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INTERNATIONAL ENERGY TECHNOLOGY COLLABORATION AND CLIMATE CHANGE MITIGATION: SYNTHESIS REPORT

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FOREWORD

This document was prepared by the OECD and IEA Secretariats in September and October 2005 in response to the Annex I Expert Group on the United Nations Framework Convention on Climate Change (UNFCCC). The Annex I Expert Group oversees development of analytical papers for the purpose of providing useful and timely input to the climate change negotiations. These papers may also be useful to national policy-makers and other decision-makers. In a collaborative effort, authors work with the Annex I Expert Group to develop these papers. However, the papers do not necessarily represent the views of the OECD or the IEA, nor are they intended to prejudge the views of countries participating in the Annex I Expert Group. Rather, they are Secretariat information papers intended to inform Member countries, as well as the UNFCCC audience.

The Annex I Parties or countries referred to in this document are those listed in Annex I of the UNFCCC (as amended at the 3rd Conference of the Parties in December 1997): Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, the European Community, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom of Great Britain and Northern Ireland, and United States of America. Korea and Mexico, as OECD member countries, also participate in the Annex I Expert Group. Where this document refers to “countries” or “governments”, it is also intended to include “regional economic organisations”, if appropriate.

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OECD and IEA information papers for the Annex I Expert Group on the UNFCCC can be downloaded from: http://www.oecd.org/env/cc/

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Executive Summary

This paper is the last in an AIXG series that looks at international collaboration, particularly for energy technologies, in the context of climate change mitigation. The papers and case studies point out that there is little information to indicate that technology collaboration alone leads to emission reductions on the scale needed to limit growth in greenhouse gas emissions. For many energy production and consumption activities, technology change is a slow process. So to improve the environmental performance of energy technologies and accelerate their uptake, governments need a portfolio approach that includes technology and complementary economic and social policies that provide an adequate framework for essential private sector investment.

As the papers and case studies show, international collaboration can help in the quest by speeding momentum, sharing risks, exchanging knowledge and resources, sharing learning investments and harmonising standards. The incentives for collaboration include the need to "learn" from technical and operational solutions and failed approaches of others, to improve the reliability of tools and techniques, to develop standards across market areas and to foster technical expertise for regulatory and standard setting processes. Technology collaboration can also provide a framework for long-term co-operation on climate change and energy challenges in which Annex I and Non-Annex I Parties can participate.

The rationale for governments to engage in international collaboration is considered in the second part of this paper including the benefits and possible drawbacks of co-operative endeavours. Long-term and large-scale transformative energy technologies and systems that entail significant costs and risks are well suited for broad collaboration, as illustrated in the examples of hydrogen-fuel cells and fusion power (see annex) and carbon capture and storage. As new technologies progress towards commercialisation, the scope for collaborative RD&D becomes more limited. However, there is ample range for international co-operation in market deployment efforts, information dissemination and standards development.

Government collaboration related to energy technology and climate change is carried out in a variety of forms. The formal enabling mechanisms are surveyed here with examples of current initiatives and, where available, evidence of their results. All of the mechanisms considered here are based on common objectives, voluntary participation and a shared view that collaboration can provide benefits additional to an independent pursuit. Beyond those elements, the characteristics of collaborative mechanisms vary widely and range from pronouncements of "good intentions" to legal contracts with non-compliance provisions. Some approaches include centralised management, defined milestones, cost-sharing, monitoring and evaluation provisions; while others function on a dispersed basis and are largely for data and information exchange. There is not one model that accommodates the various modes in which governments pursue co-operative international energy technology development. What is important in designing effective joint activities is flexibility in the nature of the collaboration, the participants and the scope of the programme.

The form of an approach for near-market collaborative activities, for example an energy efficiency labelling scheme for refrigerators, is most likely to be distinct from co-operative research on nanotechnologies. Joint research consortia for large-scale energy technology innovation tend to have a structured framework, significant duration and a diversity of players. The design features that need to be considered for developing an effective collaboration dealing with new energy technologies and systems - from setting goals to sharing results - are summarised in the last section.

1. Context

Mitigating climate change and achieving stabilisation of greenhouse gas atmospheric concentrations – the objective of the United Nations Framework Convention on Climate Change (UNFCCC) – will require deep reductions of greenhouse gases (GHG), including energy-related carbon dioxide (CO_2) emissions. Further development and deployment of improved and new low-carbon energy technologies are needed. Indeed, some Annex I Parties are promoting the development of innovative energy technologies as the cornerstone of their national climate change policy strategies. Besides reducing GHG emissions, improved energy technologies can enhance energy security and environmental protection, and provide co-benefits such as improved air quality. In addition to research, development and demonstration (RD&D) efforts, effective policies, regulations, market deployment strategies and economic tools need to be part of a comprehensive approach.

To address these issues, the AIXG decided at its September 2002 meeting to focus attention on the numerous challenges faced in promoting new and alternative, low and carbon-free technologies. Two AIXG papers broadly addressed possible drivers for a significant technological change: *Technology Innovation, Development and Diffusion* (Philibert, 2003) and *International Energy Technology Collaboration and Climate Change Mitigation* (Philibert, 2004), while five specific technology case studies provided insights on the role of international technology collaboration.[1] This paper summarises the previous work and looks at frameworks that governments engage in for international technology collaboration. The annex summarises the specific case studies, which cover selected current and emerging technologies, and includes some information on two very visible long-term co-operative activities, namely the International Thermonuclear Experimental Reactor (fusion) and international efforts to develop a hydrogen economy.

2. Broad Lessons from the Previous Studies

New technologies will play a critical role in achieving the objective of the UN Convention on Climate Change. Without radical changes in lifestyles, only a massive deployment of low or no carbon energy technologies can power the world economy and satisfy growing energy needs, especially in the developing world, while stabilising atmospheric CO_2 concentrations in the long run.

Over the next several decades, some low or no carbon energy technologies are not likely to be competitive with current high emitting technologies beyond some niche markets, particularly given the relative abundance of carbon-rich fossil fuel resources. However, delaying action until prices are competitive may lead to unacceptably high CO_2 atmospheric concentration levels. Pricing carbon emissions (directly or indirectly, e.g. through quantified objectives) would expand markets for existing and forthcoming carbon-free technologies and accelerate their deployment.

In addition to carbon pricing, creating markets for new energy technologies requires a broad range of measures. Support for research and development is of primary importance, and current levels in most countries are insufficient. In most cases, however, "learning investments" will have to be made before new technologies can be fully competitive with embedded energy technologies.

[1] The case studies are: *Concentrating Solar Power Technologies*; *Co-operation in Agriculture – R&D on High-yielding Crop Varieties; Appliance Energy Efficiency; Clean Coal Technologies; Wind Power Integration into Electricity Systems.*

International technology co-operation, by sharing information, costs and efforts, can accelerate and facilitate technical change towards more climate-friendly technologies. Co-operation between countries may drive governments to increase their efforts, especially in supporting basic research and development. Technology co-operation can also help engage more countries into action to mitigate GHG gas emissions.

Today's trend in globalisation of investment, trade and innovation is an opportunity to leverage direct efforts for deployment of environmentally-sound energy technologies. However, governments must act to strengthen and "green" trade and investment in order to realise this prospect.

Technology transfer to developing countries has been a primary concern of climate negotiators. Its aspects include technology needs assessments, technology information, enabling activities and capacity building. The Global Environmental Facility, which serves as the financial mechanism of the Convention, is financing some projects that aim to reduce the costs of climate-friendly technologies by increasing their market shares. The Marrakech Accords set out three new funds to create conditions and leverage for private financing, including technology transfer for adaptation and mitigation purposes.

The flexibility mechanisms in the Kyoto Protocol can also increase the availability of private financing for technology dissemination at a time of scarce public resources in many countries. Its Clean Development Mechanism is expected to help with technology transfer to developing countries. As well, developed countries support technology development and diffusion through bilateral agreements and multilateral organisations.

Regarding international collaboration on energy technology RD&D, the International Energy Agency has acquired one of the highest levels of experience and capabilities in the world. It has more than 40 Implementing Agreements covering virtually all aspects of energy technology that are relevant for climate change.

Strengthening international technology co-operation for mitigating and adapting to climate change and may follow several avenues:

- further strengthen and "green" international trade and investment;
- seek new or strengthen existing agreements in ways to share the "learning investments" necessary to bring climate-friendly technologies into the marketplace;
- better co-ordination between governments, e.g. testing methods, consumer information obligations, performance standards, promotional labelling;
- the flexible mechanisms for technology diffusion might be greatly enhanced by a move from project-based mechanisms to international emissions trading, where such a system included industrialised and developing countries.

Effectively dealing with climate change will require significant technical changes. As it takes time to develop, demonstrate and manufacture new technologies, there is urgency in getting stronger collaboration. Since effective technology change requires a combination of both new technologies and new policy measures to induce their up-take, international collaboration on technology policy can be equally important as collaborative RD&D.

Drawing on these broad lessons, the following sections discuss the rationale for international technology co-operation, and provide examples of various forms of co-operative frameworks and elements that governments may wish to consider in designing international collaborations to increase their chances of success.

3. The Case for International Technology Collaboration: Why Do It?

Collaborative technology approaches are intended to facilitate work to advance and deploy technology by using the expertise and resources of each party. The motivations of governments to participate are varied. Governments take part in co-operative RD&D to meet different policy objectives: they aim to foster knowledge creation; share costs; access facilities and resources; enhance domestic scientific capabilities through the exchange of information and experience; support specific economic, technological, political objectives and create goodwill through science. Countries that have large RD&D systems may need a compelling reason to join international activities rather than strictly fund their domestic programmes, but declining government energy RD&D budgets make international co-operation attractive as a means to leverage limited national resources. Researchers join in order to access funding, link with foreign partners, access research facilities, share information in real-time and to enhance creative thinking. Collaborative activities between advanced countries and those with less scientific and technical expertise can be a good conduit for developing countries to access knowledge, build capacity and then adapt it to local problems, as exemplified in the *R&D on High-yielding Crop Varieties* case study.

Countries have a common interest in fostering the development of innovative technologies, but they also have an interest in helping domestic enterprises to take the lead in international economic competition. Generally, co-operation is most common in the early stages of technology development where research costs are high and the prospects for commercialisation are not readily apparent. As a technology becomes ready for deployment in the market, the scope for collaboration becomes more limited.

<u>Box 1</u>

Benefits of International Technology Collaboration

- Foster basic and applied science synergies
- Share costs; pool technical and data resources; spread risks; avoid duplication
- Connect researchers; strengthen national R&D capabilities and capacity building in developing countries
- Accelerate the development, market-learning effects and deployment of technological and best practice innovations
- Reduce cost of national deployment support policies
- Harmonise technical standards

International technology collaboration has a number of benefits, including those highlighted above. While international collaborations have higher transaction costs than working individually, co-ordinated RD&D to address common problems can provide synergies and shared benefits that outweigh the increased administrative costs.

There are drawbacks to international technology approaches, as well, and some of these concerns are listed below.

- Concerns about intellectual property rights protection in countries with a history of weak enforcement.
- Possible loss of existing competitive advantage.
- The time and resources needed to build an agreement among numerous parties could distract from more productive activities.

- Some players with vested interest in one technology may deliberately slow progress of new technologies.
- Collaboration on a particular technology might prematurely foreclose potentially significant technology pathways. "Following the crowd" could limit efforts to find the transformative technologies that are needed to make significant GHG reductions.
- Participation may attract those that have the most to gain and those that have the least to contribute. This may create an inherent unevenness of intent and sharing capability, which was presumed in the development of a set of common objectives and goals. Players have an incentive to engage in strategic behaviour of various kinds, including less than full disclosure of their ongoing research and/or technical progress until they see what their relative position is to that of the group.

The challenge is to design approaches that make effective use of competition, where appropriate, and to use co-operative means in circumstances where there are mutual benefits.

There is little information in the literature to indicate that international collaboration leads to emission reductions without supplemental polices and measures. As technology change is slow, a portfolio approach that includes both technology and other tools is needed.

As highlighted in *Technology Innovation, Development and Diffusion*, quantitative climate change objectives, price instruments and measures such as standards are needed to achieve short-term greenhouse gas emission reductions with the current set of energy technologies. Yet they might not be sufficient to promote the development of innovative technologies needed to achieve the large, long-term reductions required to stabilise atmospheric CO_2 at any level. However, it is unlikely that an approach limited to "technology push" would be sufficient to achieve the Convention's objective. Therefore, policies that foster technology development and provide a "market pull" are needed. International collaboration that encourages both information and cost-sharing can significantly enhance the effectiveness of policies for developing and deploying clean energy technologies in reducing development costs, broadening markets and allowing governments to shape better policies by learning from each others' successes and failures. It can help to create a framework for long-term co-operation to address climate and energy challenges in which Annex I and developing countries can participate.

4. Forms of Recent International Technology Collaboration

4.1 Nature of Collaboration

Governments engage with academia, private enterprise and other governments to foster energy technology development and deployment. Governments that join generally have complementary perspectives on technology development pathways, political will and a view that combining efforts can provide benefits that outweigh a solely independent approach. The focus of collaborative activities can target any stage of technology innovation, e.g. basic research, demonstration, market transformation, standards development. The nature of collaborations can range from brief informal arrangements to long-term contractual obligations. They can be as simple as data gathering and information sharing or as complex as basic science for materials to be used in thermonuclear reactors.

4.2 Enabling Mechanisms

Governments employ various means to implement international collaborative efforts, e.g. bilateral or multilateral agreements, contracts, public/private partnerships, voluntary agreements. This section reviews several forms of international collaboration and considers their advantages and disadvantages.

4.2.1 Bilateral Approaches

Bilateral approaches are established with a treaty, memorandum of understanding or other agreement, usually between two sovereign nations. It details their mutual understanding and obligations on a particular matter, such as trade or scientific exchanges. Bilateral co-operation programmes are numerous and many examples are noted in national communications under the UNFCCC.

Bilateral approaches for energy technology collaboration are entered into freely by both parties with shared objectives and mutual benefits. They are tailor-made agreements and so can specify the degree of flexibility – participation, cost-sharing, intellectual property rights, term – and the monitoring and evaluation elements that govern the collaboration. They are easier to negotiate than multi-party agreements. On the other hand, a two-party approach provides narrow participation which can limit the scope of intellectual, physical and financial resources to nurture the innovation process.

4.2.2 Multilateral Approaches

Multilateral collaborative approaches are similar to bilateral means but involve more than two parties. Generally such arrangements for energy technology are consummated with an agreement to co-operate on specific technologies or sectors. Like bilateral approaches, there is not a common template that structures the relationships. The arrangements can be very broad and loosely based or can set out objectives, terms of reference for participation, dissemination requirements and monitoring. This category also includes relevant programmes of multilateral agencies such as the UNEP, UNDP, and World Bank, and regional organisations such as the European Union.

An example is the European Community Framework Programme for Research, Technological Development and Demonstration (FP6), which is based on the treaty that established the European Union. FP6 is a collection of actions at EU level to fund and promote research (Box 2). Its strategic objectives are to strengthen the scientific and technological bases of industry and to encourage its international competitiveness, while also supporting other EU policies. Funds from the FP6 support R&D in seven priority areas, including sustainable development, global change and ecosystems. FP6 projects must include co-operation across borders.

A further aim is to contribute to the creation of the European Research Area by improving integration and co-ordination of research in Europe, which has been largely fragmented, and expand its international dimension. In this regard, legal entities from any country in the world are eligible participants in FP6 (with some differences in participation and funding rules for various country groups). Part of the motivation for the international dimension is to harness the science and technology resources of the EU and other countries to work together on initiatives that address significant global problems such as climate change.

Box 2

EU Sustainable Energy Systems Research Programme

Aims to:

- reduce pollution and greenhouse gas emissions;
- increase security of energy supply;
- improve energy efficiency and the use of renewable energy;
- enhance the competitiveness of European industry;
- improve the quality of life.

A distinction is made between near and long-term research activities and the budget appropriation is split equally. The short-to-medium term research category targets innovation that can deliver results to meet 2010 policy objectives, whose main challenges are: technological, including market-related and financial issues; to demonstrate cost reductions or integration under full-scale operating conditions. The medium-to-long term research objective is to develop new and renewable energy sources and carriers such as hydrogen. These research activities are mainly R&D and pilot plants whose main risks are scientific and technological rather than market or financial. International scientific co-operation is supported for research addressing the environmental consequences of energy policies, energy supply inter-dependency and cross-border energy and environmental issues.

While it is difficult to draw broad conclusions about what elements in bilateral or multilateral co-operative agreements help to ensure effective results, a few insights emerge in the *Clean Coal Technologies* case study, which looks at several co-operative technology activities between OECD countries and China. It references a number of bilateral collaborations with a common aim to improve the environment through more efficient use of coal, but with very different technology approaches (Novem 2003). Most of the bilateral programmes also aim to generate economic gains through trade or technology transfer: typically governments tend to promote domestic industry.

The results of these bilateral activities have been mixed. For example, a bilateral collaboration that focussed specifically on blended coal combustion showed that increasing efficiency from 35 to 40% was possible and affordable (Boyd, 2004). Another bilateral approach included almost all possible clean coal technologies and built a number of demonstration plants, but most have not been replicated (Oshita and Ortolano, 2003).

In the review of different forms of collaboration including patent acquisitions, the study notes that China is keen to establish a position whereby much of the equipment for clean coal and other technologies are obtained under a licensing arrangement and subsequently manufactured in China. Weak protection of intellectual property rights in acquiring countries is a risk for providers who fear that their technology may be “stolen”.The case study points out that weak protection of intellectual property rights can be a deterrent for developing country acquirers as well, due to concerns that competitors in their own market could copy the technology while not having to pay (Jin and Liu, 1999). This highlights the importance of establishing the terms of intellectual property and patent rights at the outset of a co-operative programme.

The case study also looks at clean coal collaboration in China with multilateral organisations. It indicates that the environmental performance of World Bank funded coal-fired power plants has been very good when compared with non-Bank projects. Not only are emissions much lower, but China’s electric power authorities have taken responsibility for environmental management and supervision. In addition to its direct contribution, the Bank leveraged its influence through analytical and advisory activities that contributed significantly to power sector reform and institutional development.

A large Global Environment Facility (GEF) project to introduce efficient coal-fired industrial boilers in China has led to an estimated 637 Mt of emission reductions – about one-third of the total reductions for all GEF climate-related projects – at a cost of about US$ 0.03 per avoided tonne of CO_2. Investment funding was provided in two phases to nine Chinese boiler manufacturers to acquire advanced boiler technologies and to produce model units, and later advanced production equipment from abroad to allow mass production of the successful models. The project did not seek simply to market and sell efficient boilers to China. Instead it transferred the knowledge, the intellectual property rights and the tools to allow the Chinese boiler industry to produce its own efficient boilers.

Similar arrangements may take place with corporations as well, with IPRs being transferred to China or other developing countries and associated manufacturing agreements. Moreover, in some cases research centres have been built, which are staffed by local scientists and have arrangements whereby its inventions belong to the host country with a royalty-free license granted to the investor company.

A lesson for designing co-operative deployment related programmes is that "projects are more successful when they have a clear concept of which market they wish to transform, which market barriers have to be overcome and have a well-defined and narrow target group"(GEF 2004). Further the boiler project showed that technology procurement will follow market rules even with GEF and government involvement, so the project design and implementation needs to avoid being too drawn out and complex so as not to hinder active involvement of the private sector.

By contrast to its success with industrial boilers in China, the GEF's lack of success thus far to introduce concentrating solar power (CSP) technologies in developing countries also provides useful insights. A number of the reasons are considered in the case study, but perhaps the most pervasive is the current weakness of the CSP industry in industrialised countries. It is sensible to involve developing countries in an effort to bring a nascent technology into the market, to enlarge markets, to accelerate learning-by-doing processes and to make a technology cost competitive as soon as possible. However, pursuing such strategies only in developing countries combines country-specific risks with those of any new technology, and this combination of risks may prove insurmountable.

Political Initiatives

Political initiatives are another form of multilateral engagement that gathers a number of countries to address climate relevant issues, among other policy concerns, and support international collaboration. Such initiatives set out shared objectives and frequently a plan of action, which usually does not specify milestones, cost-sharing, resources or how it is to be operationalised. Therefore, it is difficult to judge the actual level of co-operation or its effectiveness for many of these initiatives.

An established initiative, the Group of Eight (G8) has considered climate change issues at the highest government levels.[2] At their summit in 1999, the G8 pledged to work towards common environmental

[2] The G8 does not have a fixed structure or a permanent administration. The presidency rotates annually and it is up to the host country to set the agenda and organise the annual summit. At the summit, heads of government discuss key global issues and seek to reach informal agreements on measures that they can take individually, but in a co-operative manner, to achieve their goals more effectively. Leaders agree on certain initiatives at each summit. The G8 website indicates that there are follow-up meetings throughout the year to make sure that commitments are being honoured (www.g8.gov.uk). The G8 includes France, Japan, United States, Germany, Italy, United Kingdom, Canada and Russia.

guidelines for export finance agencies and to help developing countries to address climate challenges.[3] In 2003, the G8 set out an action plan to accelerate the research, development and deployment of clean energy technologies and to increase international collaboration in the context of their "Science and Technology for Sustainable Development" plan. In 2005, the G8 reaffirmed a commitment to the UNFCCC and its ultimate objective to stabilise greenhouse gas concentrations. It set out a further plan of action on climate change, clean energy and sustainable development (see highlights in Box 3). Progress and accomplishments on the 2005 Plan of Action are due to be reported to the G8 Summit in Japan in 2008.

Box 3

Highlights of Co-operative Initiatives of Gleneagles Plan of Action

"Climate Change, Clean Energy and Sustainable Development"

July 2005

Transform energy use: energy efficiency is a key area for G8 action

- Develop indicators to assess efficiency.
- Encourage partnerships such as Renewable Energy and Energy Efficiency in outreach to developing countries.
- Encourage co-ordination of international policies on appliance labelling, standard setting and testing procedures.
- Encourage co-operation on RD&D of more efficient and lower-emitting vehicles.
- Undertake collaborative work … to enhance safety, improve fuel efficiency and reduce emissions in air transport.
- Develop partnerships with major industrial sectors to reduce emission intensities.

Power a Cleaner Future: diversify and improve efficiency throughout the process chain.

- Work with industry, national and international research efforts to demonstrate the potential of advanced fossil fuel technologies.
- Accelerate the development and commercialisation of carbon capture and storage technology.
- Promote continued development and commercialisation of renewable energy, including launching a Global Bioenergy Partnership.
- Draw together research on optimising electricity networks and integrating renewables.
- Promote networks for research and development of energy technologies.

Finance the Transition to Cleaner Energy

- Support market-led approaches to encourage efficiency and accelerate investment and deployment of clean technologies, appropriate to national circumstances.

Manage the Impact of Climate Change

- Strengthen international co-operation related to global earth observations.
- Invite the World Bank to develop and implement best practice guidelines for investment screening in climate sensitive sectors, and encourage other development organisations to adopt similar guidance.

[3] In December 2003, OECD countries announced an agreement to strengthen their common approaches for evaluating the environmental impact of infrastructure projects supported by export credit agencies with a view to ensuring that they meet established international standards.

4.2.3 Legal/Contractual Approaches

Multi-party RD&D collaborations can be established through specific contracts or legal frameworks. One of the most widely used mechanisms is the Framework for International Technology Co-operation of the International Energy Agency (IEA). It sets out common rules for technology contracts known as Implementing Agreements. The legal structure includes:

- ✓ who can participate;
- ✓ management requirements;
- ✓ initial term and extension process;
- ✓ progress report requirements;
- ✓ dissemination of results;
- ✓ and distribution of the benefits derived from the co-operative work.

The Implementing Agreement mechanism is flexible and accommodates various forms of energy technology co-operation. It can be employed at every stage in the energy technology cycle from research and demonstration to validation of technical, environmental and economic performance and market deployment. The IEA acts as a facilitator for the collaboration but is never a direct signatory to an agreement. The IEA also provides a direct link between research expertise and policy-making through its structure of expert groups and committees. This serves to increase the effectiveness of national and international approaches to accelerate development and market penetration of promising technologies (IEA, 2005).

Activities that take place under the umbrella of an Implementing Agreement can be task-shared or cost-shared. Task-sharing works well when there are a number of different concepts that are being investigated by various participants in parallel, while cost-sharing is more appropriate for funding a single joint activity or experiment. Some collaborations use common funds to cover the costs of central administration, leaving the projects costs to be task-shared. Others rely entirely on task-sharing, which reduces accounting burdens but requires a detailed definition of each participant's rights and obligations. Individual activities within an agreement can involve a subset of the participants (IEA, 2005a).

For more than 30 years, the IEA collaborative programme has provided a framework for participants to develop and deploy more efficient and less environmentally damaging energy technology. In 2005, there were 40 collaborative agreements with several thousand participants from 58 countries, organisations or companies. They focus on technologies for fossil fuels, renewable energy, efficient end-use and fusion power, and information centres with world-wide dissemination such as the Greenhouse Gas Technology Information Exchange. The collaborations involve expenditures of more than US$ 120 million annually and co-ordinate more than half the world's nuclear fusion research. More than 100 studies on GHG reduction technologies and carbon capture and storage are part of the implementing agreement highlighted in Box 4.

The collaborative programme has proven highly successful in increasing the efficiency of global energy technology development. Cost-sharing reduces the expenditure for individual countries by 50 to 95% from what they would have spent to finance the projects alone. The resulting increased rate of technological progress and increased flow of information from activities and networks developed through the Implementing Agreements provide added benefits (IEA, 1999).

For example, under the IEA Wind Agreement, aerodynamic testing was undertaken by five laboratories in four countries at an estimated total cost of US$ 2–4 million. It would have cost each country about US$ 3 million to do the same work individually. Plus, the work was accelerated by allowing data collection in parallel under a variety of wind and atmospheric conditions not readily available in individual countries.

IEA Wind developed testing and evaluation practices that have been adopted as the basis for national and international standards for wind turbine performance testing. Activities under the Implementing Agreement have evolved along with the maturity of wind power technology and now include collaborative research to address grid integration issues, as reviewed in the *Wind Power Integration into Electricity Systems* case study.

Box 4

Greenhouse Gas R&D Programme

IEA Implementing Agreement

The Greenhouse Gas R&D Programme (GHG) has been operating as an international collaboration since 1991 and has produced more than 100 studies on technologies for reducing greenhouse gas emissions, particularly CO_2 capture, transport and storage. Today the programme is supported by fourteen IEA member countries, Venezuela, India, the European Commission and ten industrial sponsors. Based on a scale related to CO_2 emissions, they contribute annually to a common fund which is used by the operating agent to carry out work on priorities established by an executive committee on which each country and sponsor is represented. The contributions amounted to about € 1.25 million in 2004.

The GHG Programme considers its activities successful in helping to achieve general acceptance that carbon capture and storage (CCS) is technically feasible and could be a major option for climate change mitigation. Of particular interest in the 2004 work were studies examining CO_2 storage monitoring requirements and a study in a "technology stretch" series of post-combustion capture. Several members of the GHG team are substantially involved in the IPCC's "Special Report on Carbon Dioxide Capture and Storage" to be published in late 2005. International experts actively participate in GHG developed research networks. A new website makes available information on CCS research activities that are underway worldwide.

www.co2captureandstorage.info
www.ieagreen.org.uk

IEA's experience in stimulating effective international collaboration underscores the importance of flexibility in the *nature* of the collaboration, the *scope* of work undertaken and in the *participants*. Added to flexibility is the fact that participation is purely voluntary: no one can force a country or entity to collaborate.

The interplay of flexibility and voluntary participation allows international collaboration through such a mechanism to be, to a large extent, self-organising and self-regulating. New agreements, or tasks within the agreements, are created by building coalitions of common interest in which potential participants automatically find a balance between the benefits they expect to obtain from the collaboration and their own contribution of resources.

IEA's Committee on Energy Research and Technology and its energy technology Working Parties exercise stewardship over a number of Implementing Agreements within their specific technology domain.[4] These collaborative programmes, operating at the hands-on level of R&D, bring together several thousand energy technology researchers and associated stakeholders, including industry, in OECD and non-OECD

[4] Working Party on Fossil Fuels, Working Party on Renewable Energy Technologies, Working Party on Energy End-Use Technologies, Fusion Power Co-ordinating Committee.

countries. The Working Parties channel results from the R&D activities of the Implementing Agreements through the IEA's committee structure to policy-making levels in member countries. This provides an essential interface between the centres of R&D expertise and key decision-makers in the energy community. Several hundred people take part in Working Parties and expert groups to optimise R&D and deployment of improved energy technologies.[5] They represent experience that can increase effectiveness of both national and international technology programmes. They publish technology updates, conduct analyses and disseminate authoritative information in their respective technology areas.

4.2.4 Public/Private Partnerships

The public/private partnership approach was advocated at the 2002 Johannesburg Summit on Sustainable Development as an important mechanism to meet the growing demands for energy, water and public health. Public/private partnerships have become a popular mechanism to accelerate technology innovation because they leverage and channel public research funds to areas with expected high returns. Some Annex I Parties place a lot of emphasis on domestic partnerships, and to a degree on international public/private ones, in their greenhouse gas mitigation strategies.

In the context of this paper, public/private partnerships involve collaboration between public and private actors in several countries. These government and industry RD&D partnerships can catalyze the application of basic research, speed innovation and advance the commercialisation of environmentally-sound energy technologies.

Both the public and private sectors have certain advantages relative to the other in carrying out specific tasks. The motivation for the private sector is to generate revenue or expand market access; for the public sector it is for social and economic added value. Developing and disseminating low-no carbon energy technologies to address the global scale of climate change concerns needs the expertise and the extensive technical, financial and managerial resources of the private sector. Yet, it can be difficult for private firms to take part in long-term or high risk energy R&D and to appropriate the full benefits of their investments when externalities are not reflected in the market.

Box 5

Methane to Markets Partnership

Launched in late 2004, the Methane to Markets Partnership is an international initiative to promote near-term methane recovery from coal mines, oil and gas systems and landfills, and to use the methane as an energy source. Methane to Markets has a target of a 50 million metric ton equivalent of carbon reduction by 2015.

Fourteen countries, eight of which are non-OECD governments, are signatories (designated as Partners) to a voluntary, non-binding framework to collaborate among themselves and with the private sector. The enabling terms of reference puts funding at the discretion of the Partners and sets a five-year term. Private sector participation is promoted through an informal mechanism called the Project Network. The network is considered an essential element to build capacity, transfer technology and promote private direct investment.

www.methanetomarkets.org

[5] Hydrogen Co-ordination Group, Experts Group on R&D Priority-Setting and Evaluation, Advisory Group on Oil & Gas Technology, Ad Hoc Group on Science and Energy Technologies.

4.2.5 Voluntary Agreements

Voluntary agreements to reduce greenhouse gas emissions, as generally discussed in the literature, are a policy instrument rather than an enabling mechanism for international technology collaboration. Yet, they can provide the initiative and framework for collaborative RD&D and dissemination of energy technologies.

OECD countries have employed a variety of domestic and international voluntary agreements to achieve environmental goals or to limit GHG emissions. In terms of numbers, voluntary approaches dominated in reporting for the 3rd National Communications of 23 Annex I Parties. Generally, voluntary agreements set energy or environmental performance parameters that are beyond what is required by law. They range from loose affiliations, non-binding agreements on reporting emissions and progress, internal targets, to legally-binding negotiated agreements with non-compliance provisions (Bygrave and Ellis, 2002). Not surprisingly, voluntary agreements vary significantly from one another in their design and structure. They can be categorised in four broad groups: information and awareness; pledges; voluntary reporting; and performance monitoring.

Voluntary agreements can be easier and quicker to put in place than regulatory or multilateral approaches. In some cases, voluntary agreements may increase the availability of government supported technical assistance and reduce regulatory oversight. In other cases, compliance with a voluntary scheme can serve to differentiate participants' products or services in a positive manner such as ISO 14001 certification for environmental management systems.[6] Voluntary approaches can contribute significantly to educating players in key sectors and information dissemination. However, lack of monitoring and performance standards creates opportunities for free-riding among participants. Evidence suggests that negotiated agreements and voluntary programmes can be more efficient when employed in a policy mix and to explore new policy areas (OECD, 1999).

Consider, for example, that international voluntary agreements have contributed significantly to providing product performance information for appliances, which has effected the adoption and wider deployment of more efficient technology in some markets. The *Appliance Energy Efficiency* case study points out that the countries with the most success in this area have used a mix of policy approaches including voluntary labels, mandatory minimum energy performance standards and information campaigns.

Energy efficiency labels such as ENERGY STAR® have proven to be very effective in reducing office equipment electricity consumption. ENERGY STAR, started by the US Environmental Protection Agency in 1992, is an international voluntary labelling scheme for a variety of products. Through agreements with the US Government, five international partners promote certain qualified products.[7] The collaboration helps to unify voluntary energy efficiency labelling schemes in major global markets and makes manufacturers' participation easier by providing a single set of efficiency qualifications, instead of a patchwork of varying country-specific requirements.

ENERGY STAR's specifications for personal computers (PCs) were modified in 2005 to remedy excess energy consumption in standby mode. With these improvements and fairly rapid turn-over of computer equipment, savings of 50% of electricity used by PCs is expected, with concomitant reduction in CO_2

[6] International Organization for Standardization (ISO) 14001 specifies requirements for an environmental management system. Currently it is the only ISO 14000 series (environmental management) standard against which it is possible to be certified by an external certification authority. ISO 14001 itself does not state specific environmental performance criteria.

[7] Australia, Canada, European Union, Japan, Taiwan.

emissions, depending upon the carbon profile of the electricity production. As a voluntary initiative, the Energy Star scheme may not be able to capture all of the market potential. It has, however, contributed notably. Linking it with minimum standards to enhance energy efficiency in a range of products would provide broader effects.

While the variety of structures for voluntary approaches makes it difficult to draw specific conclusions, numerous studies suggest that voluntary agreements do not provide certainty in reaching environmental goals. Recent OECD analysis notes few cases where voluntary approaches have contributed to environmental improvements significantly different from what would have happened anyway. Voluntary agreements provide weak incentives for innovation or the development of new abatement technologies. The OECD study does not alter the findings of previous analyses that economy-wide economic instruments in many cases can be better policy options than voluntary approaches, both from the point of view of environmental effectiveness and economic efficiency (OECD, 2003).

4.3 Design Features

The World Energy Council concludes that there is substantial scope for strengthening international co-operation in energy RD&D, as also set out in "Powerful Partnerships" (WEC, 2001; PCAST, 1999). They call for industrialised countries to make greater efforts to deploy advanced, environmentally-friendly energy technologies in their domestic markets, both for mitigation purposes and to 'buy-down' technology costs to permit speedier diffusion of appropriate technologies elsewhere in the world. This will help to provide faster access to modern energy services for all and to reduce environmental pollution and GHG emissions around the world. Also it would strengthen compliance with the technology transfer and co-operation provisions of the Climate Change Convention (Article 4.5).

If countries are going to respond to this advice, they need to learn about how successful collaborations have been developed, what made them successful and what they should consider before entering into an agreement. This section identifies some of the steps in developing collaboration and important elements that could be included in an agreement.

In broad terms the key stages for establishing a collaborative agreement include:

1. initial decision and design;
2. identify key participants;
3. identify funding sources and mechanisms to share resources;
4. determine the organisation and management structure;
5. determine key issues to be negotiated among partners;
6. identify methods to assess and communicate outcomes;
7. identify methods to assess benefits and evaluate progress.

However, as illustrated by the examples of enabling mechanisms, international technology collaborations are implemented in a wide variety of ways – from statements of “good intentions” to legal contracts.[8]

It is easier to recommend more and better international energy technology collaborations than it is to design effective ones to develop and diffuse energy technologies to address energy security and climate change concerns. The form that international collaboration for clean energy technology should take and the

[8] The OECD Global Science Forum is developing a template for international scientific research with a sample *Memorandum of Understanding* and *Request for Proposals to Host the Secretariat* (Michalowski, 2005, draft).

conditions under which it is likely to succeed are not prescriptive. There is not a single template. In general, though, collaborative approaches tend to be more straightforward for information dissemination, labelling initiatives and pre-competitive research, than for near-commercial processes and products.

In outlining the basic design elements here, the consideration is a framework that could be effective to spur advances in significant new energy technologies and systems.

Elements of an International Collaboration Agreement for Innovative Technology R&D

Launch

- Governments and relevant partners with shared objectives see mutual benefits in a collaborative approach and voluntarily develop a framework to set the parameters for the co-operation.
- Governments articulate the benefit, e.g. scientific, political, economic, of participation beyond their borders.
- Particularly for mega-science collaborations, it can be useful for a domestic inter-agency/stakeholder group to develop a strategic vision and co-ordinate government’s efforts in international consortia.

Goal-Setting

- Be clear about the implicit and explicit goals of the collaboration. Do all the parties have the same goals?
- For long-term and wide ranging endeavours, a consensus on promising scientific fields and identification of critical technology barriers can help to improve the integration of basic and applied research.

Participation

- Participants need to have mutual interest and demonstrate mutual commitment. Involvement is voluntary.
- Success or failure is tied to the effectiveness of the participants. Individuals with credibility to promote and foster the initiative – sometimes referred to as “champions” – can be significant.
- Set out parameters for participation, including:
    - how participants are selected;
    - who can participate – sub-national and non-government entities;
    - whether there are categories of affiliation with different rights and responsibilities;
    - what the responsibilities of a participating party are;
    - when participants can be brought in; options for non-founding partners to join;
    - procedures for opting to terminate participation.

Agenda-Setting

- Develop a common vision and strategic intent for the arrangement. Establish a time horizon.
- Collaborations for pioneering energy technologies or systems inherently have high levels of uncertainty. Governments can address the risks by supporting a suite of options. Innovation is not a linear process so the collaboration needs to build in flexibility and to be able to evolve.
- Delineate the tasks to be carried out, the skills and resources required, and the sequencing and duration of the tasks.

Duration

- Set an initial term and procedures for extension and termination.
- The length of an agreement is a feature that deserves attention. Successful agreements or ventures do not last forever. If the private sector is involved, the horizon is usually shorter.

Structure

- Determine the institutional structure that is best suited to the achievement of the shared objectives. Do new structures need to be created or can existing multilateral initiatives or established frameworks such as IEA Implementing Agreements suffice? Does the nature of the research collaboration involve diverse and dispersed actors and organisations that can present particular challenges for linking work?
- The structure needs to take due regard of equity issues. There are large discrepancies in material resources available for researchers in various parts of the world and unequal conditions can alter the nature of the interaction. Capacity building should be facilitated through the collaborative structure if participants have unequal conditions.
- The framework needs to set out the decision-making apparatus, legal or bureaucratic rights and obligations, dispute resolution and ownership elements. Key issues to negotiate include: intellectual property rights; legal arrangements, if necessary; access and sharing of information; production and publication rights, access to facilities, communication linkages.

Support

- Determine the range of cost-shared versus task-shared elements.
- Develop consensus on equitable funding, sharing or subsidy arrangements early in the design phase. For example, is a primary funder or host institution to have special rights or privileges?
- The long-range horizon associated with large-scale energy technology development and deployment requires that support and commitment need some stability to develop and retain momentum and expertise. This may be at odds with government budget cycles, which can restrict future financing commitments or prohibit funding of non-national organisations. Short-term political pressures can also affect continuity of the research endeavour.
- Secure financial support through one or a mix of means. Options include: funding on a voluntary or pro-rata subscription basis of an operating agent; providing in-kind services; funding of specific sub-elements in a programme. An operating agent or broker arrangement can serve a co-ordination role, including to pool funds which can be dispersed as needed for tasks regardless of the nationality of the source or the recipient.

Ownership

- Establish the terms of intellectual property and patent rights as part of the framework, including pre-existing proprietary information as well as inventions and patents that emerge from the collaborative efforts.
- A balance is needed between providing incentives for innovation and technical advances and the diffusion of technology and knowledge, which could reduce social returns.

Communication

- Consider how clear and effective communication between participants can be developed and maintained, recognising the difficulties inherent in different languages, culture and working practices.
- Set out how progress will be reported periodically to sponsors.
- Develop an external communication strategy for interim and final task results.

Monitoring and Recalibrating

- Milestones and metrics need to be built in from the start in order to monitor the effectiveness of the collaborative programme. They need to be mindful of the highly iterative nature of the processes of innovation and development: some failures are part of the learning process.
- Tracking and evaluation procedures are needed to keep the efforts focused and appropriately co-ordinated. Self-assessments by participants help to provide feedback.
- Means to redirect or terminate tasks/programmes that are without prospect need to be delineated.

Results

- Setting out milestones and metrics as part of the programme design is also essential for evaluating the outcomes. Demonstrating direct causality between government R&D investment and economic/social benefits is difficult, but indicators can be tailored to the specific collaborative activities.
- Frameworks need to set out how results are shared among participants and disseminated externally.

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ANNEX

This Annex summarises the five case studies and provides information on the frameworks of two current international collaborations for large-scale energy technology innovation (fusion and hydrogen/fuel cells).

1. International Energy Technology Collaboration Case Studies

1.1 Concentrating Solar Power Technologies

This case study reviews international collaboration in concentrating solar power (CSP) technologies. It presents the current status of CSP technologies, recent achievements and development prospects. It analyses the successes and failures of different forms of international collaboration in these technologies, and draws lessons for further elaboration of international technology collaboration in addressing climate change.

CSP technologies concentrate solar light to raise the temperature of a transfer fluid and run turbines and electric generators; they might also be used to produce hydrogen or other energy carriers. In regions with high direct solar insolation they can provide on-grid power at a lower cost than other solar technologies, though higher than fossil-fuelled plants. Though proven by more than fifteen years of satisfactory experience in California, these technologies are still in their infancy. RD&D and market deployment efforts may bring them to competitiveness within a decade or so.

Current initiatives include:

- The IEA SolarPaces Implementing Agreement has been instrumental in organising international CSP research and development efforts, facilitating cost-sharing of various experiments or scientific facilities, information sharing and dissemination and promoting awareness.
- The Global Environment Facility (GEF) has recognised the potential of these technologies to mitigate GHG emissions and is supporting projects in Egypt, India, Mexico and Morocco. However, none of these projects have yet to break ground.
- In 2002, several international organisations, national administrations and industry associations joined forces to create a new form of international collaboration on concentrating solar technologies, the Global Market Initiative. It aims to facilitate and expedite the building of 5 000 MW of CSP technologies worldwide over ten years.

Several lessons emerge from this case study:

- International collaboration may help, but domestic policy decisions remain decisive. National or local governments need to provide a policy framework that provides incentives.
- In technology transfer, non-financial barriers must not be underestimated.
- Deploying new technologies only in developing countries may not work: it inhibits industry’s ability to benefit from learning-by-doing in countries where risks are lower.
- Sharing “learning investments” can help accelerate the deployment of clean energy technologies.

1.2 Co-operation in Agriculture: R&D on High-yielding Crop Varieties

This case study traces the role of international collaboration in research, development and diffusion of high-yielding varieties (HYV) seeds to the world's farmers. It looks mainly at the Consultative Group on International Agricultural Research (CGIAR). It draws lessons from international collaboration in the field of agriculture that could inform collaboration for climate-friendly technology.

The paper differentiates between two incentive structures for collaborative R&D on HYV. First it looks at the regime that ignited and sustained the Green Revolution in the 1970s and 1980s. This innovation system linked international research institutes and aid agencies to local and national governments, research institutes and universities. It therefore embodies two complementary dimensions of international technology collaboration: one is largely between developed countries and concentrates on research, and the other is mainly between developed and developing countries and focuses mainly on technology transfer and development. The second incentive structure can be seen in the current evolution of the agricultural R&D innovation system, characterised perhaps most markedly by a greater involvement of – and increased interactions between – public, private and civil society actors, as well as evolving laws and policies affecting the ownership and use of genetic material.

A number of lessons can be drawn both from the experience in international collaboration that enabled the Green Revolution and from how existing collaborative arrangements adapt to the changing incentive structure.

- International collaboration on technology RD&D can benefit from strong links with national and local dissemination systems.
- International technology RD&D collaboration can best achieve its full potential where there is a minimum absorptive capacity in place. For low capacity parties, collaboration may best be facilitated by focusing on building capacity.
- Striking a balance between nurturing scientific and technological excellence while taking into account complex social and environmental problems is challenging for technical collaborative arrangements. Parties need to remain focused, while accommodating an increasing number of stakeholder viewpoints.
- International collaboration can play a key role in helping countries to harness the private sector's financial potential for conducting RD&D activities and to disseminate new technologies.

1.3 Appliance Energy Efficiency

Energy efficiency improvements in appliances can bring significant GHG emission reductions at low or negative cost to society. More efficient appliances can lower overall energy use and consumer expenditures without reducing the quality of service, and decrease overall energy investment needs.

In addition to technology development collaboration and sharing information, common approaches are of particular relevance for energy efficient appliances, where cost-effective technology is usually available, but market barriers prevent its broad dissemination. Some lessons for international collaboration include:

- Successful examples of technology transfer relied on training and capacity building of existing local industry, and not on the transfer of ready-made technologies developed in industrialised countries. The availability of efficient technology is crucial, but the context for its transfer and effective implementation is also key.

- International collaboration helps to improve the market for efficient appliances by widening the adoption of best standards to more countries. Such collaboration is essential for updating standards and labelling schemes as the technologies evolve.

- International collaboration for energy efficient appliances can raise political interest in participating countries and provide momentum for the design and implementation of supportive national policies.

- Technology collaboration for energy efficient applicances has been most efffective where local manufacturing capacity existed and know-how could be transferred via changes in manufaturing pocesses. Upgrading of local manufacturing can be achieved through a number of routes involving international collaboration, e.g. training, licensing agreements and joint ventures.

1.4 Clean Coal Technologies

This case study reviews recent experience in international collaboration in clean coal technologies with a focus on fuel combustion and power generation, including supercritical coal plants; efficient industrial boilers; fluidised bed combustion; coal gasification, and various "end-of-pipe" pollution abatement technologies – including carbon dioxide capture and storage. The study focuses on China because of its significant use of coal and the numerous international efforts to transfer clean coal equipment and technologies.

Information is presented on six IEA Implementing Agreements that deal with clean coal technologies. These agreements provide for cost-sharing experiments, RD&D programmes and high-quality information syntheses and exchanges. Other forms of international collaboration are also included, such as the European Union's activities that directly or indirectly contribute to clean coal technology development and deployment.

In China, many countries have undertaken bilateral efforts to facilitate access to clean coal technologies. Multilateral institutions, such as development banks and the Global Environment Facility (GEF), have also been active in this field. The following lessons can be drawn from successes and failures of these various international collaborative efforts.

- Technology transfer is about more than equipment transfer. The various successes of bilateral efforts and GEF to bring clean technologies to China suggest that technology transfer is more widespread when manufacturing technology is also transferred to the host country. Besides the transfer of clean-coal equipment, this implies transferring the technical ability to replicate and manufacture the equipment locally. More generally, it appears that technology transfer would benefit from domestic policy that fosters technology diffusion. With a few notable exceptions, transfer of clean coal technology has been in 'one-off' demonstration projects with little replication.
- Intellectual Property Rights (IPR) protection matters for transferors and transferees. The conventional notion is that the weak IPR protection in developing countries deters foreign companies from transferring their technology because of a risk that it may be appropriated. While this is true, companies that are willing to acquire the technology (via licenses) may also be deterred by inadequate domestic IPR protection: host companies may be reluctant to acquire technology that competitors in their own markets could freely copy. IPR protection addresses both concerns.

A paradoxical finding from this case study is that strong growth in electricity demand is not necessarily conducive to the introduction of advanced technologies. While economic growth provides opportunities to introduce new, more efficient technologies, in the case of electricity generation in China, it creates concerns about power shortages. Generators may choose the fastest solution which is often based on local technology. Moreover, they are discouraged from closing older and less-efficient plants. This suggests a need to combine collaboration on supply-side technologies with strengthened international technology collaboration and domestic policies related to efficient end-use technologies to dampen the rate of demand growth.

1.5 Wind Power Integration into Electricity Systems

Rapid growth of wind power since the 1990s has led to notable market shares in some electricity markets. This growth is concentrated in a few countries with effective research, development and demonstration (RD&D) programmes and with policies that support its diffusion into the market place. The speed and depth of its penetration in those electricity markets has amplified the need to address grid integration concerns, so as not to impede the further penetration of wind power. Research on technologies, tools and practices for integrating large amounts of wind power into electricity supply systems is attempting to respond to this need. In recent years, existing international collaborative research efforts have expanded their focus to include grid integration of wind power and new consortia have been formed to pool knowledge and resources. Effective results are of benefit to the few countries that already have a significant amount of wind in their electricity supply fuel mix, as well as to the potential large markets worldwide.

Several observations emerge from this case study that may have relevance for other clean energy technology development and diffusion efforts:

- Government, industry and international collaborative RD&D efforts have resulted in major design improvements and increased technical and economic performance of wind turbines and related components. Subsequently, the successful and rapid diffusion of these technologies by a variety of incentives has revealed a new set of technical and operational challenges - grid interconnection. Since research programmes did not keep pace with the rapid deployment of wind power, this suggests that such efforts were either disconnected from deployment programmes or were not sufficiently well connected. RD&D and market deployment programmes must take account of "learning effects"; i.e., go beyond the immediate needs of stakeholders and foresee technical requirements in anticipation of deployment, particularly when new infrastructure is required.

- Technology development is a continuum that spans from RD&D through market deployment. Polices that support deployment, whether for renewables or other low-carbon energy technologies, should be tailored to maximise the benefits of market experience or "learning". This underpins the need for collaboration in the deployment as well as the RD&D phase.

- Responding to a challenge, such as the need to rapidly find technical and operational solutions to grid interconnection issues, can foster more co-operative research. As in the case of wind power, other clean energy technology collaborations at the market penetration phase may develop in international clusters that reflect common characteristics.

2. Technology Collaboration Can Provide a Framework for Long-term Co-operation to Reduce Greenhouse Gas Emissions

Absent changes in government policies, energy-related emissions of CO_2 will grow marginally faster than energy use and will be more than 60% higher in 2030 than 2002 (IEA, 2004a). While some low-no carbon energy technologies already exist, e.g., nuclear and renewables, they accounted for only about 11% of global energy supply in 2002. In the coming decades, fossil fuels will continue to dominate the global energy mix while the shares of nuclear and renewables will remain limited in the period to 2030. A massive deployment of low-no carbon energy technologies is needed to satisfy growing energy needs and power the world economy, while limiting growth in GHG emissions.

Collaborative technology push and pull strategies can help to bring large-scale, long-term energy technology innovation from the drawing board to practical implementation. Indeed, international collaboration and cost-sharing seem to be prerequisites for risky and/or expensive investments into radically new energy technologies. Two recent examples of highly visible collaborations are summarised below.

2.1 Long-term Technology Perspectives: Fusion and Hydrogen-Fuel Cells

Fusion

The International Thermonuclear Experimental Reactor (ITER) is a collaborative venture, under the auspices of the International Atomic Energy Agency, to demonstrate the scientific and technical feasibility of electrical power from thermonuclear fusion. The experimental reactor is projected to take eight years to build and will be a base for twenty years of experiments at a total costs of US$ 10-15 billion. The magnitude of such an effort is demanding in terms of financial and scientific resources. It has also taken a considerable amount of time to operationalise the consortium. (Fusion R&D has accounted for 10-11% of total government energy technology R&D in OECD countries for the last three decades, though overall energy R&D budgets have declined.)

Given the huge investments required for fusion RD&D, the four major fusion programmes (European Union, Japan, United States, and the former Soviet Union) joined forces in the late 1980s for the ITER project, thus initiating one of the largest international co-operation projects in the technology field. A decision on siting ITER in Cadarache, France was reached in June 2005 by six-party agreement (EU, Japan, Russia, United States, Korea, China), based on a bilateral agreement between Europe and Japan on cost-sharing and the overall approach. The six parties are negotiating a Joint Implementation Agreement, a process that started in 2001, and anticipate that the ratification process will proceed in 2006.

Hydrogen and Fuel Cells

Another long-term option to address climate change and energy security concerns is the use of hydrogen as an energy carrier and fuel cells as a conversion technology for power generation, other stationary uses and in the transport sector. Potential benefits of hydrogen and fuel cells are promising; however, significant challenges – technical and otherwise – must be overcome before they can offer cost-effective alternatives. Fuel cell technology will need to compete with a number of entrenched technologies and the costs of switching and the infrastructure needed to service some applications are expected to be high (OECD 2005).

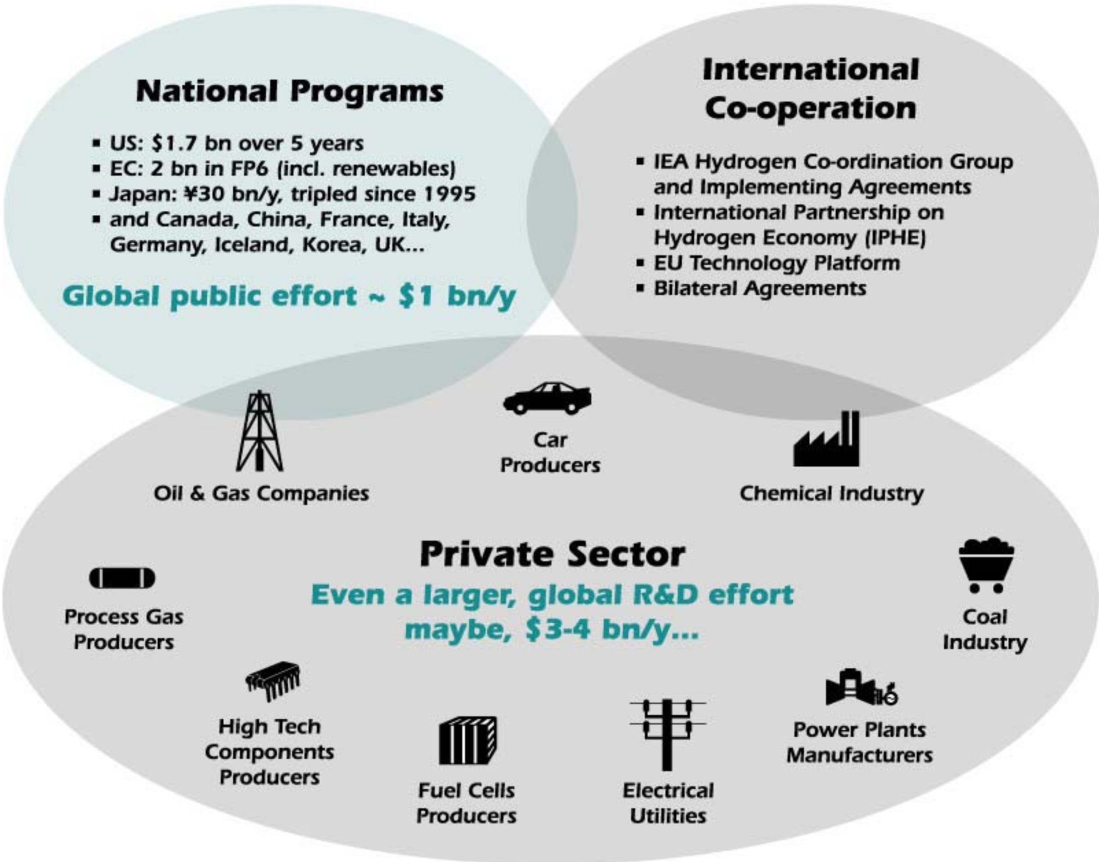
OECD governments recently have increased their hydrogen and fuel cell RD&D efforts. On a world-wide basis, government RD&D investment in hydrogen and fuel cells is estimated at US$ 1 billion per year. A number of countries have planned multi-year investments: US$ 1.7 billion over five years in the United States; up to € 2 billion including renewable energy in the European Community 6th Framework Programme; ¥ 30 billion per year in Japan; and multi-year programmes in Canada, Germany and Italy (IEA, 2004b).

Co-ordinated national and international efforts are playing a catalytic role by engaging the diverse stakeholders and helping to create a common vision that can minimise uncertainties. Government RD&D programmes and strategies are complemented by three major international co-operation initiatives.

- The ***IEA Hydrogen Co-ordination Group*** was established by twenty-four OECD member countries in 2003 to enhance co-ordination among national efforts. It builds on the IEA's international co-operation framework for energy technologies.
- The ***International Partnership for the Hydrogen Economy*** (IPHE) was established in 2003 and includes thirteen OECD member countries and Brazil, China, India and Russia. It builds on existing bilateral and multilateral relationships to strategically focus resources and as a forum to advance policies and common standards to stimulate progress towards a hydrogen economy. IPHE partners are governments that have signed a non-binding terms of reference. It states that costs will be borne by the partner that incurs them; intellectual property rights will be defined by specific arrangement; and sets a term of ten years. The Partnership aims to foster large-scale public-private co-operation. Capital deployment in research and demonstration projects such as hydrogen fuelling stations are viewed as essential roles for the private sector. By June 2005, consensus had not yet been reached on the methods and the degree to which the stakeholder community should be engaged in IPHE.

Figure 1

Hydrogen and Fuel Cells – National and R&D Efforts and International Co-operation



Source: International Energy Agency, 2004

- The ***European Hydrogen and Fuel Cell Technology Platform*** was established in 2004 by the European Commission. It aims to co-ordinate European programmes and initiatives both existing and new and to ensure active participation of major stakeholders, i.e. industry, scientific community, public authorities, consumers, civil society.

While the government supported research is an important key in the development process, the level of private sector R&D effort on hydrogen and fuel cells is considerably larger (Figure 1). Specific data on the R&D investment of large and small entities in the hydrogen and fuel cell market are not available, but the IEA estimates that it may be in the range of US$ 3-4 billion per year (IEA, 2004).