucially affected by what is already known."[60] Consequently, policies aimed at the cultivation of "absorptive capacity"[61] (the capacity for integrating outside knowledge) of economies are instrumental.

While overcoming various barriers to diffusion will require concerted and ambitious efforts on the part of national governments, there is still a decisive role for international collaboration. Only efforts at the international level can create the global market necessary for diffusion. Additionally, linking national efforts to international mechanisms enhances the credible commitment required for investors. The elaboration of policy frameworks can be significantly assisted by incorporating lessons learned in other countries. Finally, global accumulated knowledge is unevenly distributed and collaborations facilitating knowledge transfer is crucial.

52. Ibid, 3.

53. Center for Clean Air Policy, 2009, 2.

54. Institution Investors Group on Climate Change, 2009, 1.

55. Financial Times, 23 September 2009.

56. Ibid.

57. McKinsey & Company, 2009.

58. OECD/IEA, 2008.

59. Lundvall, 2004.

60. Powell and Grodal, 2006, 67.

61. Cohen and Levinthal, 1990, cited by: Fagerberg, 2006, 11.

How Current Collaborations Contribute to Diffusion. Examples

The previous section on innovation outlined the potential benefits of collaboration in innovation; many of these also apply to the case of diffusion. This section will offer examples of specific activities that demonstrate the mechanisms by which these efforts support diffusion. A brief inventory and description of international organizations promoting the diffusion of low carbon technologies can be found in the annex.

Activity	Example
Knowledge dissemination: explicit and codified	The Energy Technology Data Exchange, an IEA Implementing Agreement established over 20 years ago, boasts the largest collection of energy research and technology literature in the world.[20] It has over 4 million searchable records and affords access to over 60 developing countries.[21]
	The EGTT has established a technology transfer information clearing house, "TT Clear". Its function is to supply a range of information and publications about technology transfer aimed at practitioners and private sector users.[22]
Developing norms and standards	The "4E" Efficient Electrical End-Use Equipment IEA Implementing Agreement has undertaken a mapping and benchmarking project. The purpose of this exercise is to encourage harmonization and eventually develop common minimum efficiency standards.[23]
Developing innovative approaches to project finance	The Climate Technology Initiative (CTI), in cooperation with the UNFCCC EGTT has engaged private sector finance institutions through the Private Financing Advisory Network (PFAN). PFAN brings together bankers, project management coaches and interdisciplinary teams that guide and facilitate projects in developing countries.[24]
Collection and dissemination practical information on current projects	A joint project by the Climate Technology Initiative (CTI) and UN Environmental Programme (UNEP), "Technology Without Borders" compiled case studies of successful low carbon technology transfer in a variety of national settings and for several different technologies.[25]
Defining specific country needs	Technology Needs Assessments (TNAs) provide information on regional and sector-specific technology needs, capacity-building needs, barriers and opportunities for technology transfer. GEF has provided funding to 94 developing countries to undertake TNAs.[26]
Guidelines and pilot projects in energy efficiency labeling	The Asia-Pacific partnership for Clean Development and Climate has undertaken a five-year long project in building certification for energy efficiency. This project seeks to demonstrate the potential to save energy and also to improve market transparency.[27]
Expansion of the bandwidth of communication, increases opportunities to transfer "know-how"	A recent analysis of the Clean Development Mechanism noted that the probability of technology transfer increased if the project included foreign participants.[28] The transfer of tacit knowledge, or "know-how"[29], is more likely in a close interaction between people.

Recommendations

This report has described how fundamental characteristics of technological innovation and diffusion create opportunities for collaborative efforts. Specifically, collaboration expands the potential for organizations to transcend constraints to pool risks and achieve scale, to share knowledge to advance mutually beneficial projects, create a global market, facilitate policy learning and align efforts in technology, finance and policy. Collaboration can also contribute to the construction of coherent frameworks to overcome economic and non-economic barriers to low carbon technology innovation and diffusion.

Key activities of on-going international collaborations have been described, with a primary focus on large energy production technologies, in particular solar and carbon capture and storage. These examples demonstrate that current collaborations are active in a broad and varied range of activities supporting innovation and diffusion and provide specific examples.

Yet, according to many analyses, including the IEA's BLUE Map Scenario described below, the current pace of innovation and diffusion of low carbon technologies is not sufficient to achieve the transition to a low carbon trajectory. Closing this gap can be aided by the expansion of current collaborative efforts and the creation of new ones.

The Need for a Low Carbon Technology Revolution

If the global temperature rise is to be limited to 2°c, the IPCC has indicated that greenhouse gas emissions must be reduced by 50%-85% by 2050.[62] The IEA has outlined the Blue Map Scenario based on optimistic assumptions about technological progress of low carbon technologies.[63] The Blue Map Scenario articulates the level and rate of innovation and diffusion required to shift from current "business as usual" trends to a low carbon trajectory that could achieve the IPCC's reduction target. It is built on assumptions about a portfolio of low carbon technologies, including: carbon capture and storage in industry and power generation, nuclear, renewable, power generation efficiency and fuel switching, end use fuel switching

62. IEA, 2008, 38.

63. Ibid, 39.

and end use electricity and fuel efficiency. The necessary trajectory shift from baseline estimates is both monumental and must be rapidly executed.

The IEA estimates that the investment needed to realize the Blue Map Scenario is about US$1.1 trillion annually.[64] Some of the technologies concerned are not yet commercially available and will require major funding and efforts for research, development and demonstration. For example, CCS has been singled out as the key technology in the Blue Map scenario accounting for 19% of emissions savings.[65] The IEA's roadmap for CCS indicates that 20 full-scale demonstration plants must be in operation between 2015-2030.[66] The CSLF Technology Roadmap (2009) surveyed current CCS project activities worldwide. The survey indicated that there are currently four operational commercial-scale integrated CCS projects and three pilot plant projects focused on CO_2 storage in the energy sector.[67] Additionally, 24 major projects have been announced. Evidently, there is still a significant gap in the current level of CCS demonstration and the level signaled by the IEA Blue Map as required for meeting aggressive emissions reduction targets.

There are large gaps in all technology sectors between the current pace and scale of innovation and diffusion and levels deemed necessary for limited global temperature rise based on analysis by the IPCC, IEA and the Stern Review, among others. International collaboration is widely cited as a necessary mechanism for achieving the degree of trajectory shift in the time frame required.

Recommendations for Increasing Collaboration

Integration of Mitigation and Technology Efforts under the UNFCCC

Just as greenhouse gas emission reduction is inextricably linked to low carbon technologies; the UNFCCC should unify technology and mitigation provisions. Technology-based NAMAs should link technology goals to mitigation efforts and to financial options. This approach would enhance cooperation on technology innovation and promote greater diffusion of key low carbon technologies.[68]

Expansion the Global Market for Low Carbon Technologies

A global market for low carbon technologies is indispensible to aid diffusion and provide incentives for innovation. Collaborative efforts at market building include addressing both economic and non-economic barriers to low carbon technology diffusion, including keeping trade barriers low. There is potential for increased collaborative action in linking geographically separated manufacturers and markets, developing international standards and norms, and linking industrial and technical know-how to countries with significant mitigation requirements. Policymakers can also encourage diffusion through a clear, credible and long-term commitment to a carbon price and specific instruments such as technology-based NAMAs.

Expansion and Amplification Participation in Existing Collaboration Networks

Building on existing efforts can capitalize on the networks and relationships that have already been forged. Participation in current efforts should be expanded to include a greater number and diversity of countries, in particular IEA non-member states. Moreover, participants in collaborative efforts should be actors with the power and capacity to transmit the results of common efforts to their particular national context. Existing collaborations can also benefit from links with similar efforts.

Broaden Access to Accumulated Knowledge

One of the strengths of existing collaborative efforts is the accumulation and sharing of codified knowledge. This is typically explicit knowledge: facts, theories, research results and information about practical projects. Current collaborative efforts have generally excelled at collecting and disseminating this type of knowledge and examples are abundant. Diffusion of this knowledge usually takes the form of databases, publications, workshops, seminars and reports. Mechanisms for broader dissemination of this knowledge should be

64. Ibid.

65. Ibid, 41.

66. Ibid, 135.

67. Carbon Sequestration Leadership Forum, 2009a.

68. Center for Clean Air Policy, 2009, 3.

expanded to IEA non-member states, non-governmental organizations and the private sector, in particular.

Enlarge Bandwidth for Tacit Knowledge Transfer

Another important type of knowledge is tacit knowledge, or "know-how", which refers to skills, (ie. the ability to do something).[69] This key component of knowledge transfer is often overlooked and is typically embodied in workers' knowledge, production systems and processes. As noted by Ziman (1979), this type of knowledge resists codification to a large extent and is rooted in experienced-based learning.[70] In technology diffusion efforts, diverse implementation teams should consist of experienced and inexperienced workers from the foreign and national enterprises working closely together to facilitate knowledge transfer. Examples include CDM projects with high foreign-worker participation, which are correlated to higher rates of successful technology transfer. It should be noted, however, that there are important challenges to tacit knowledge transfer. The most important vectors of tacit transfer are employees who move between firms or work environments, which in many settings is constrained by various restrictions on labor mobility.

Funding for Collective Innovation based on the Open Source Model

The UNFCCC presents an opportunity to optimize funding mechanisms to support collective innovation activities based on the open source model. The open source model is not a regime that eliminates property rights, but instead is a system of rights based on inclusion instead of exclusion. As Weber (2004) explains, "*property in open source is configured fundamentally around the right to distribute, not the right to exclude.*"[71] A central problem in this model is free-riding, as potential beneficiaries have incentive to wait for others to make the necessary investments in outcomes that all will share. To address this problem, contributors must be convinced that: (1) they are engaged in a long-term cooperative relationship[72], and (2) the importance of "group fate" outweighs the cost incurred of contributing.[73] The UNFCCC exemplifies a collective action approach by parties inextricably linked by a common fate. In practice, this model could be invoked along sectoral lines for specific applications of high potential technologies that have significant mitigation potential, such as CCS.

Establish Regional Innovation Systems

In order to balance the benefits of cooperative efforts while resisting a "one-size-fits-all" top-down approach, regional innovation systems have the potential to exploit a broader pool of resources without diluting sensitivity to national circumstances. In the words of Asheim and Gertler (2006), a regional innovation system can be understood as, "the institutional infrastructure supporting innovation within the production structure of a region".[74] Regional innovation systems could serve as an important level of coordination between innovation clusters.

A Multidisciplinary Approach to Capacity Building

Policies intended to strengthen the innovation potential of national economies require far-reaching and long-term efforts. These policies should avoid narrow, prescriptive measures that silo technologies and professional disciplines. Rather, innovation should be viewed as a broader, economy-wide activity that depends on human, social and financial capital as well as a supportive institutional framework. Efforts should be multidisciplinary and wide benefits can be achieved through cooperation between government, industry and research institutions. Best practices should be shared, but intelligently applied to national circumstances.

69. Lundvall, 2000, 10.

70. Ibid.

71. Weber, 2004, 16.

72. Axelrod ,1984, cited by: Von Hippel and Von Krogh, 2006, 215.

73. Schwartz and Paul, 1992, cited by: Von Hippel and Von Krogh, 2006, 215.

74. Asheim and Gertler, 2006, 299.

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1. Pacala and Socolow, 2004, 968.
2. Shukla, PR, et al, 2008, 132.
3. IEA, 2008, 134.
4. SolarPACES website, 2009.
5. Clean Coal Sciences, IEA Implementing Agreement website, 2009.
6. "SolarPACES IEA Implementing Agreement website, 2009.
7. Electric Power Research Institute website, 2009.
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9. SolarPACES website, 2009.
10. Alberta Research Council, 2007, 14.
11. Electric Power Research Institute, 2008, 14.
12. Bob Pegler, Deputy CEO of Global CCS Institute, Phone Interview, September 2009.
13. Carbon Sequestration Leadership Forumwebsite, 2009.
14. IEA Greenhouse Gas R&D Programme website, 2009.
15. SolarPACES website, 2009.
16. IEA Photovoltaic Power Systems Programme website, 2009.
17. IEA Photovoltaic Power Systems Programme website, 2009.
18. SolarPACES website, 2009.
19. Hans-Paul Siderius, Chairman of the Executive Committee of "4E" Efficient Electrical End-Use Equipment Implementing Agreement, Phone Interview, September 2009.
20. Energy Technology Data Exchange IEA Implementing Agreement website, 2009.
21. IEA, 2007, 30.
22. UNFCCC Expert Group on Technology Transfer, 2007.
23. 4E – Efficient Electrical End-Use Equipment Implementing Agreement website, 2009.
24. IEA, 2007, 29.
25. OECD/IEA, 2001.
26. UNFCCC Expert Group on Technology Transfer, 2007.
27. Asia-Pacific Partnership on Clean Development and Climate website, 2009.
28. UNFCCC Expert Group on Technology Transfer, 2008.
29. Lundvall, 2000, 4.

Annex

International Organizations Promoting Low Carbon Innovation

International Energy Agency (IEA)

The IEA has over thirty-years' experience in supporting international collaboration in energy technology in the form of "Implementing Agreements". In the early years, Implementing Agreements were open only to IEA member country participation, however the possibility for membership has expanded to include non-member countries, industry as well as inter-governmental organizations and industrial associations.[1] There are currently over 42 different Implementing Agreements, organized according to technology, which benefit from the support and expertise of the IEA.

Carbon Sequestration Leadership Forum (CSLF)

The CSLF is a Ministerial-level international collaborative effort aimed at facilitating the "development of improved cost-effective technologies for the separation and capture of carbon dioxide for its transport and long-term safe storage."[2] Additionally, the CSLF proposes to support diffusion efforts and promote the appropriate technical, political and regulatory environments for CCS technology.[3] The CSLF was founded in June 2003 and current membership includes 22 national governments and the European Commission.[4] The CSLF supports "CSLF recognized" projects, which have passed the scrutiny of review committees, with regular assessments and recommendations.

European Commission Seventh Framework Programme (FP7)

The EU has allocated a total of 1.9 billion for funding environmental programs, including those pertaining to climate change.[5] Funding is directed to cooperative efforts between countries in the European Union and intends to "improve competitiveness and strengthen European industries' position in world markets for environmental technologies."[6]

Asia-Pacific Partnership on Clean Development and Climate

Officially launched in 2006, this is a partnership along seven major Asia-Pacific countries (Australia, Canada, China, India, Japan, Korea and the US) that aims to "promote economic development, reduce poverty and accelerate the development and deployment of cleaner, more efficient technologies."[7] The partner-

1. IEA, 2003.
2. Carbon Sequestration Leadership Forum, 2009b.
3. Ibid.
4. Carbon Sequestration Leadership Forum website, 2009.
5. Seventh Research Framework Programme website, 2009.
6. Ibid.
7. Asia-Pacific Partnership on Clean Development and Climate, 2009.

ship is organized into eight different task forces, along sectoral lines. Currently, over 100 projects have been indentified and are in the process of being implemented.[8]

Global Carbon Capture and Storage Institute

The Global CCS Institute is an international initiative launched in April 2009 as a not-for-profit company focused on accelerating the development and deployment of CCS technology. The Australian Government has committed AUD$100 million per year to fund the Institute.[9] The Institute aims to perform the role of a "knowledge broker" and will also fund selected collaborative projects.[10]

Electric Power Research Institute (EPRI)

A US-based non-profit organization with international participation extending to 40 countries, EPRI undertakes research and development relating to the generation, delivery and use of electricity. EPRI supports an ambitious technology innovation program addressing a wide range of low carbon energy technologies.[11] Funded by over 1,000 organizations in 40 countries, EPRI's work is based on a collaborative model that creates multi-disciplinary teams that may include engineering and scientists from EPRI, members and experts from academia and industry.[12]

World Economic Forum

The World Economic Forum's Task Force on Low Carbon Prosperity is a multi-stakeholder collaboration that brought together over 80 private enterprises and experts from nearly 40 public sector, academic, and non-governmental institutions.[13] Through workshops and virtual meetings facilitated by the World Economic Leaders Community (WELCOM) system, the Task Forces set forth recommendations for accelerating low carbon innovation and diffusion.[14]

8. Ibid.

9. Global CCS Institute, 2009.

10. Bob Pegler, Deputy CEO Global CCS Institute, Phone Interview, September 2009.

11. Electric Power Research Institute, 2008.

12. Electric Power Research Institute website, 2009.

13. World Economic Forum, 2009.

14. Ibid.

International Organizations Promoting Diffusion of Low Carbon Technologies

International Energy Agency: Implementing Agreements

The IEA's Implementing Agreements facilitate diffusion in several ways. Some agreements, such as the one for Photovoltaic Power Systems include tasks that address specific diffusion issues. Two agreements, the Climate Technology Initiative and Renewable Energy Technology Deployment, specifically focus on diffusion as the primary activity.

UNFCCC Expert Group on Technology Transfer (EGTT)

The EGTT was established in order to implement the framework on technology transfer established at the seventh session of the Conference of Parties (COP) in 2001. It aims to advance the technology transfer activities under the UNFCCC, in particular the implementation of Article 4, paragraph 5.[15] The work program addresses each key theme of the technology transfer framework: technology needs and needs assessments, technology information, enabling environments, capacity-building, mechanisms for technology transfer.[16]

Clean Development Mechanism (CDM)

The CDM is one of three market-based mechanisms included in the Kyoto Protocol that encourages emission reductions in developing countries while allowing industrialized countries additional degrees of flexibility in how they reach emission reduction targets.[17] A 2008 study of technology transfer examined over 3,000 CDM projects in 67 host countries.[18] The study indicated that 36% of project claimed to achieve technology transfer. Another key finding was that the probability of technology transfer increases with project size, the inclusion of foreign participants and declines for host countries with larger populations. In addition, technology transfer was noted to be more likely for agriculture, N_2O,

15. UNFCCC Expert Group on Technology Transfer, 2007.

16. Ibid.

17. UNFCCC website, 2009.

18. UNFCCC Secretariat, 2008,

landfill gas and wind projects, and less likely for biomass energy, cement, and hydro.[19]

The World Bank Group Energy Program

In the past year, the World Bank Group has increased its funding for renewable energy and energy efficiency projects and programs in developing countries to $3.3 billion last year. Nearly half of the spending last year was dedicated to energy efficiency projects, the rest was directed toward renewables including solar, biomass, geothermal, and hydropower. Moreover, two-thirds of spending on energy projects by the International Finance Corporation directed at private sector efforts was in the renewable and energy efficiency sectors.[20]

19. Ibid.

20. The World Bank website, 2009.

Global Environment Facility (GEF)

The GEF supports four Operational Programmes in the area of climate change. According to GEF reports, it is currently funding thirty different climate-technologies for energy efficiency, renewable energy and urban transport. It has invested $2.7 billion in climate change projects in developing countries and economies in transition, providing an additional $17.2 billion in co-financing.[21] It is primarily focused on funding early stage diffusion.

21. The Global Environment Facility, 2009.

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analyses

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International Collaboration: the Virtuous Cycle of Low Carbon Innovation and Diffusion

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